Pollution Potential of Cemeteries

WRc plc

R&D Project Record P2/024/1

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Statement of use
This report should be read in conjunction with Draft R&D Technical Report 223. It 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 local Environment Agency Office is advisable.

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FOREWORD

The question of the potential for adverse environmental impact of burial grounds is, potentially, 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 using risk assessment techniques, and should be framed in such a way that the effort expended on considering each application should be proportional to the environmental risk posed.

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 when considering applications.

The authors acknowledge the support of Mr David Hybert of the Environment Agency, for his advice and discussions in his role as Project Manager, and to Dr Phillipe de Henaut, Mr Ian Davey and Ms Amanda Patterson, also 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 document and the accompanying Guidance (Technical Report P223) are those of the authors and do not necessarily represent those of the Environment Agency.

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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 information gathered has related principally at the potential threats to groundwater resources, but account has been taken of possible risks to surface waters, soils and the atmosphere.

The work has been carried out through desk studies, without direct field investigations. An initial appraisal of relevant information, seeking particularly the results of published site studies, was carried out through the medium of computer based literature searches of appropriate data bases 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 this Project Record and incorporated into the conclusions and recommendations. Information on the existing procedures and guidance by the Regions was collected and collated using appropriate questionnaires, followed up by visits and discussions with Regional staff. The Regional visits provided additional contacts with specific interests in the matter, in particular amongst the Planning and Environmental Health functions 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 information and views which were gathered have been collated and analysed to provide the basis on which the guidance has been developed in the Technical Report. This Project Record brings together the detailed information and includes both reviews of published information and records of discussions with interested parties. Appendices are provided which include consolidated information on groundwater quality beneath and surrounding burial grounds, notes of the results of meetings and discussions with Agency regional staff, addresses and telephone numbers of useful contacts within the funeral industry and a glossary of terms.

KEY WORDS

Cemeteries, Burial Grounds, Groundwater, Surface Water, Soil, Air, Pollution.

1. INTRODUCTION

Cremation currently accounts for about 70% of funerals in the United Kingdom, but interment of bodies in cemeteries remains a widespread practice. Although no recent examples of environmental pollution by cemeteries have been recorded in the United Kingdom, and there is a general lack of specific information on environmental impact, the Environment Agency has identified graveyards as potential sources of threats to, *inter alia*, groundwater quality (Policy H, Policy and Practice for the Protection of Groundwater (PPPG), Environment Agency 1998). The Environment Agency is a statutory consultee on planning applications for such matters and wish to be in a position to offer sound technical advice, on a uniform basis, both regionally and nationally.

A comprehensive literature review was undertaken at the beginning of this project, with the initial findings forming the main subject of the first progress report. The review has been on-going throughout the project and is detailed in this Project Record. A review of the approaches to the issue of cemeteries and pollution that is taken by the Regions of the Environment Agency is also detailed and was complied following detailed discussions and meetings.

The Project Record records all the information collected during the project and is a complete account of the work undertaken. An R&D Technical Report (P223) has also been produced which, as well as giving a summary of the findings of the literature search and review of the Regions, gives comprehensive guidance for use by Environment Agency staff in assessing the risk of pollution from cemeteries.

2. OBJECTIVES

The overall aim of this project is:

- To provide detailed guidance which will enable Agency staff to adopt a consistent approach when assessing the risks associated with cemetery developments. The guidance is to be directed principally at potential risks to groundwater resources, but taking account also of surface waters, soil and air.

The specific objectives are:

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 of these objectives are detailed in this report, with the third forming the main part of the R&D Technical Report P223.

3. LITERATURE REVIEW METHODOLOGY

In conducting this review, the following specific objective was observed:

- 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.

3.1 Outline approach to the review

The extent of published information on the subject before the review was reputed to be small. A database relating to the potential impact of cemeteries upon the water environment, compiled by WRc during the development of NRA Project Record 351/7/T (Environmental Assessment by External Developers and Organisations (Phase II) 1994/95) has been expanded by the use of on-line, computer based literature searches. Appropriate databases were interrogated which resulted in references from the UK, Europe and North America, as well as world-wide, for example Australia and Brazil.

The review concentrated principally on the accumulation and analysis of information related to the burial of human cadavers, but also took into account the possible risks associated with the burial, singly or in groups, of domestic and farm animals.

3.1.1 International abstracting databases

On-line searches of the international abstracting databases have been completed using the following key words:

- cemetery? or grave? or church? or burial? or cadavers or corpse?
- water or groundwater or surface water or air or soil;
- contamination or pollution or pathogen? or virus?

Nine datafiles (BIOSIS, CABA, CONFSCI, EMBASE, HEALSAFE, POLLUAB, SCISEARCH, LIFESCI AIDSLINE) were selected as being possible data sources on the polluting potential of cemeteries in the soil and water environment.

These were linked together and searched simultaneously using the multifile procedure of the Scientific and Technical Information Network (STN).

3.1.2 Supplementary information

The literature search has been supplemented by information and further literature obtained from a number of personal contacts and meetings with Mr George Nash, representing the Institute of Burial and Cremation Authorities, and the Revd Dr. Peter Jupp, representing The National Funeral College. The latter, in particular, provided names, addresses and telephone numbers of practitioners and academics with specialised interests including "green" and woodland burials, the re-use of graves and advances in embalming technology, many of whom were consulted in the course of the project. An industry contact list is given in Appendix D.

3.2 Overview

Information obtained during the literature review was, as suspected, sparse. The majority of papers had limited hydrogeological or chemical data and no published case studies for the UK were found. Similar results have been obtained by others researching the problem. For example, a search of United States and Canadian literature, undertaken during an examination of the potential contamination of groundwater by preservatives containing formaldehyde (Soo Chan, 1992), yielded no information. Another world-wide search of documentation on the hydrogeochemical aspects of cemeteries, made by Knight, M.J. and Dent, B.B. (1996), found very few published works on contamination or elemental dispersal from cemeteries nor were there any detailed understandings of the processes at work. The search was part of the National Study of Cemetery Groundwaters, which has been underway in Australia since 1996. As a major researcher in this field, contact was made with Boyd Dent (Lecturer in Applied Geology, University of Technology, Sydney, New South Wales). He has made available further information on on-going work, including results from field studies. Copies of recent papers, presented to the International Association of Hydrogeologists conference in Melbourne (February, 1998), were made available as soon as presented and are summarised in this Report.

Despite the limited amount information available, particularly studies which included reliable environmental quality data, a number of useful sources of information and case studies were identified and these are detailed in this Report.

4. LEGISLATION, REGULATION AND GUIDANCE IN RELATION TO BURIAL GROUNDS

4.1 Introduction

This section draws together information gathered on the laws of England and Wales which control the siting and operation of burial grounds, information collected on guidance provided currently or in the past by national and regional bodies and a consideration of proposed European Union Directives which may influence future trends.

4.2 Legislation

The principal legislation related to burial grounds is summarised below:

1. **Cemeteries Clauses Act 1847**. This Act applied to places of burial other than cemeteries provided by burial authorities (vide s 214 Local Government Act 1972) - Ch 13, p 201 Polson, 1975. Ss 20-22 relate to water (see also Goodman and Beckett, 1977). The Act provided for a fine of £50 for allowing offensive matter from a cemetery to enter water, with an additional fine of £10 per day from 24 hours after the notice is first served until the offence is stopped (s 22). This Act was one of the earliest which dealt specifically with the control of water pollution, and certainly the first to address specifically the problem of contamination from cemeteries.

2. **Burial Act 1855**. Prohibited interment within 100 yards of existing dwelling without consent. Position clarified by Burial Act 1906 (Polson 1975, pp 202,203).

3. **Public Health Act 1875 and Public Health (Interments) Act 1879**. Prohibit houses being built within 200 yards of a burial ground (see Goodman and Beckett 1977).

4. **Dogs Act 1906 (6 edw. 7, C32).** The section relating to burying of carcasses states "Any person who shall knowingly and without reasonable excuse permit the carcass of any head of cattle belonging to him, or under his control, to remain unburied in a field or other place to which dogs can gain access shall be liable on conviction under the Magistrates' Courts Act 1952 to a fine not exceeding £10 [Dogs Act 1906, s. 6, as amended by Dogs (Amendment) Act 1928, s. 3, and Criminal Justice Act 1967, 3rd Sched.]. In this Act, the expression "cattle" includes horses, mules, asses, sheep, goats and swine [Dogs Act 1906 s. 7].

5. **Town and Country Planning Act 1971**. Contains provisions for the development of burial grounds and contains provision for remains to be removed and re-interred (Polson 1975, pp 257-260).

6. **Local Government Act, 1972** sections 214 and 215 + Schedule 26, brought together Victorian and later legislation (Polson, 1973, p 204).

7. **Local Authorities Cemeteries Order 1977** (amended from 1974), Article 9 and Pts II and III of Schedule 2, grant of burial rights not to exceed 100 years, but grants made earlier may be in perpetuity. Commonwealth War Graves Commission exempted from 100 year rule (Polson, 1975, pp 234-237).

The Local Authority (LA) rules specify a minimum depth of burial of 3 feet, or not less than 2 feet in friable soils. No depth is specified for private cemeteries. In general, the nearer to the surface a body is buried, the faster it will decay. This is an important factor in assessing potential risk to the environment, both in the short and long term. Rapid decay could lead to a short sharp impact on the local environment, conversely slow decay could mean less impact but over a longer timescale.

4.3 Ministry of Agriculture, Fisheries and Food (MAFF) - Code of Good Agricultural Practice for the Protection of Water

Although this Code of Practice is directed at the on-farm disposal of dead animals, it is widely employed within Environment Agency Regions to assess the acceptability of burial ground proposals. The code suggests that, if other ways of disposing of carcasses are not practical, and a notifiable disease is not suspected or has been ruled out, carcasses may be buried on farms. In order to comply with the Code, the burial site must:

- be at least 250 metres away from any well, borehole or spring that supplies water for human consumption or to be 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;
- be free of standing water when first dug.

4.4 Southern Water Authority, Aquifer Protection Guidance 1985

The Southern Water Authority first issued its Aquifer Protection Guidance in 1978. The 1985 revision made specific reference to the view that would be taken by the Authority in the case of proposals for new cemeteries or extensions to existing sites. The guidance was based on zonation of the area, using a mixture of calculated saturated zone flow times and aquifer types. Zone I was defined as the 50 day flow zone around public supply and major private supply sources, irrespective of aquifer material. Zone 2 comprised the outcrops of the Chalk and Upper Greensand aquifers, other granular aquifers were classed as Zones 3 and 4, and impermeable strata (non-aquifers) as Zone 5. The principal guidance may be summarised:

- Zone I - No cemeteries and no burial of animal carcasses;
- Zone 2 to 5 - Cemeteries acceptable.

<u>Disposal of Human Cadavers</u> - preferred sites should be identified in pre-planning and should be remote from wells and boreholes which are to be used for potable supplies. They should be at least 500 m from water supply sites. Bodies should not be deposited in wells and boreholes, even if not designated for use. Corpses should not be deposited in rivers.

<u>Disposal of the Animal Carcasses</u> - As far as practicable, animal carcasses other than those needed for food supplies should be buried or burned or disposed of as for human dead. If it is necessary to leave carcasses in the area where death takes place, they should at least be removed from the immediate vicinity of water supplies.

4.5 Severn Trent Water Authority - Groundwater Protection Policy

Appendix 7 of the Severn Trent Water Authority Groundwater Protection Policy (1976, update 1989) deals with the technical background to the Inner Protection Zone Concept and specifically to sources of microbiological contamination. It summarises the technical background to the avoidance of microbiological contamination of groundwater and attempts to set out guidelines for the use of outside agencies, such as planning authorities, and operating personnel alike.

It states that the potential sources of microbiological contamination to groundwater are numerous but can be categorised under two broad headings:- (a) sewage derived and (b) agriculture derived. The burial of infected livestock is mentioned in section (b) and "must be treated with caution" in relation to the risk to underground water resources. Besides the two major categories of potential pollution the document states that "there are other minor, largely point, sources such as graveyards and landfill sites".

4.6 Policy and Practice for the Protection of Groundwater (Environment Agency, 1998)

The Policy and Practice for the Protection of Groundwater (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 bacteria and viruses 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 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.

4.7 EC proposals for strengthening groundwater protection

In 1980, the EC introduced a Groundwater Directive (80/68/EEC) which was aimed largely at the control of discharges of specified substances to groundwater. Recognising the limitations of existing community wide regulations, a proposal by the European Commission for a Groundwater Action Programme[1] was adopted in November 1996, 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...* (sole Article). Part 2 of the Annex to the proposal contains details of four lines of action. Action line 4 deals with the control of point source pollution from activities and facilities which may affect groundwater quality, including... *graveyards and animal burial sites...*(para 2 Action line 4). Proposed action at the member State level for major facilities is to be based on the proposed Directive on Integrated Pollution Prevention and Control (IPPC - 96/61/EC), but it is stated that protection of groundwater against pollution by smaller installations (non-IPPC's) should equally be ensured, from which it appears 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, *inter alia*, groundwater and which prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems.

- Article 2, which provides definitions and includes the same definition of "groundwater" as found in 80/68/EEC and now transposed to UK law under Article 15 of the Waste Management Licensing Regulations 1994. The Article also defines "groundwater status" and "good groundwater status" and other terms, some by reference to environmental objectives. A discussion paper on the definition of groundwater quantitative status has been prepared by the European Topic Centre on Inland Waters, located at WRc Medmenham, for the European Environment Agency.

- Article 13 (Programme of measures) 3 (g) requires - a prohibition on the direct discharge into groundwater of the substances listed in Annex VIII. The Annex contains a single list of twelve pollutants, of which the final is - *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.

1 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 154/02 - COM (97) 49 final - Brussels, February 1997.

In summary, 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.

4.8 Draft ICRCL Industry Profile - Cemeteries, Burial Sites and Crematoria - Undated

This is one of a series of industry profiles which list the processes, materials and wastes associated with particular industries and the types of land contamination which may be encountered. The principal points made in the document are:

- Burial in coffins from 18th Century;
- Most rapid decay in aerobic, neutral, moist (but not waterlogged) soils. Decomposition is slower in heavy soils;
- Legal requirement for animals to be buried deep enough to prevent excavation by dogs;
- The document recognises the possibility of high BOD in soil water in the event of mass burials.

4.9 Management of 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 (Rickett, 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.

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 holder of a Certificate of Technical Competence (CoCT) awarded by the Waste 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.

4.10 Burials on private land

The Natural Death Centre has reviewed the laws and regulations in the UK for burial on farmland and in private gardens (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. The right to private burial has persisted from the days when the Quakers often used to bury their relatives in the garden.

5. BACKGROUND INFORMATION ON BURIAL PRACTICES

5.1 Introduction

In order to provide a framework within which to examine and assess the pollution potential of burial grounds, background information on burial practices and the processes which occur after death were obtained. A knowledge of these processes and the factors affecting them is vital in reviewing research reports and case studies related to the potential environmental threat posed by cemeteries, and in identifying and quantifying the actual risks of pollution.

5.2 Hydrogeological principles

The hydrogeological factors which control the pollution potential from burial grounds are the same as those which apply in the case of any other potential source of pollution. Strata and sediments which allow rapid movement of infiltrating liquids, with minimal dilution and limited opportunities for physical, chemical or biologically mediated attenuation processes to operate, are likely to pose the greatest threat to both groundwater and surface water quality. However, the same conditions may encourage rapid, principally aerobic degradation, so that the time is restricted over which potentially polluting compounds from an individual burial are released to water or air.

Assessment of the risk to soil, water and air is therefore site specific and should be approached by the Source(s) - Pathway(s) - Receptor(s) protocol, in which the Source term should take account of the loading factor (that is the rate at which fresh burials take place within a given area) as well as the probable rate of release of liquid and gaseous compounds and the accumulation of residual solids, which are controlled primarily by local soil conditions and the treatment of corpses prior to burial. Once the influence of local factors on the Source term has been defined, assessment of the Pathways, including any attenuating processes, may follow with respect to soil, water and air Receptors.

5.3 Current UK burial practices

Information obtained from meetings with Mr George Nash (Institute of Burial and Cremation Authorities) and Revd Dr Peter Jupp (The National Funerals College) is summarised below. Information received from Mr Ken West (Cemeteries Manager Carlisle) is also included. From these discussions it was found that there are currently about 200,000 human interments annually in England and Wales, representing 30% of all deaths.

5.3.1 Background

In urban areas, the average death rate is slightly more than 1% of the resident population. On this basis, the "ideal" size of a cemetery to serve a typical London Borough is about 50 acres.

On the basis of a 100 year lease on grave plots (many are actually 50 - 75 year leases), after which new burials in the plots would be possible, continuous use is theoretically achievable.

Mr Ken West commented that 20 years ago the advice given was to bury at about six feet, with underdrains. Now burial in clay is preferred, in order to "contain" decay products. He has recently been giving advice about Woodland burial (see Section 5.3.4) in Norfolk - a proposal which is supported by the Environment Agency, but opposed by the Local Authority.

Mr West commented also on the problems of burial on slopes. He believes that ideally burials should commence at the bottom of a hill and progress up-slope, so that any water running into graves as they are dug has not been polluted by upgradient burials. If you start at the top of the hill and work down, the water may become progressively more polluted and disposal may be difficult (normally any excess water is irrigated over existing buried area).

5.3.2 Coffins

Currently the great majority of coffins for both interment and cremation are made of chipboard with a paper veneer, although these are being replaced with medium density fibreboard (MDF). Few solid wooden boxes (estimated less than 5%) are used in the UK, whilst only a very minor percentage (0.002%) of coffins are 'lead-lined' (current practice uses soldered zinc).

Chipboard coffins begin to disintegrate very quickly; observation by Mr West shows that it may not be possible to lift them after only one month of burial. In contrast, wet elm coffins could last more than 60 years in the ground and other solid wood boxes may remain in good condition after 15 - 20 years.

5.3.3 Diseases

Burial is not refused on the basis of disease. The cause of death is not recorded on the burial register (as it is in cremation) but only on the death certificate, so that the funeral director may not know the cause of death. Each Environmental Health Department has a Code of Practice detailing precautions to be taken for placing the body in the coffin. If exhumation is required, the Burial Act 1855 provides details. There are circumstances where Home Office agreement to exhumation is not required.

5.3.4 Green/Woodland burial

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 a 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 sites were then in operation in Great Britain. The recommended burial depth of 4 ft 3 inches, is more likely to be aerobic than deeper burial. Embalming is discouraged.

Green burials may represent a move away from institutionalised disposal of the dead and it is becoming possible to obtain Do-it-Yourself cardboard coffins, wooden coffins and woollen shrouds so that relatives and friends of the deceased may carry out the burial arrangements themselves. Cardboard coffins are generally used (pers comm Mr West), these do not contain the aldehyde bonder found in chipboard coffins and they collapse rapidly onto the corpse once the grave is filled, therefore less topping up of the soil around the grave is needed. The costs of such funerals fall considerably below that charged by established funeral directors.

Obviously multiple burials are not possible, without uprooting the tree, so space is at a premium. The density of burial is estimated at 800 per acre (compared with 1000 per acre for conventional lawn burial). Trees should be locally grown, native species are preferred, and may be mixed deciduous and conifers. The aim is to restore local ecological communities.

These green or woodland burials are clearly growing in popularity. Mr West estimates that about 1% of burials are woodland burials, with the increase is generally thought to be at the expense of cremation. Of the annual burials, it is estimated that some 30% already own graves (husband/wife/children). Advantages of woodland burials over traditional lawn burials are given below (Table 5.1).

Table 5.1 Advantages of woodland burial against traditional lawn burial

Factor	Woodland Burial	Lawn Burial
Funeral cost	Potentially low - cardboard coffins - DIY arrangements by relatives - no headstones/ memorials	Higher - coffin costs - memorials.
Maintenance costs	Low, reversion to natural conditions. Reburial after maybe 20 years potentially possible (depends on trees)	About £4 per year for 100 years (municipal cemetery costs).
Infiltration/drainage	Thick mat of surface vegetation (establish site may be 8 - 12 inches + tree root mat - infiltrating water mainly transpired so less "leachate" produced	Thin surface vegetation around grave, surface of grave may have no vegetation (marble chips etc.) so high potential infiltration and "leachate" formation.

5.3.5 Re-use of graves.

Since the time that burial in coffins became the standard practice, about 150 years ago, there has been an increasing reluctance to re-excavate a grave after a suitable time, remove the bones to a charnel house and re-use the plot. In many areas, the situation has been reinforced by the granting of "perpetual" rights to grave plots in the earlier part of this century. Such rights are no longer granted, but exclusive use rights may be set for periods of between 50 and 100 years. There are currently moves to encourage once again the reuse of graves (for example, Mr Ian Hussein, Secretary of the Institute of Burial and Cremation authorities). However, the disturbance of burial grounds may lead to widespread public objections, even when relatives of the deceased cannot be traced, and it is likely that reuse of existing burial grounds will only slowly become accepted.

5.3.6 Burial at Sea

Each year a small number of UK burials take place at sea (approximately 20). The licence is free and there are no regulations as such, however, compliance with the Ministry of Agriculture guidelines tends to discourage the practice. The Home Office also advises on the subject. The coffins should have holes drilled in them and heavy weights added to ensure they sink and are not brought in-shore by tides.

5.4 Disposal of Bodies - Procedures by Religious Affiliation

The procedures adopted following death vary considerably according to the religious affiliation of the deceased. For example Muslims are usually buried without a coffin (a coffin is not required by law for burial of a body), and in single graves. Some religious groups, for example the Jews and Muslims, may have their own cemeteries or dedicated burial areas within cemeteries. The different procedures for the faiths and the various denominations are summarised in Table 5.2

Table 5.2 Procedures following death according to religious affiliation.

FAITH Denomination	Cremation	Embalming	Other comments
CHRISTIAN			Body traditionally aligned East-West, feet to East.
Armenian Orthodox	Not favoured	No information	Burial in coffin within about 3 days of death (1)
Baptist	Accepted	Rarely in UK, common in USA	Burial in coffin (2)
Strict and Particular Baptist Society	Strongly opposed	No information	Burial in coffin (3)
Christian Science	Accepted	No information	Burial in coffin (4)
Christian Spiritualists	Preferred method	No information	Mainly cremated, 3 to 5 days may elapse between death and cremation (5)
Anglican (Church of England)	Predominant method (c. 70%)	No information, probably relatively common.	Burial in coffin (6)
Church of Scotland	As C of E	As C of E	Burial in coffin (7)

FAITH			
Denomination	Cremation	Embalming	Other comments
CHRISTIAN cont'd			
Churches of Christ	Increasing	No information	Burial in coffin. Dedicated cemeteries at Kirkby in Furness and Saughall nr. Chester (8)
Congregational Church	As other Free Churches	As other Free Churches	Burial in coffin (9)
Elim Church	As other Free Churches	As other Free Churches	Burial in coffin (10)
Free Church of England (Reformed Episcopal Church)	No specific information	No specific information	No specific information (11)
Free Presbyterian Church of Scotland	Forbidden	No specific information	Burial in coffin (12)
French Protestant Huguenot	No specific information	No specific information	Burial in coffin (13)
Jehovah's Witnesses	Accepted	No specific information	Burial in coffin (14)
Lutheran	Generally accepted	No specific information	Burial in coffin (15)
Methodist	Accepted	As C of E	Burial in coffin (16)
Moravian	Now accepted	No specific information	Burial in coffin (17)
Evangelical Christian Churches (The Peculiar People)	Not encouraged	No	Burial in coffin (18)
Plymouth Brethren	Favoured	No specific information	(19)
Presbyterian Church in Ireland	No specific information	No specific information	Burial in coffin (20)
Presbyterian Church of Wales	Allowed	No specific information	Burial in coffin (21)
Roman Catholic	Opposed until 1963, now increasing	No specific information	Burial in coffin (22)
Orthodox, Russian	Not prohibited, but not approved.	No specific information	Burial in coffin (23)
Orthodox, Serbian	No	No specific information	Burial in coffin, not until at least 48 hours after death. Reserved cemetery in Cardiff (24)
Orthodox, Greek and Polish	As Armenian	No specific information	As Armenian. Reserved cemeteries for Greek branch in London and Cardiff (25)
Seventh Day Adventist	No specific information	No specific information	As other Protestants (26)

FAITH

Denomination	Cremation	Embalming	Other comments
CHRISTIAN cont'd			
Society of Friends (Quakers)	Accepted	No specific information	Burial in coffin (27)
Swedeborgian	Not common?	No specific information	Burial in coffin (28)
Swiss Protestant	Similar to Presbyterian	Similar to Presbyterian	Similar to Presbyterian (29)
Unitarian and Free	Common	No specific information	Burial in coffin (30)
BUDDHISM	Common	No specific information	Burial in coffin? No reserved burial grounds in UK (31)
HINDUISM	Dominant	No specific information	Burial rare (32)
JUDAISM			
Orthodox	No	No specific information	Burial in coffin, as soon after death as possible. Graves 21 inches apart, one body only per grave (33)
Reformed	Accepted	No specific information	Burial in coffin, as soon after death as possible. Graves 21 inches apart, one body only per grave (33)
ISLAM			Traditionally buried North-South, body on right side facing Mecca.
Shi'it Sunni (No specific information on differences)	No	No specific information, but unlikely in view of rapid burial	No coffin. Depth of burial 5 - 6 ft. Body laid on side facing Mecca in niche cut into side of grave and bricked up. Multiple burial in grave possible. Muslim burial area at Brookwood cemetery (34).
ZOROASTRIANISM (Parsees)	Possible, gas or electric crematorium.	No information	No information on coffins. Parsee cemetery at Brookwood (35).

Note: References 1 - 35 from C J Polson and T K Marshall - The Disposal of the Dead (Third Edition). The English Universities Press 1975. 412 pp. ISBN 0 340 16247 3 :
1 - p 264; 2 - p 265; 3 - p 266; 4 - p 266; 5 - p 266, 6 - pp 266-268; 7 - p 268; 8 - p 268; 9 - p269; 10 - p 269; 11 - p 269; 12 - pp 269- 270; 13 - p 270; 14 - p 270; 15 - p 270; 16 - p 270-271; 17 - p 271; 18 - p 271; 19 - p 271; 20 - p 272; 21 - p 272; 22 - pp 272-275; 23 - p 275; 24 - p269 and pp 275276; 25 - p 269; 26 - p 276; 27 - pp 276-277; 28 - pp 277-278; 29 - p 278; 30 - p 278; 31 - p 278; 32 - p 279; 33 - pp 279-280; 34 - pp 280-284; 35 pp 284-285.

5.5 Burial v Cremation

The churchyard existed as a place for burial long before the construction of separate burial grounds and cemeteries. The majority of people were buried without a coffin in the yard at their parish church with, at the best, temporary (wooden) grave markers. Reburial into plots after lapse times of a few tens of years was commonplace. As a result, churchyards were able to service the needs of populations of even relatively well populated parishes for several hundreds of years. The erection of stone markers and more elaborate tombs began to gain ground in the eighteenth century, but was largely restricted to the wealthy. However, with the advent of the Industrial Revolution and the drift to expanding towns during the latter part of the eighteenth century, the pressure on town churchyards began to increase. The potential problem which this created was further intensified by the increase of burial in coffins and the desire for "perpetual" burial plots. By the mid-nineteenth century urban parish churches could no longer meet the needs of the community, and overcrowding of churchyards led to the formation of private companies to provide cemeteries on a commercial basis. The owners of large, private cemeteries sought powers under private Acts, which subsequently led to the Cemeteries Clauses Act, 1847 - which is still in force in relation to places of burial other than cemeteries provided by burial authorities, within the meaning of Section 214 of the Local Government Act, 1972. Appalling conditions led to the first Burial Act in 1852. At this time cremation was not available.

For centuries the Christian Church was strongly opposed to cremation. The public were first offered cremation facilities at Woking, with the first cremation taking place in 1885. Opposition was initially strong and police protection was necessary during a cremation. After Woking, further crematoria were opened in Manchester (1892), Glasgow (1895) and Liverpool (1896). Subsequently, more crematoria were opened and between the two World Wars the number gradually increased. Between 1950 and 1960 the number of crematoria rose still further (from 58 to 148) and by 1973 there were over two hundred. The percentage of people choosing cremation increased from about 16% of total deaths in 1950, to 57% in 1972 (Polson, 1975) to a current peak of about 70%. At the present time the ratio between burial and cremation in urban areas of the UK is approximately 80% cremation and 20% burial, with the proportion of burials being higher in rural areas.

There is a view in the funeral industry (George Nash - Institute of Burial and Cremation Authorities) that there may be a slight swing back towards burial for the following reasons:

1. The capacity for cremation has now reached the peak of the service it can provide;

2. Cremation is often viewed as adopting a 'distance approach' and seen as less satisfactory by the relatives of the deceased;

3. Environmental issues, including atmospheric emissions and the visual impact of crematoria.

If there were to be a swing back towards burial, even of only 5%, it would create the need for more burial land, may well lead to an increase in pressure to re-use old graves and will impose additional costs for Local Authorities in maintenance of graveyards.

An important factor in determining whether cremation or burial is preferred is thought to be the distance from the homes of the deceased and family to the crematorium. In small villages and traditional communities, with stable populations, the graveyard is likely to be visited by relatives and friends of the deceased, and local people have an interest in any proposed extensions. In towns and villages with significant transient commuter populations, the 'NIMBY' (Not-In-My-Back-Yard) syndrome is more likely to apply if burial grounds are proposed, and generally cremation is favoured. However, in these same areas, the NIMBY attitude is likely to become apparent also if new crematoria are proposed.

5.6 Changes to the Body after Death

Five stages of decomposition are recognised;

1. fresh;
2. bloat;
3. active decay;
4. advanced decay; and
5. dry skeletal remains.

After the first three stages there is a rapid decrease in corpse biomass. The changes which take place to a body following death are summarised in Table 5.3. The threat to underlying groundwater comes from the fluids produced as bodies decompose, and which leak out into the ground. Even supposedly leak-proof caskets are thought to leak. It is suspected they corrode from the inside out due to the pressure of gases and fluids resulting from the anaerobic decay of the body tissues (Dent, pers comm). In Australia there is opposition to plastic linings for coffins or body bags as they distort the natural time sequence of decay process (Dent, pers comm). Gaseous by-products may cause atmospheric pollution, whilst solid residues could contaminate the ground.

According to Van Haaren (1951), the human body has a composition approximating to:

- Water 64%
- Protein 20%
- Fat 10%
- Carbohydrates 1%
- Mineral salts 5%

For an average human corpse this can be translated into about 10 kg protein, 5 kg fat and 0.5 kg carbohydrate, which, it was estimated from observations and analysis of oxygen diffusion, would require 10 years for bio-oxidation when buried at 2.5 m depth in sandy soil under Dutch climatic conditions (Van Haaren, 1951). The leaching rate, expressed as excess precipitation was calculated at about 40 cm/year, yielding a leachate volume of 0.4 m^3/year for a typical single grave.

A more recent reference to the composition of the body is found in Forbes (1987), where the body of a lean adult male weighing 70 kg is stated as containing: 16 000 g carbon, 1800 g nitrogen, 1100 g calcium, 500 g phosphorus, 140 g sulphur, 140 g potassium, 100 g sodium, 95 g chlorine, 19 g magnesium, 4.2 g iron and water 70 – 74% by weight; the female proportions are 2/3 - 3/4 of these. Proportions for most of the other elements, i.e. trace elements and heavy metals, rapidly decrease to milli- and micro-mole amounts. Cadmium for instance is 0.05 g, and mercury is highly variable depending on lifetime exposure and dental fillings.

Table 5.3 Changes to a body following death

Time since death	Changes
Between 0.5 and 8 hours	Muscular flaccidity ('primary flaccidity') Desiccation may start - dullness of eyeballs - especially in warm, dry atmospheres. Hypostasis - drainage of blood under gravity. "Upper" skin pallid, "lower" areas pink-purple, rapidly darkening except when death is due to carbon monoxide poisoning - bright pink (methaemoglobin).
From 3 - 6 hours until up to 60 hours	Rigor mortis. Begins with face and neck muscles, generally complete by 12 hours after death and continues for up to 48 hours. Rigor mortis gradually passes away in the same order in which it began. Secondary flaccidity follows.
Stages below are for a body exposed to air	Putrefaction (due to bacterial action, autolysis and moulds) N.B. Timing affected by temperature, humidity etc.
1 week	Greenish discoloration of body, starting at lower abdomen. Putrid odour possible.
2 weeks	Skin blistering with putrid blood-stained fluid. Abdomen distends with gas. Lungs breakdown and may be forced through mouth and nose due to gas pressure.
4 weeks	Body bloated and swollen. Nails, teeth and hair loose - easily detached. Body cavities ruptured.
Up to 12 months	Liquefaction of internal organs completed (but uterus and prostate resistant beyond 12 months). Joints separate as muscles decay.
6 years	Complete decay of children.
12 years	Complete decay of adults.

Notes:-
1. Disease bacteria in a corpse "soon die, being consumed together with the body tissues by the putrefactive process" (Polson 1975 - p 321.)
2. Suggested production of hydride diphosphane gas by decomposition in phosphorus rich environments (graveyards - "corpse candles") Alan Pentecost The Last Word, *New Scientist* No 2098, 6 September 1997.

The rate of decay, however, does depend upon a number of variables, as listed in Table 5.4 These factors can be translated into various timescales dependent on the condition of burial, as given in Table 5.5.

The coffin construction and material also influence the potential decay rate. In general, cheaper coffins decay quicker, allowing more rapid access to the corpse of insects and other invertebrate scavengers, resulting in a quicker onset of rapid decay of the contents. Chipboard and plywood coffins contained formaldehyde based glues, as does MDF (Medium Density Fibreboard), which is now the preferred material. The formaldehyde would be expected to degrade aerobically, with time, but it is noted that formaldehyde, possibly derived from embalming treatments, was found in grave water at a London cemetery (see Section 7.3).

Table 5.4 Variables affecting decay rate of the human body

Variable	Effect on Decay Rate [1]
Temperature	5
Access by insects	5
Burial and depth	5
Carnivore/rodent access	4
Trauma (penetrating/crushing)	4
Humidity/aridity	4
Rainfall	3
Body size and weight	3
Prior embalming	3
Clothing	2
Surface body rests on	1

[1] Subjective criteria, with "5" the most influential factor.

Table 5.5 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: 0.5m deep 1.5m 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	

Information provided by Mr George Nash of the Institution of Burial and Cremation Authorities indicates that corpses exposed to the air decay eight times faster than those buried in soil, and that bodies submerged in flowing water decay four times more rapidly than those in the ground.

The soil type at a cemetery is a prime factor in determining rate of decay, and is likely to be strongly influenced by the underlying geology. Decay will be quicker in porous, well-aerated soil than one which is dense or clayey, waterlogged or surcharged with organic material. For example, in a sandy or gravelly, well drained soil it may take 4 to 5 years for decomposition to be completed, but in solid clay, with no air, it will take many times longer. Preservation in peat bogs is well known and is explained by the cold, airless and acidic surroundings, in which bacterial growth is inhibited. It is also thought likely that humic and tannic acids operate to tan the remains (Polson, 1975). In addition to the geological/geochemical processes at work in a cemetery, grave construction and backfilling, grave density and the groundwater flow will also be important, especially when assessing the risk to the local groundwater. Further details and case studies are discussed in Section 7.

The greatest effect on a body's decay rate, however, is temperature and access to the body by carrion insects and vertebrates. Warm temperatures accelerate decomposition, freezing temperatures drastically slow the process, primarily by promoting or reducing the activity by scavengers such as carnivorous insects. Anything that protects a body from these invaders slows decomposition (Iserson, 1994).

5.7 Embalming - reasons, techniques and chemicals used

The following details are obtained from a number of sources, principally the books "The Disposal of the Dead" (Polson and Marshall, 1975), "Death to Dust" (Iserson, 1994) and a paper by Soo Chan (1992).

Embalming is the art of disinfecting human remains and thereby slowing the process of decomposition. It retards putrefaction and lignification by "fixing" the skin and underlying tissues. It is undertaken for two main reasons, to render the body safe for handling and transport to burial (public health), and to allow the natural appearance of the tissue to be retained for funeral viewing purposes.

There is some doubt (Iserson, 1994 p188-190) as to the benefit to public health from embalming. In the US, embalming is rarely required for public health reasons because it is believed that corpses carry little disease risk, but that if they did, embalming might not prevent transmission. According to Dr. Jesse Carr, former Chief of Pathology at San Francisco General Hospital, dead bodies present considerably fewer risks to the living than do other people. "There are several advantages to being dead," he said... "You don't excrete, inhale, exhale or perspire"[3]. Public health authorities regard embalming as posing minimal health risks to the practitioners, which may be effectively reduced by using standard protective garments, such as gloves.

[3] Carr, J. As quoted in: Mitford, *American Way of Death*, pp 82-83, extracted from Iserson, 1994.

Another article (Lazarini *et al*, 1974) discusses the hazard to those involved in forensic (legal) medicine, of contamination by the agents of viral hepatitis. It states that recent publications appear to show that the antigen may be contractible during a certain stage in cadaver putrefaction. Details of procedures to be adopted to prevent infection are given and include washing of equipment and the wound with Javel water (potassium chloride).

Despite claims by some areas of the funeral industry, embalming does not kill all disease-causing organisms in a body. One study showed that many common pathogens, including that which causes tuberculosis, were present in twenty-two of twenty-three cadavers within 24 to 48 hours after being embalmed. Other infectious organisms, such as those that cause anthrax and tetanus, are virtually unaffected by normal embalming procedures (Iserson (1994) p225).

According to industry experts, the most danger to embalmers comes not from the bodies they embalm, but from the chemicals they use. Sapin *et al* (1976) describe a mechanised apparatus for the long-term preservation of embalmed cadavers, which was successfully used in Moscow. The apparatus reduces the amount of manual labour necessary and significantly decreases the pollution of the surrounding air with fumes from the preserving fluids.

A number of types of chemicals are routinely used by embalmers for different purposes; the main preservative chemicals, formaldehyde and methyl alcohol, change the nature of the body's cell proteins (and any bacteria in the body) so that they will not putrefy; dyes are used to colour tissues; anticoagulants prevent blood clotting; surfactants allow the fluid to flow through the smallest blood vessels; the smell of the chemicals used is masked with perfuming agents and some surface disinfectants contain germicides to kill bacteria.

Modern embalmers use four methods, with arterial embalming being the most commonly used method in the United States:

1. *arterial* embalming, in which they inject three or four gallons of chemicals into a large artery whilst simultaneously removing blood from a large vein. A rule of thumb for the volume of embalming fluid - volume in pints = weight of body in stones (1 stone = 14 lb) + 1;

2. *cavity* embalming, in which the abdomen and the chest are injected with chemicals to preserve internal organs, between 1 and 6 pints per corpse. The fluid is a disinfectant and contains a wetting agent (e.g. sodium hexametaphosphate). If used alone it rarely preserves the body. It is often used as a supplement to arterial embalming;

3. *hypodermic* embalming, in which they inject chemicals (preservatives) under the skin in certain areas. This action may be necessary because the arterially injected chemicals did not reach those sites;

4. *surface* embalming, in which they apply chemicals in liquid or gel form directly to the body surface. It is normally used to supplement other forms of embalming. Dyes such as saffranine, methyl red, or eosin yellow are added to embalming fluid to restore skin colour, and mineral oil based creams used to lubricate the skin.

When embalmers inject chemicals they use hand-held syringes, gravity drainage or, most commonly, centrifugal pump. Simultaneously, embalmers drain blood and fluid from the body using gravity or an aspirator, with the blood that comes out being collected in pails or put into the sewer. Different types of chemicals, solution strengths and injection rates are used. After embalming, the muscles harden gradually over an eight to twelve hour period. Once they are set, the body's position cannot be altered.

An additional question is raised by this practice, which relates to the adequacy of the fluid collection and treatment/disposal procedures for possibly infectious blood.

5.7.1 Historical embalming fluids

Early embalming may have used natural products. Polson (1975) reports -*"During alterations in the church at Danbury in 1779 it was recorded by the village doctor that they came upon the grave of Sir Gerard de Braybroke, who died in 1422. The coffin of elm and a lead shell were opened and contained a tolerably preserved body lying in an aromatic fluid which the doctor, who tasted it, said resembled mushroom ketchup and a pickle of Spanish olives."*

At the beginning of this century fluids containing chlorides of mercury and zinc were commonly used for embalming. However, due to their intrinsically poisonous nature and the fact they interfered with toxicological analysis, the practice was unsatisfactory and dangerous. In 1893, the hardening action of formaldehyde was discovered by Blum and it was introduced as a preservative of tissues for microscopy and latter adopted as an embalming fluid, replacing the solutions of metallic poisons.

In 1910, the use of arsenic in embalming liquids was banned by the US federal government as it was interfering with the investigations of suspected arsenic poisonings. It was replaced with formaldehyde, which acts by precipitating protein and destroying enzymes in the body.

The use of arsenic continued to be possible in the United Kingdom until 1951, when embalming with preparations containing metals (As, Pb, Cu, Zn, Ag, Sb, Bi) or alkaloids (morphine, codeine, narcotine, atropine, hyoscine, strychnine, cocaine, brucine) was prohibited. The principal embalming fluid in use became formaldehyde prepared in water in 2% solution (commercial "formalin" - contains 7.5% methyl alcohol), with 2% borax added to aid injection (keeps blood liquid). Glycerine, phenol (2%), potassium citrate and potassium nitrate may also be present, with chloramine, benzaldehyde and salicylic acid being added on occasion.

5.7.2 Current trends in embalming

In the UK, embalming is carried out for temporary preservation purposes, i.e. to arrest odours. Formaldehyde was widely used but in some areas this has been replaced by a strong saline solution, which is less hazardous to the embalmer. There is little evidence of any further preservation treatments being widely applied in the UK.

Contact was made with Jon Davies, of the Midlands School of Embalming. He informed WRc that, in the UK, embalming fluid is predominantly Formalin (standard strength is 2% formaldehyde solution in water, 10 litres per body), with a small proportion of wetting agent (Lauryl sulphate) and dyes (red colours). The use is mainly restricted to those who are to be buried (30% total deaths). About 50% of burials are embalmed (that is 15% of total deaths) of which 30% are low index embalming (1% formaldehyde, 5 litres - say 4% total deaths). High index embalming (7% formaldehyde solution, 15 litres) is generally reserved for bodies to be returned to destinations outside the British Isles Davies, (1998). The main supplier of the fluid is Dodge Chemicals.

Mr A. Haler of Dodge Chemicals was contacted and he confirmed the general composition of the fluid concentrate. He claims that some cavity disinfectants contain phenol (but not those made by Dodge). He also claims that formaldehyde reacts with protein and prevents "wet stage" decay.

Contact was also made with a company called Caple Melbourne Ltd. who have carried out a survey of service sector requirements for Funeral Directors and is about to begin a similar survey for Embalmers. It believes that there are regional differences in proportion embalmed, for two reasons:

- major conglomerates (Co-op; SCI) sell embalming as part of package ("Sanitation - Preservation - Presentation");
- social/religious reasons - there is an above average number of embalmings in the North West due to the large Irish population in Liverpool, where they continue the practice of viewing bodies at home "wakes" or they take them back to Ireland for burial. In the East End of London there is also an above average number of home viewings. (Melbourne, 1998).

In the United States, the Federal Trade Commission has repeatedly found that more than 90% of those not opting for cremation purchase embalming services. Even if cremation is chosen, 25% opt for viewing and 14% of all corpses are embalmed. More than half of all Americans believe that the law requires embalming (Polson and Marshall, 1975, p224), but this is not the case. It is noted that Service Corporation International (SCI) an American based company, now owns a significant proportion of the United Kingdom funeral business, and there may be pressure for a higher proportion of embalmings prior to burial.

5.8 Radioactivity of Dead Bodies

No special precautions are required in the preparation or disposal of corpses so long as the following limits are not exceeded (Polson and Marshall, 1975, p54.):-

- 5 millicuries colloidal yttrium-90 or gold-198;
- 10 millicuries phosphorus-32;
- 15 millicuries of iodine-131, or sealed yttrium-90 or gold-198.

5.9 Pet Cemeteries

The death of a pet is now taken seriously, with a number of companies offering cremation and burial services. An article on the subject appeared in The Times (Sat. 7 February 1998, p17) which explained that owners may pay up to £200 for the headstone alone, with the burial of a Labrador sized dog costing around £300, or about £85 if cremated.

The legal status of pet cemeteries as waste management facilities is noted in Section 4.9, and persons operating them should be technically competent.

Mr Ricketts of "Paws to Rest Pet Bereavement Service", of Carlisle, was contacted. He is Chairman of the self-regulatory Association of Private Pet Cemeteries and Crematoria. Current guidance is to avoid water courses, drains, streams, with burial below plough depth (0.9m). Most pets are buried in small biodegradable cardboard coffins, but about 30% have "wood" coffins (made by the companies who make them for human use - therefore probably chipboard). Embalming is very rare. The cemetery operated by Mr Ricketts is for woodland burial, others have lawn burials. The density for canine burials (most common subject in pet cemeteries) is between 9,000 and 10,000 per hectare (about 4 times human occupancy rate).

5.10 Large-scale Emergencies and Mass Burials

Mr Chris Statham, of Kenyon International Emergencies, who deal with international disasters, provided useful information on the procedures followed when mass burial is required.

Possible reasons for mass burials include:

- Air crash;
- Rail crash;
- Coach/bus crash;
- Industrial explosion;
- Mine collapse/gas explosion;
- Drownings;
- Terrorist attack.

The arrangements for disposal of the dead from disasters depends on the scale of the incident and whether or not the bodies can be identified. If it is not possible to identify any of the bodies, then they are cremated and all the ashes are buried together in a single coffin. If the bodies can be identified, then relatives may want individual burial (or cremation). Some bodies may be taken away, but if mass burial is decided then Local Authority will need to identify, procure and prepare a suitable burial area within, at most, three weeks of the disaster. This is likely to be "fast tracked" and the Environment Agency will have very little time to comment. It is suggested that local criteria be developed well before any incident occurs, as part of emergency response planning.

There are no guidelines on the siting of temporary mortuaries, but warehouse or hangars are often considered. If external drain discharges are unsatisfactory (i.e. to soakaway or to local surface waters) then Local Authority Environmental Health could designate a "wet" area (to contain body fluids/wastes and chemicals) and seal the drains. Specialist contractors would be employed to remove fluids to safe disposal. Identification of suitable temporary mortuaries in advance of any incidents would be prudent.

The threat of epidemics from delays in burying the dead from a disaster are discussed by De Ville de Goyet (1979): An increase in disease transmission may appear in the wake of a disaster due, for example, to deterioration in environmental hygiene or contamination of water supplies following disruption or flooding of sewers, which may expose many people to dangerous pathogens. However, this is rarely the case and alarmist stories in the news media about the dangers of epidemics because of the delays in burying the dead may be exaggerated, although conditions in which this could take place would be found in very widespread disruption and devastation, such as caused by hurricanes. Epidemics are possible only if the particular pathogenic agent is present in the environment.

For psychological and religious reasons it is preferable to attempt proper identification and burial of the victims according to local custom rather than order immediate cremation or burial in communal graves. Epidemiological surveillance forms an essential part of adequate contingency planning and of the rational organisation of medical services after a natural disaster (De Ville de Goyet, 1979).

5.10.1 View of a Local Emergency Planning Unit - Berkshire CC Emergency Planning Team

WRc held discussions with Mr C. Blease, of the Berkshire CC Emergency Planning Team. No specific guidance has been followed in planning for the disposal of dead from peace-time disasters, as far as he was aware, but he believes that most of the bodies would be taken away to other places for burial (for example a plane crash). If there were to be a major chemical incident, with many dead from a small area, forward planning was stated to be only preliminary. It was expected that temporary mortuaries would be on military bases, but thought had not been given to possible drainage problems. If mass killings took place in time of war, Mr Blease suggested that burials would be into limed communal graves.

5.11 Diseases and plague pits

During the 18th, 19th (and earliest years of the 20th) century epidemics of diseases such as cholera continued to break out from time to time, particularly in large cities, with the consequent need for large numbers of burials. Bodies consigned to pest-fields and plague-pits were usually buried without coffins and were only wrapped in rugs or sheets, encouraging rapid decay. Holmes (1896) was of the opinion that at the end of the 19th century, it was no longer dangerous when such pits are opened. Holmes also reported that in the old plague-pits, in the crowded churchyards and in the private grounds where the soil was saturated with quicklime and the coffins smashed at once, decay was in every way hurried so that these grounds were likely to be less insalubrious than those grounds where lead and oaken coffins, specially intended to last for generations, are still in good preservation and only occasionally give way and let out the putrefactive emanations. Sly (1994) discusses the possibility that an epidemic of small-pox in Quebec arose from the disturbance of an intramural cemetery 214 years old, but no conclusions are drawn.

However, Holmes (1896) noted that problems for both human and animal health had been associated with sites where large numbers of burials had taken place and recorded that George Alfred Walker, a surgeon of Drury Lane, had collected details of many causes of death and illness directly attributable to contact with human remains in a state of putrefaction (Holmes, 1896 p208), and that in London, sheep grazing churchyards had been killed by swallowing the poisonous products of the overfilled ground with the grass (Holmes, 1896 p268).

6. SURVIVAL OF BACTERIA AND VIRUSES AND TRANSPORT PATTERN TO GROUNDWATER

6.1 Introduction

In order to develop adequate guidelines and assess the potential public health risks for the placement and maintenance of cemeteries, information is needed on the potential fate of pathogenic micro-organisms in soils and groundwater.

The fate of pathogenic bacteria and viruses is determined by their survival and retention by soil particles. Both survival and retention are largely determined by the nature of the soil, the climate and the nature of the micro-organism. Climate controls two important factors in determining viral and bacterial survival: temperature and rainfall. The survival of bacteria is greatly prolonged at low temperatures; below 4 ^{o}C they can survive for months even years (Gerba *et al*., 1975). At higher temperatures, inactivation or die-off is fairly rapid. In the case of bacteria (and probably viruses), the die-off rate is doubled with each 10 ^{o}C rise in temperature between 5 ^{o}C and 30 ^{o}C (Reddy *et al*., 1981). Above 30 ^{o}C temperature is probably the dominant factor determining virus survival time. Rainfall mobilises previously retained bacteria and viruses and greatly promotes their transport to groundwater. Several studies have shown how the greatest degree of well water contamination occurs after periods of heavy rainfall (DeWalle *et al*., 1980).

The nature of the soil also plays a major role in determining survival and retention. Soil properties influence moisture holding capacity, pH and organic matter, all of which control the survival of bacteria and virus in the soil. Other soil properties such as particle size, cation-exchange capacity and clay content influence retention. Microbial resistance to environmental factors varies among different species as well as strains. Bacteria are believed to be removed largely by filtration processes while adsorption is the major factor controlling virus retention (Gerba and Bitton, 1994).

In order to adhere to the Source - Pathway - Receptor protocol, the corpse as a potential source of pathogenic organisms is first reviewed.

6.2 Microbiology of the human corpse

Types of organisms isolated from general tissues of human corpses are broadly similar to those isolated from tainted meat carcasses or from the lymph nodes of humans or animals. Table 6.1 lists the most common types of organisms occurring in the human large intestine and faeces (Corry, 1978). A large majority (ca. 90%) of organisms are strict anaerobes (*bacteriodes spp*. and gram-positive non-sporing anaerobes - bifidobacteria, eubacteria, etc.) with lower numbers *of Lactobacillus, Streptococcus* spp. (mostly enterococci) and Enterobacteriaceae (about 10% in all). In addition, small numbers of other groups may be detected; *Clostridia spp*. (anaerobic sporeformers including *Cl. perfringens*), *Bacillus spp*., yeasts and less commonly, *Staphylococcus spp*. and *Pseudomonas aeruginosa*. Enterobacteriaceae are the most commonly isolated organisms from human tissues, with lesser members of Gram positive cocci, coryneforms, *Cl. perfringens* and yeasts. Micrococcaceae and coryneforms originate from the skin, where they are the predominant flora.

Table 6.1 Bacteria isolated from the healthy intestine (from Corry, 1978)

Families and genera represented	Prominent species	Other species isolated from the intestine
Pseudomonadaceae: *Pseudomonas*		*Pseudomonas aeruginosa; Ps. faecalis*
Enterobacteriacae: *Klebsiella; Enterobacter; Proteus*	*Escherichia coli*	*Klebsiella pneumoniae. Enterobacter aerogenes. Proteus miribilis*
Bacteroidaceae *Bacteroides; Fusobacterium*	*Bacteroides fragilis*	*Bacteroides capillosus, B. oralis, B. clostridiformis, B. putredinis, B. coagulans, B. ruminicola. Fusobacterium mortiferum, F. necrogenes, F. fusiforme, F. girans*
Neisseriaceae *Neisseria; Veillonella*		*Nesseria catarrhalis, Veillonella parvula, V. alcalescens*
Micrococcaceae *Staphylococcus; Acidaminococcus; Sarcina; Peptococcus*		*Staphylococcus albus, Peptococcus asaccharolyticus, Sarcina ventricuki, Acidaminococcus fermentans*
Streptococcaceae *Streptococcus*	*Streptococcus faecalis*	*Strep. sangius, Strep. viridans, Strep. faecium,*
Lactobacillaceae *Lactobacillus; Leptotrichia; Bifidobacterium; Ruminococcus; Peptostreptococcus*	*Lactobacillus acidophilus; Bifidobacterium adolecentis, B. longum Ruminococcus bromii*	*Lactobacillus brevis, L. casei, L. catenaforme, L. fermentum, L. leichmanii, L. plantarum. Leptotrichia buccalis. Bifidobacterium bifidum, Bif. breve Bif. cornutum, Bif. eriksonii, Bif. infantis. Peptostreptococcus intermedius, P. productus*
Propionobacteriaceae *Propionobacterium; Eubacterium*	*Eubacterium aerofaciens*	*Propionobacterium (Corynebacterium) acnes, P. granulosum. Eubacterium contortum, Eu. cylinderoides, Eu. lentum, Eu. lipsum, Eu. rectale, Eu. tortuosum,*
Corynebacteriaceae *Corynebacterium*		*Corynebacterium pseudodiptheriticum, C. xerosis, C. ulcerans*
Bacillaceae *Bacillus; Clostridium*	*Clostridium perfringens, Cl. paprputrificum*	*Bacillus cereus, B.subtilis. Clostridium cadaveris, Cl. innocuum, Cl. malenominatum, Cl. ramosum, Cl. tertium, Cl. bifermentans, Cl. sporogenes, Cl. indolis, Cl. felsineum, Cl. difficile, Cl. oroticum*

In a review detailing post-mortem ethanol production by Corry (1978), evidence is provided that at least two factors influence the predominant organisms that occur after death:

(a) There are indications that the antimicrobial defences of the body are not completely inactivated until some time after death. Tissues are known to remain relatively free of micro-organisms during the first 24 hours post-mortem unless the invader was a type not previously encountered by the host. Bacteria such as Salmonellae can be found throughout the body when injected into the intestine after death, and are only destroyed during the first 24 hours post-mortem if the animal were immunised against the organism during life. It is usual that, after a period of one day following death, colonisation may occur with any suitable organism.

(b) The Eh of tissues falls rapidly so that by the time antimicrobial activity has been lost, the Eh is low enough to prevent obligately aerobic organisms such as micrococci, pseudomonads and acinetobacters growing, except very close to the surface. The predominant flora in the corpse would be that capable of multiplying most rapidly, and hence *Clostridium spp*. could fill this role. Bacterial breakdown of meat under warm conditions (25-40 ^{o}C) is caused predominantly by *Cl. perfringens*, accompanied sometimes by other *Clostridium spp*. However, it would seem unlikely that *Cl. perfringens* would be the causative agent responsible for the decomposition of corpses in the UK unless this occurred in unburied corpses during a warm summer or in a heated room, or if sufficient heat was generated during putrefaction to raise the temperature of the corpse. The temperature in a vault or grave would be in the region of 5 - 15 ^{o}C. At these intermediate temperatures there is little information on the flora which predominate in the decaying human corpse. It is likely that *Clostridium spp*., which grow at sub-optimal temperatures, initiate putrefaction of human tissue. It also seems probable that putrefaction is caused by a succession of organisms progressively degrading, rather than by one type.

The method by which bacteria invade the tissues of dead bodies is not entirely clear. However, the source appears to be mainly intestinal, although injury resulting in skin breakage may introduce exogenous micro-organisms in the blood stream and throughout the body. There is evidence that bacteria may penetrate the intestinal walls during death and be distributed throughout the tissues in the blood stream. Even after clinical death has occurred these organisms may be prevented from multiplying or actually killed by the residual antimicrobial defences of the body. The anaerobic organisms will be inhibited initially by the high Eh, but within a few hours, provided the temperature exceeds 5 ^{o}C, they will start to multiply. This primary invasion is probably reinforced by a secondary invasion of intestinal organisms, starting via the hepatic portal vein and intestinal lymph system, and spreading around the body via the vascular system.

Although the intestine harbours a wide variety of organisms, the majority obligate and fastidious anaerobes, only relatively few groups have been implicated as major colonisers of corpses during putrefaction; these include, in order of importance, *Clostridium spp*. which exhibit vigorous saccharolytic, lipolytic and proteolytic activities, enterobacteria (frequently *E.coli* and *Proteus spp*.), Micrococcaceae (frequently *Staph. aureus*), streptococci and *Bacillus spp*. Jones and Winkler (1991) detail the principal pathogenic organisms which may also be present in human and animal remains, albeit in substantially lower numbers. However, since these micro-organisms are known to be associated with waterborne diseases, their survival in a corpse and subsequent transport in the subsurface may represent a serious threat to public health. These pathogens include viruses (Enteroviruses, Poliovirus, Coxsackievirus A and B, Echovirus, Hepatitis A, Adenovirus, Reovirus and Rotavirus), bacteria (*Bacillus, Brucella, Campylobacter, Clostridium, Enterobacter, Escherichia coli, Leptospira, Listeria, Mycobacterium, Pseudomonas, Salmonella, Shigella, Staphylococcus* and *Yesinia*), Protozoa (*Cryptosporidium, Entamoeba, Giardia* and *Toxoplasma*), nematodes (*Ancylostoma, Ascaris, Necator, Strongyloides, Toxocara and Trichuris*) and cestodes (*Echinococcus* and *Taenia*).

6.3 Movement of bacteria and viruses through soils

The soil and the unsaturated zone are the most important lines of defence of aquifers against pathogens. The major limitation in the movement of bacteria through soils is their filtration at the soil surface. This phenomenon will be dominant if a proportion of the suspended particles are larger than the pore openings. As soon as a few such particles have accumulated, they become the straining surface for finer particles. Studies have also shown that the movement of bacteria is inversely proportional to the particle size of the soil. The size and shape of bacteria also plays a role in their removal by filtration. In a scenario where adsorption is limited, larger cells would be predicted to move faster than smaller cells. This effect has been observed in that a large encapsulated strain of *Klebsiella aerogenes* was found to have moved faster than a smaller noncapsulated strain (Gerba and Bitton, 1994).

The removal of bacteria and viruses by soil is also affected by the mechanism of adsorption. Studies have demonstrated that common cations in solution will affect bacteria adsorption to soils (Gerba and Bitton, 1994). Certain metallic cations (Fe^{3+}, Cu^{2+}, Zn^{2+}) at concentrations found commonly in soils have been shown to enhance removal of bacteria. The common fertiliser ion, NH_4^+ has also been shown to enhance bacterial removal in soil. The anions Cl^-, $SO4_2^-$ and NO_3^- have little effect on bacterial adsorption. Soluble organics may also compete with bacteria for adsorption sites onto the soil, thereby reducing bacterial adsorption.

Studies by Gerba *et al*. (1980) and Lance and Gerba (1980) suggest that viral distribution profiles and soil penetration depths are related to viral charge strength and the variation of charge strength in virus populations. In a study of Poliovirus adsorption to a range of materials and soils, Moore and co-workers (1981) showed that the presence of organic material and available surface charge were of greatest importance. Interestingly, pH and surface area were shown not to be limiting factors in viral transport through subsurface materials. The factors that may influence virus transport to groundwater are summarised in Table 6.2

6.4 Factors affecting survival of bacteria and viruses in soil and groundwater

Most enteric pathogens die-off very rapidly outside the human gut, whereas indicator bacteria such as *Escherichia coli* persist for longer periods of time. Survival times among different types of bacteria vary greatly and are difficult to assess without studying each type individually. In most cases, it appears that two to three months are sufficient for the reduction of pathogens to negligible numbers once they have been applied to soil. Factors known to influence bacterial survival in the soil are listed in Table 6.3.

Table 6.2 Factors that may influence virus movement to groundwater (from Gerba and Bitton, 1994)

Factor	Comments
Soil Type	Fine-textured soils retain viruses more effectively than light-textured soils. Iron oxides increase the adsorptive capacity of soils. Muck soils are generally poor adsorbents.
pH	Generally, adsorption increases when pH decreases.
Cations	Adsorption increases in the presence of cations (cations help reduce the repulsive forces on both virus and soil particles). Rainwater may desorb viruses from soil due to its low conductivity.
Soluble organics	Generally compete with viruses for adsorption sites. Humic and fulvic acid reduce viral adsorption to soils.
Virus type	Adsorption to soils varies with virus type and strain. Viruses may have different isoelectric points.
Flow rate	The higher the flow rate the lower the adsorption to soils.
Saturated versus unsaturated flow	Viral movement is less under unsaturated flow.

Table 6.3 Factors affecting survival of enteric bacteria in soil

Factor	Comments
Moisture content	Greater survival time in moist soils and during times of high rainfall.
Moisture holding capacity	Survival time is less in sandy soils with lower water-holding capacity.
Temperature	Longer survival at lower temperatures; longer survival in winter than in summer.
pH	Shorter survival time in acid soils (pH 3-5) than in alkaline soils.
Organic matter	Increased survival and possible regrowth when sufficient amounts of organic matter are present.
Antagonism from soil microflora	Increased survival time in sterile soil.

Studies recording the survival of viruses in soils have concluded that viral survival is related to temperature and moisture (Gerba *et al*., 1975; Lefler and Kott, 1974). In the same way as bacteria, low temperatures and most soils encourage the prolonged survival of viruses. Virus adsorption to soil does not necessarily result in viral inactivation. There is evidence which suggests that the protection afforded by the unsaturated zone may be vulnerable to the occasional breakthrough of viral agents (Duboise *et al*., 1976). Once a virus has entered the groundwater, they can remain infective for long periods of time and have the potential for spreading over long distances (Pedley and Howard, 1997). The factors that influence virus persistence in soil are summarised in Table 6.4. Depending on the nature of the soil temperature, pH and moisture content, enterovirus survival has been reported to vary from 25 to 170 days (Gerba and Bitton, 1994).

Table 6.4 Factors affecting survival of virus in soil

Factor	**Comments**
Temperature	One of the most detrimental factors.
Desiccation	Increased virus reduction in drying soils.
Soil pH	May indirectly affect virus survival by controlling their adsorption to soils.
Cations	Certain cations have a thermal stabilising effect on viruses. May also indirectly influence virus survival by controlling their adsorption to soils (viruses appear to survive better in a sorbed state).
Soil texture	Clay minerals and humic substances increase water retention by soil and thus have an impact on viruses subjected to desiccation.
Biological factors	No clear trend with regard to effect of soil microflora on viruses.

Although much is known about the parameters which control microbial transport in soils, comparatively little is known about survival of these pathogens in groundwater. Table 6.5 shows the values obtained for decay rate constants for some viruses and bacterial species in groundwater. Data available indicate that bacteria and viruses survive longer in groundwater than in surface waters. For example, the decay rate of poliovirus type 1 in groundwater is 0.0019 hr^{-1} (Bitton *et al*., 1983) compared to 0.031 hr^{-1} in river water (O'Brien and Newman, 1977) and 0.020 hr^{-1} in seawater (Matossan and Garabedian, 1967). Microcosm studies also show that viruses survive longer than indicator bacteria in groundwater (Bitton *et al*., 1983; Keswick *et al*., 1982; O'Brien and Newman, 1977).

Table 6.5 Die-off rate constants for viruses and bacteria in groundwater (adapted from Gerba and Bitton, 1994)

Micro-organism	Die-off rate (day^{-1})
Poliovirus 1	0.046 - 0.77
Coxsackievirus	0.19
Rotavirus SA-11	0.36
Coliphage T7	0.15
Coliphage f2	0.39 - 1.42
Escherichia coli	0.16 - 0.32
Faecal Streptococci	0.03 - 0.24
Salmonella typhimurium	0.13 - 0.22

6.5 Microbial monitoring of the water table in the vicinity of cemeteries

There are very few case studies of actual microbial monitoring of the groundwater around cemeteries. One study in the literature constitutes the bacteriological quality of the water table in the vicinity of three cemeteries chosen in accordance with geological and hydrogeological criteria (Pacheco *et al*., 1991). The objective of the monitoring was to determine if the selected cemeteries were at risk to the water table. A total of 67 samples were collected through 36 piezometers installed in the internal area of the cemeteries. Samples were submitted to the following bacteriological tests:

- Total and faecal coliforms;
- Faecal streptococci;
- Sulphite reducing clostridia;
- Total heterotrophs;
- Total anaerobes;
- Salmonella;
- Coliphage;
- Lipolytic bacteria;
- Proteolytic bacteria

The results of this study showed that the hygienic and sanitary conditions of the groundwater was considered unsatisfactory. It was shown that a correlation existed between the indicators of faecal contamination and heterotrophic, anaerobes and lipolytic bacteria. A comparison of the results from the three cemeteries showed that geologic differences and depth to the water table were probably responsible for variation in bacterial profiles.

Proteolytic and lipolytic bacteria were measured in high levels in the water table for each site. Studies carried out in control sites revealed that these types of organism were, for the most part, absent. The presence of these bacteria in the samples provides evidence that the products of organic decomposition are actively transported to the groundwater. The associated risk to human health from pathogens such as Salmonella was only evidenced in one sample.

Coliphage were, however, not detected in any sample, which may indicate that viruses can be more easily fixed to soil particles than bacteria and consequently are not transported to the water table.

A more recent study is in progress in Australia, the National Study of Cemetery Groundwaters (Dent and Knight, 1998). Analysis of water samples from over seventy piezometers is being carried out for a wide range of determinands including inorganics, BOD and a suite of microbiological indicator organisms (including coliform species, *Faecal streptococci* and *Pseudomonas aeruginosa*).

The results to date from Australia show the presence of the pathogenic bacteria *Pseudomonas aeruginosa* and *Faecal streptococci* at many sites, albeit in small to very small amounts. These results suggest that, in some hydrogeological settings, microbiological decay products are being carried into the groundwater.

The results from a suite of indicator and pathogenic bacteria at another Australian cemetery in the National Study, the Cheltenham Cemetery, showed no significant presence with the exception of that of *Pseudomonas aeruginosa*, a pathogenic bacterium (Knight and Dent, 1998). Its presence, in the absence of other faecal indicators, is suggested by the authors to possibly indicate something about the organism's survival in slightly alkaline conditions; but this is uncertain at present.

They conclude that the bacterial results, considered together with the BOD, suggest a high degree of cleanup of decay products by natural microbiological systems. However, they also conclude that the presence of the pathogenic bacteria *(Pseudomonas aeruginosa)*, in groundwaters which may potentially leave the cemetery boundary, is of concern. This bacterium has been found to be present in the majority of cemeteries studied by the authors.

7. REVIEW OF PREVIOUS WORK AND CASE STUDIES RELATING TO CEMETERIES

7.1 Historical or Anecdotal references

Knight and Dent (1996), reviewing the situation in Australia, confirm there are very few research studies of the hydrogeochemistry of the decay of human remains in cemeteries, although there are anecdotal studies of groundwater pollution from graveyards and apparent pollution of poorly sited wells (Section 7.1.1). Examples found include:

- higher incidence of typhoid fever among people living near a cemetery in Berlin between 1863 and 1867 (Bouwer, 1978);
- a "sweetish taste and infected odour" of water from wells close to cemeteries in Paris, especially in hot summers (Bouwer, 1978);

Although further details of these incidents were searched, none were available.

7.1.1 Examples of wells in churchyards (Holmes, 1896)

The situation in London during the 19th century has been described by Holmes- "*It is a fact that many wells, conduits and pumps in and around London were (and some still are) in close proximity to churchyards or even within them. The water from St. Clements' Well and St. Giles' Well came through the burial ground and Bride's Well is still marked by the pump in an alcove of the wall of the churchyard. There were also pumps in St. Michael le Querne, St Mary le Bow and Stepney churchyards, a well in the crypt of St. Peter', Walworth. Another in St. George's was used for drinking water until the Revd Harry Jones, during a cholera scare, hung a large placard on it reading "Dead Men's Broth!".*

7.2 Case studies detailing effects on groundwater quality

As well as the anecdotal references a number of papers were obtained through the literature search which detail examples of studies at specific cemeteries, and include some groundwater quality data. A summary table detailing analytical results from a range of technical papers is included in Appendix A. Details of the studies, pertinent facts and conclusions reached or recommendations made from these papers, are summarised below.

7.2.1 Australian Research - National Study of Cemetery Groundwaters

Background to study

In Australia, the National Study of Cemetery Groundwaters has been underway since 1996. Research has been undertaken into the hydrogeochemical and microbiological assessment of groundwaters in aquifers and as seepages at nine cemeteries, in five states, across a wide range of hydrogeological settings and soils.

Over seventy piezometers have been installed, including some specially designed seepage wells/trenches in the unsaturated zone, and a sampling programme consisting of about six events is underway, planned for completion at the end of 1998.

Analysis of the water samples is carried out for a wide range of determinands including inorganics, BOD and a suite of microbiological indicator organisms (including coliform species, *Faecal streptococci,* and *Pseudomonas aeruginosa*).

Previous work at **Botany Bay Cemetery**, New South Wales (Knight, M.J. and Dent, B.B. 1996) found that the array of common anions and ammonia were the most diagnostic for identifying decay products from interred remains and that the decay of interred human remains produce a salinity plume locally, but that it rapidly diminishes with distance from the grave. The leachate plume was found to be high in Cl, NOx, NH_3, ortho-P, 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 impact on the groundwater system, with some slight elevation in Cu and Zn close to recent interment area. Increased boron levels were also noted, but no explanation offered. The authors also carried out a world-wide search of documentation on the hydrogeochemical aspects of cemeteries as part of the research, but very few published works were found on contamination or elemental dispersal from these sites, nor detailed understandings of the processes at work.

The authors also refer to the "bucket and sponge" effect. The disturbed nature of the soil attracts and holds water for varying lengths of time (the sponge). This situation has been exacerbated in Australia by the use, since at least the 1970's, of plastic lined coffins. These hold the decay products until the weight of the overlying soil, or the decay processes within, collapse the coffin (the bucket). This ultimately effects the temporal and spatial release of the decay products to the ground.

The first public release of data from the National Study was at the "Groundwater: Sustainable Solutions Conference", Melbourne, February 1998, IAH where two papers were published: Dent, B.B. and Knight, M.J. (1998) - Cemeteries: A special kind of landfill. The context of their sustainable development; and Knight, M.J. and Dent, B.B. (1998) - Sustainability of waste and groundwater management systems. The relevant data and comments from these papers are summarised below.

Extracts from Dent and Knight (1998)

This paper gives data from the analyses of background and downgradient groundwater samples from three sites representing three rounds of sampling from each, compared to similar wells or boreholes wholly located within the cemeteries. Seepage wells are 450 mm diameter and are used as temporary storage in sites dominated by spring flow or low hydraulic conductivity soils. The comparative well at The Necropolis is topographically downgradient, and at the boundary.

The authors describe the settings of the sites considered as follows:

- **Woronora**, in a southern Sydney suburb, New South Wales, where residual sandy clays and minor clayey sands, often lateritised, overly a quartz sandstone (Hawkesbury Sandstone formation) with substantial siltstone lenses (the seepage wells are at 2.0 - 4.5 m depth);

- **The Necropolis**, at Springvale a south-eastern suburb of Melbourne, Victoria, where densely unconsolidated, firm clays to 10 - 12 m, overly sandy silts, silty sands (Brighton Group) containing a phreatic aquifer at 14 - 28 m (the seepage wells are at 2.5 - 5.5 m depth);

- **Guildford** an eastern suburb of Perth, Western Australia, where unconsolidated shallow marine deposits of clayey and silty sands and fine sands (Bassendean Sand) have a phreatic aquifer at 1.8 - 4.5 m (3 m piezometer screens straddle the water table).

The data are reproduced below (from Dent and Knight, 1998) in Table 7.1. It should be noted that the results have been collected in a time period of reduced rainfall and it is possible higher rainfall will alter the concentrations of decay products and, as the water tables rise, make them more readily available to the groundwater.

Table 7.1 National Study Data (Dent and Knight, 1998)

Analyte	Woronora		The Necropolis		Guildford	
mg l^{-1} or CFU/100 ml	1x background	2x internal seepage wells	comparative seepage well	3x internal seepage wells	1x background	2x bores downgradient at boundary
EC μS/cm	509 - 922	236 - 684	241 - 263	608 - 2204	603 - 1127	216 - 667
pH units	5.5 - 6.6	5.0 - 7.4	5.6 - 6.3	6.3 - 7.5	6.2 - 7.3	5.8 - 6.1
NO_2-N	0 - 0.001	0 - 0.003	0 - 0.002	0 - 0.056	0.002 - 0.315	0 - 0.015
NO_3-N	0.2 - 0.3	0 - 1.16	0 - 2.2	0 - 14.3	0.4 - 6.3	4.1 - 33.2
NH_3-N	0 - 0.39	0.2 - 4.72	0 - 0.79	0 - 0.22	0.1 - 0.45	0 - 0.50
Tot N	0.10 - 0.25	0.55 - 3.9	0.3 - 0.8	1.2 - 21	1.0 - 4.2	18.1 - 45.0
PO_4	0	0 - 0.85	1.6 - 2.55	0.5 - 1.6	0 - 1.9	0.06 - 4.7
Cl	85 - 170	24 - 41	40 - 45	42 - 390	133 - 160	2 0- 33
SO_4	57 - 77	17 - 56	3.2 - 3.7	48 - 290	66 - 95	0-21
TOC	2.0 - 19	1.6 - 12	2.0 - 4.0	0 - 30	58 - 73	4.0 - 23
BOD	5 - 21	3 - 16	4 - 6	0 - 9	<5 - 22	<5
Tot coliforms	0-2	0 - >500	0	3 - >2400	0 - 8	0 - 8
E. coli	0	0 - 2	0	0 - 10	0	0
F. streptococci.	0	0	0	0 - 22	0	0
Pseudomonas	0	0 - 4	0	0	0	0 - 11

Conclusions - Dent and Knight (1998) conclude that the data show considerable variation and are overall low values and that the internal waters often appear to have lower concentrations of inorganics than the background waters, for example, chloride, sulphate, TOC, BOD, pH and electrical conductivity (EC). The data also shows that internal waters are significantly higher in nitrogen, phosphate and bacterial contents. The authors highlight that the study is not yet complete and only the early results are presented, however, they conclude that the data are evidence that decay products are measurable and could have an influence elsewhere in the environment.

At Australian cemeteries, as in the UK, the typical management practice is that all burials take place above known water tables. Dent and Knight (1998) conclude that this practice, driven mostly by public health legislation, is endorsed by the National Study results, which showed the presence of the pathogenic bacteria *Pseudomonas aeruginosa* and *Faecal streptococci* at many sites, albeit in small to very small amounts. These results suggest that, in some hydrogeological settings, microbiological decay products are being carried into the groundwater. The presence of perched water tables, either permanent or seasonal, should also be considered, as burial into such areas will influence the decay process and may lead to the resultant products being more susceptible to movement. Irrigation of cemeteries further distorts the natural water budget and encourages the wetting up of graves. Groundwater fluctuations are another important consideration.

Conclusions with regard to cemetery development, both new proposals and extensions, are also discussed and it is recommended that they should be properly assessed from a geoscientific perspective prior to detailed planning. The likelihood of off-site groundwater movement should be addressed as should assessments of the soil and cemetery operations. Buffer zones on all boundaries, planted with deep rooting trees and development of cemeteries from the outside-in are suggested.

Extracts from Knight and Dent (1998)

This paper details results from two cemeteries in Adelaide, the Cheltenham Cemetery and the Centennial Park Cemetery. Near-surface groundwaters are variously reported as perched and/or with variable depths 1.5 - 6 m, saline, low yielding, locally restricted and variable and subject to level variation with rainfall and seasonally (Miles, 1952).

The **Cheltenham Cemetery** is above an aquifer of the Adelaide Plain, Pooraka Formation, with a phreatic surface between 4 - 4.7 m below ground surface. The soils comprise light and dark brown and yellow brown silty and sandy clays, silty clayey sands, and minor silty sandy lenses, which are reported to be relatively low in lime content but possibly affected by fluctuating saline groundwater. Hydraulic gradients are extremely low (0.0007 to 0.004). Since monitoring commenced (September 1996) they have shown some reversals in direction with a number of stagnant areas likely to have developed. The bores near the cemetery boundary, but still within cemetery grounds, have experienced groundwater flows from off-site as well as from the cemetery graves. Less than normal rainfall has lowered the water table in this cemetery by about 0.3 - 0.5 m in nine months. The September 1996 water table was about 0.2 - 0.6 m below average invert levels of individual graves. The authors conclude that given the hydrogeological conditions outlined, it is difficult to conceive of rapid movement of groundwater off site at any time since the first interment here in July 1876. The groundwaters being sampled in the Study, except at the cemetery margins, are therefore likely to adequately represent the geochemical influences of 121 years of burials.

Conversely, the **Centennial Park Cemetery** lies mostly in deep, transported and possibly some residual alkaline clay soils of the lower slopes of the Adelaide Hills, Hindmarsh Clay. These soils absorb surface water and internally drain at a moderate to slow rate. At present, much less is known about this site. In the uppermost part of the soil profile, to depths of up to 2 m, there are extensive networks of subsoil drains which doubtlessly influence groundwater flow in the unsaturated zone. There are also shoe-string channel fills, the pathways of which are completely unknown. Extensive lawn irrigation also effects the sub-surface water distribution at any time.

The Cheltenham Cemetery groundwaters were sampled from seven piezometers with 3 m screens which straddled the water table. They are slightly to moderately saline (electrical conductivities 1230 - 6200 (µS cm^{-1}), slightly alkaline (pH 7.3 - 7.9), oxidated (Eh 59 - 234 mV), with oxygen contents in the range 5.8 - 59.4 % saturation with significant carbon dioxide contents (135 - 325 mg l^{-1}) and alkalinities of 294 - 960 mg l^{-1}, essentially attributed to bicarbonate ions.

In concert with other cemetery groundwaters being studied, they show the suite of nitrite, nitrate, chloride, sulphate, ammonium and orthophosphate ions in varying amounts and at various locations reflecting decay products from the interred remains (Dent, 1995). With the exception of chloride and sulphate, the quantities of other key ions are low to very low.

The range of values measured is depicted in Table 7.2. This separates the results into those related to at-boundary bores and those otherwise well within the cemetery. Because of the variable hydraulic gradients discussed earlier, any one boundary bore may not act as a permanent background and is likely to experience flows containing decay products at some, variable times.

An analysis of the results is not conclusive in establishing the isolation of the decay processes to within the cemetery. The increased nitrate presence in the internal bores is the best indicator of these processes here. The waters can be either said to be spatially the same, or that groundwater with a slight influence of the cemetery may be leaving the cemetery boundaries.

The near boundary bores are influenced by groundwater moving in and out of the cemetery under the influence of reversing gradients, however, the dominant flow direction is to the west. The bores considered include two at the up hydraulic gradient end and one at the lowermost downgradient position. The results from this last bore, if isolated, show upper end-of-range values in - ammonia, total kjeldahl nitrogen, total organic carbon, BOD - which is an indication of decay products concentrating downgradient. However, the possibility of contaminant sources outside the cemetery affecting the results is still to be evaluated.

Conclusions - The authors conclude that these results differ in some aspects when compared with other data being gathered nationally; the orthophosphate level is considerably higher; BOD levels are at the lower end of the range; total organic carbon is low and carbon dioxide is high, compared with other sites. These observations, considered together with the waters' redox status, suggests that the decay process, involving soft tissues, is proceeding well in this environment.

Table 7.2 Range of Key Cemetery Analytes Cheltenham Cemetery, S.A. (12/2/97 - 30/9/97)

Analyte	pH	NO_2-N	NO_3-N	Cl	SO_4	NH_3-N
Near-boundary bores (g)	7.5 - 7.8	0 - 0.034	0 - 0.6	52 - 1120	22 - 255	0.01 - 0.59
Internal bores (f)	7.3 - 7.9	0 - 0.010	0 - 11.4	107 - 576	52.5 - 179	0 - 0.53

Analyte	PO_4 (a)	TKN (b)	TOC (c)	BOD	CO_2 g
Near-boundary bores (g)	0 - 7.0	0.16 - 0.81	1.6 - 28.0	<2 - 15 (d)	210 - 325
Internal bores (f)	0 - 6.2	<0.05 - 0.61	1.3 - 21.2	<2 - 16	135 - 220

Analyte	Total coliforms	Faecal coliforms	Faecal streptococci	*Pseudomonas aeruginosa* (e)
Near-boundary bores (g)	0 - 2000	0 - 1	0 - 1	0 - 1
Internal bores (f)	0 - 17	0	0	0 - 40

All measurements in mg l^{-1} except for pH units and bacterial counts which are per 100 ml; (a) measured as orthophosphate; (b) total kjeldahl nitrogen; (c) total organic carbon; (d) 2 mg l^{-1} is the detection limit; (e) *Pseudomonas aeruginosa* was only sought from the second round of sampling; (f) internal bores are well within the cemetery; (g) Near- boundary bores are near the boundary but within cemetery grounds.

The results from a suite of indicator and pathogenic bacteria show no significant presence with the exception of that of *Pseudomonas aeruginosa*, a pathogenic bacterium. Its presence, in the absence of other faecal indicators, possibly indicates something about the organism's survival in slightly alkaline conditions; but this is uncertain at present. Certainly the bacterial results, considered together with the BOD, suggest a high degree of clean-up of decay products by natural microbiological systems.

However, the presence of pathogenic bacteria, in groundwaters which may potentially leave the cemetery boundary, is of concern. This bacterium has been found to be present in the majority of cemeteries studied by the authors.

The Cheltenham Cemetery (approximately 4 hectares) has had interments for over 121 years and has practised "lift and deepen" techniques for grave re-use since the late 1980s. Grave density is extremely high with effectively 100% of grave space utilised. The authors suggest from the groundwater monitoring results to date that, in this particular hydrogeological setting, there is little to be concerned about in terms of long term accumulation of deleterious decay products and that only very small amounts of these are likely to join groundwater flowing slowly off-site.

They conclude that these results allow the preliminary suggestion that the concept of grave re-use is a viable, ecologically sustainable activity. From a scientific perspective the study has only just begun the examination and consideration of the effects of cemeteries. Also there is no other scientific database from which to make comparisons and hence judgements on the environmental impacts of cemeteries.

The authors comment that "Grave re-use is widely practised around the World and has been part of the culture of numerous civilisations for centuries. With the continuing pressures on Australian capital city burial space, it is a worthy area for much greater consideration from the hydrogeological perspective".

Overall Conclusions and Recommendations from the Australian Study

Although the Study is continuing a number of general recommendations in respect of cemetery operations and planning have been made by Dent and Knight, along with some initial conclusions.

- There has been widespread, low level detection of indicator and pathogenic bacteria, and nutrients, in the groundwaters. However, their effects and longevity is unknown;
- There should be prevention of direct contact of decaying remains with groundwater as this will provide pathways for pollution. The prevention of burials into water tables appears sound policy;
- Appropriate hydrogeological assessment and/or monitoring should be carried out to determine groundwater level fluctuations so that the base of graves is well above any fluctuations. Perched and/or seasonal water tables should be taken into account;
- Buffer zones should be mandatory in cemetery design, ideally at the cemetery boundary. If they are planted with trees this should reduce groundwater flows leaving the cemetery boundary with the trees take up nutrients and maybe even accumulating trace metals. No burials should occur adjacent to the cemetery boundary;
- Ideally interments should be well spread in time and position within the cemetery to reduce point loading and the potential impact on groundwater.

7.2.2 Holland

One of the first published papers on groundwater pollution from cemeteries was in the 1950s and was carried out in Holland by van Haaren (1951). He set up a model for the breakdown of bodies based on an average weight of 50 kg (lower than now used, probably due to the number of sick children being buried) and calculated how much organic content there will be and how it breaks down (see Section 5.6). As well as studying the decomposition processes, samples of groundwater and watercourses near churchyards were obtained. In Holland, churches are often surrounded by ditches and these are in intimate contact with the churchyard. Groundwater and surface water samples were taken over time from various parts of the selected churchyard with different burial histories. Two further churchyards were also sampled. It was concluded that the identity and quantity of substances which drain off a churchyard cannot be ascertained, but that the groundwater and adjacent watercourses were badly polluted. The average chemical parameters of shallow groundwater below graves in a sandy soil under Dutch climatic conditions was given as:

Colour (platinum-scale units)	75
Electrical conductivity	2.3 millimhos
COD (using $KMnO_4$)	95 mg l^{-1}
Chloride	500 mg l^{-1}
Sulphate	300 mg l^{-1}
Bicarbonate	450 mg l^{-1}

(from van Haaren, 1951)

However, individual samples were quite variable with one sample containing 45 mg l^{-1} ammonium (van Haaren, 1951).

Following van Haaren's conclusions, the influence of cemeteries on the quality of surface water, drain water and groundwater was studied, in the south of Holland, by van der Honing (1988). Physical, chemical, microbiological and toxicity parameters were measured on two occasions at five cemeteries (chosen from eleven sites) and showed no elevated concentrations near cemeteries when compared to the reference waters. It was concluded that no, or scarcely any, influence was observed. However, the presence of pathogenic bacteria or viruses was not investigated and the paper concluded that, as a precaution, the water beneath cemeteries should not be used for recreation or spraying on plants for consumption (e.g. allotments). It was recommended that where new cemeteries are being constructed, the drain water be led to the municipal sewage system and it was not expected that this would increase the risk from normal sewerage.

7.2.3 West Germany

Groundwater in West Germany was sampled at a depth of 50 cm below grave level at different distances from a row of graves in a West German cemetery (Bouwer, 1978, from Schraps, 1972). The results are reproduced in Table 7.3 below.

Table 7.3 Groundwater quality in relation to distance from a row of graves

Distance from graves (m)	0.5	1.5	2.5	3.5	4.5	5.5
Bacteria count (per ml)	6000	8000	8000	3600	1200	180
NH_4 (mg l^{-1})	6	0.75	-	-	-	-
NO_3 (mg l^{-1})	4.8	0.1				
COD (mg l^{-1}, using $KMnO_4$)	26.7	16.4	15.4	15.4	11.4	11.4

The graves were located in unconsolidated alluvium underlain by siltstone. The data show contamination in the immediate vicinity of the graves, but rapid attenuation with distance from the grave. The results led Schraps to recommend that water tables in cemetery plots be at least 2.5 m below surface, which at the customary depth of burial of 1.8 m, gave an unsaturated filter zone of 0.7 m. This depth was considered adequate for groundwater protection in medium textured soil materials, such as loams and sandy loams. Schraps included details of studies at a Hamburg cemetery, at which the unsaturated zone was of a comparable depth, and where there was no evidence of groundwater pollution. Highly permeable materials, such as gravels, or soils that are so fine that anaerobic conditions prevail, even with a filter zone present above the water table, should be avoided. Where cemeteries are underlain by fractured or karstified rock, the author concludes that serious groundwater contamination can result.

7.2.4 Brazil

Two papers relating to studies in Brazil were identified and are summarised below.

In a paper by Pacheco *et al* (1991), direct groundwater investigations were carried out at three cemeteries. Bacterial indicators showed contamination at all three. The extent of pollution was found to be influenced by the depth to water table and the lithology.

Another study by Martins *et al* (1991) collected groundwater samples from piezometers at three cemeteries in geologically distinct areas of S. Paulo and Santos, Brazil. The samples were analysed in order to determine their hygienic and sanitary conditions. Faecal coliforms, faecal streptococci, sulphite reducer clostridia and Salmonella were assayed for the purpose of evaluating sanitary conditions, and total coliforms, heterotrophic bacteria, proteolitic and lipolitic micro-organisms for evaluating hygienic conditions. In some samples, nitrate levels were also determined. It was discovered that these waters do not present adequate sanitary and hygienic conditions and that, in some cases, nitrate levels were extremely high (75.7 mg l^{-1}). In most samples, higher levels of faecal streptococci and sulphite reducer clostridia than faecal coliforms were detected, which suggests that the two former indicators would be more appropriate for evaluating the sanitary conditions of this kind of water. Salmonella were detected in only one of 44 samples analysed and coliphages in none. In the statistical analysis, the correlation matrix showed significant correlations among three faecal pollution indicators, as well as among anaerobic and aerobic heterotrophs and lipolitic bacteria. A direct relationship between the deterioration of water quality and the geological and hydrogeological conditions of the environment studied was observed. When cemeteries are constructed these conditions should, therefore, be taken into consideration.

7.2.5 Canada

A detailed soil and groundwater investigation was carried out at Mount Pleasant Cemetery, Toronto in May 1992 (Beak Consultants Ltd., 1992). The site was chosen because of its size (200 acres) and age (120 years), as it was thought if chemicals were being discharged by cemeteries into soils, then it would be probable that in a cemetery of this size and age there would be a good possibility of detecting them in the sub-surface. The soil conditions were generally fine grained silts with seams of coarser sand.

Drilling, sampling, and leach tests (Ontario Ministry of the Environment Regulation 309) were undertaken. Three groundwater monitoring boreholes were installed, using hollow-stem auger, to between 8 and 16 m. All boreholes were drilled into the water table but exact water level depths are not recorded in the paper. Analyses were undertaken for chemicals in use, and historically used, in embalming and in coffin materials. These included formaldehyde, methanol, arsenic, solvents and various metals, as well as DOC and TOC.

A summary of results is presented in Table 7.4. The higher levels of DOC (7.6 mg l^{-1}) and TOC (1.23 mg l^{-1}) were recorded in samples from the same area, but were explained by the historical presence of a pond in this area and the natural organics associated with it. It was concluded that there were no elevated levels to cause concern in either soils or groundwater at the cemetery.

Table 7.4 Mount Pleasant Cemetery, Toronto, Ontario (Beak Consultants Ltd, 1992)

Parameter	Soils	Groundwaters (mg l^{-1})
Arsenic	<0.005 mg l^{-1} *	<0.002
Formaldehyde	<10 μg g^{-1}	<0.2
Methanol	<100 μg g^{-1}	<0.01
TOC	0.25, 0.48, 1.23 μg g^{-1}	-
DOC	-	1.0, 1.6, 7.6
Faecal coliform (/100 ml)	-	<4

* Arsenic concentration in soils following leaching test

7.2.6 Greece

An environmental study of a karstic limestone and limestone debris area in Greece was carried out (Stournaras, G. 1994). Details include sketchy data on volume and composition of "leachate" per corpse (0.4 m^3/year/corpse) and a chemical composition that includes high concentration of Cl^-, SO^{2-}, HCO^-, NO^{2-}, NH^{2+}, COD, and a number of pathogenic bacilli, rods, and other microbes. However, Bouwer advised caution when attributing contamination to burial grounds, commenting that a well located in limestone near a cemetery with an increased bacterial content was more likely to be caused by human activity at the limestone outcrop than by the cemetery itself (Bouwer, 1978 from Brausz, 1952).

7.3 Groundwater pollution related to embalming

A literature search to examine the potential for contamination of groundwater by preservatives containing formaldehyde in the United States and Canada obtained no information on the subject (Soo Chan, *et al* 1992). It was the first investigation of its kind in North America. The study by Soo Chan included a survey of standard burial practices, which indicated that, in populated areas of Ontario, 90% of bodies are embalmed and then placed in caskets. Formaldehyde has both mutagenic and carcinogenic effects, by both damaging DNA and inhibiting its repair. Its use within the human environment extends beyond that of preservation of cadavers and includes uses in agriculture, tanning practices and the manufacture of plastics. Groundwater sampling was conducted at six sites in Ontario on shallow sandy aquifers (Soo Chan, *et al* 1992). Most wells were located down gradient of cemeteries, and ranged in depth from 3 to 24 metres; burial times ranged within 100 - 8 years; and separation distances from the potential source ranged between 500 to 2000 metres. Each well was purged for 5 minutes prior to the collection of unfiltered samples. Samples were kept refrigerated before analysis for formaldehyde, nitrates, bacteria and phosphates.

The following estimations were made (Soo Chan, *et al* 1992). Formaldehyde loading calculations were estimated at 0.117 litre of formaldehyde per body. Assuming the maximum density of 500 bodies per acre, gave 58.5 litres of formaldehyde per acre over 10 to 15 years, which equates to 0.012 litres of formaldehyde per day. Measured concentrations of formaldehyde ranged from 0.001-0.03 mg l^{-1}. After dilution within the aquifer the authors conclude that the results indicate that cemeteries are not a significant contributing source of formaldehyde to groundwater.

Circumstantial evidence was obtained of arsenic, which may be leaching into the groundwater from embalmed Civil War (USA) corpses, where up to 3 lb of arsenic was used per corpse (Anon, 1990). Use of arsenic was banned in 1910 by US federal government as it was interfering with the investigations of suspected arsenic poisonings. There were no confirmed cases of groundwater pollution from arsenic but one company had found traces in groundwater monitoring wells adjacent to a civil war cemetery. No further details have been found on this case. A French paper (Truffert, 1974), obtained during the literature review, discusses how, in some circumstances, arsenic can actually fix itself after death into hair, penetrating so deeply that it resists all washing and is thus indistinguishable from arsenic deposited during life. The paper also states that it is also possible for visceral remains to become impregnated even in waters where the percentage of arsenic is not superior to that of drinking water, due to the formation of mud with a high arsenic content. Tests were also carried out involving impregnation with other toxic metals including lead, thallium, mercury and cadmium and it was concluded that all these may become fixed in a similar way.

It is reported by Nash (pers comm 1997) that analysis of perched water from a recently excavated grave at Northwood cemetery showed the presence of ammonia at 409 mg l^{-1} and formaldehyde at 8.6 mg $l^{-1.}$ The source of the ammonia is not confirmed, high levels can be associated with sewage contamination, decomposition of animal or vegetable material and with nitrogenous based fertilisers. The analysis report states that the formaldehyde result is equivalent to 0.00086% - concentrated formaldehyde solution would be 36 - 40%. Further reports of air monitoring for formaldehyde during the excavation of a grave in London were received. Formaldehyde was not detected in the absorbing solution (ammonium acetate) from either of the two grave diggers monitored (< 0.01 mg l^{-1}) and in addition no formaldehyde was detected using Draeger tubes at the base of the grave.

7.3.1 Formaldehyde degradation

Information was obtained from a colleague at WRc Swindon (Rod Palfrey) on the degradation of formalin (35-40% solution of formaldehyde - HCHO - in water) under anaerobic conditions. At high concentrations it is toxic to bacteria and acts as a disinfectant. At lower concentrations it would leach and degrade via formate to methane/carbon dioxide along with other fatty acids. Aerobic degradation is to carbon dioxide and water. At high concentrations formaldehyde reacts with proteins to prevent disintegration of tissues and is antibacterial. (See also comments by Mr Haler of Dodge Chemicals re embalming fluids in Section 5.7.2).

7.4 Pathogenic organisms

The main factors which are being taken into consideration are: (i) the identity of pathogens of various types that may occur in buried material; (ii) the rate of decay of any surviving pathogens; (iii) the possibility of regrowth of pathogens; (iv) the susceptibility of those at risk (many pathogens are host specific, whereas others such as salmonellae and *E coli* 0157 are more universal in their ability to cause infection and overt illness); (v) routes of human exposure, infectivity and LD_{50}.

It is recognised that a particular concern in carrying out a risk assessment would be the novel infectious agents, particularly BSE. Although knowledge of this agent is still incomplete it is known to be very resistant to natural processes of biodegradation. However, the agent is only present in specific animal organs of a few animals and, in the UK, these organs are being segregated for disposal by special means to ensure they do not get used for any purpose. In the case of humans who die from new variant CJD, confirmation of the cause of death requires the brain to be removed for autopsy. In the event of subsequent burial of the corpse (rather than cremation) the principal source of prions (the brain) would be absent, although nvCJD material could, theoretically, remain present in the spinal cord and optic nerves. Careful consideration of this restricted occurrence would need to be taken into account in any risk assessment.

In general terms tolerance to biodegradability and persistence in the environment is likely to be:

BSE > bacterial spores > parasites > viruses > vegetative bacteria

Several serious human diseases are caused by types of bacterial spores notably the species of Clostridia (tetanus, botulism, gangrene and food poisoning) although the spores of some species of Bacillus can be regarded as pathogenic.

Table 7.5 Categories of pathogenic organisms

Category of Micro-organism	Examples
Vegetative bacteria	salmonellae Enterobacteriaceae
viruses	enteroviruses, hepatitis
parasites	Taenia, Ascaris, Cryptosporidium
bacterial spores	clostridium, bacillus
Protein based infectious agents	BSE, Scrapie, nvCJD

7.5 Animal burial

A German article (Klein W., Reprint 1997) discusses on-farm burial of dead stock and concludes that it may lead to local contamination of groundwater by nitrogen species and dissolved organic matter. It also concluded that there is a definite risk of localised pollution, the size of which depends on the number of dead animals buried and the hydrogeological conditions of the site.

7.6 Atmospheric emissions

Past problems of odours associated with inadequate burial procedures are noted by authors such as Holmes (1896), author of The London Burial Grounds.

An unusual variant has been identified by Pentecost (1997), who has suggested that "corpse candles" (otherwise *ignis fatuus* or *will-o'-the wisp*) may be the result of the production of diphosphane from the putrefaction of corpses, with the gas undergoing spontaneous combustion on contact with oxygen in the air. Twenty three instances have been recorded since about 1552, of which thirteen have been during the 20th century (Appendix F). With the exception of appearance associated with sewage sludge at Mill Hill in London (1980) all were associated with burials of humans or animals, commonly in waterlogged ground. Whether or not the combustion of diphosphane gas gives rise to atmospheric pollutants is uncertain, but the potential occurrence of flickering lights over burial places is unlikely to be conducive to public equanimity.

Dr Pentecost (1998), of the School of Life, Basic Medical and Health Sciences, King's College London, visited WRc and discussed the occurrence of ignis fatuus and the conditions which lead to its production. Papers related to the topic were received from Dr Pentecost. These included an article in *New Scientist* "Graveyard ghosts are a gas" (Emsley, J., 1993), which referred to the German scientists, Gassmann and Glindemann who found micro-organisms which can make both the gases phosphane and diphosphane. A number of other records of observations of the phenomenon (Irrlichtern) in Germany were also received, principally dating from the latter part of the last century and the first two decades of this, but did not include any reference to gaseous emissions specifically associated with burials. A review of theories from the 18th, 19th and early 20th centuries on the causes of Will-o'-the-wisp (Mills, 1980) concluded that although the phenomena had attracted considerable scientific debate no specimen has ever been 'captured' for laboratory study.

An article by Sly (1994) discusses a report which had appeared in *The Journal of Public Health* (UK), Volume 1, No. 2, published in June 1855. The article discussed the possibility that an epidemic of small-pox in Quebec arose from the disturbance of an intramural cemetery 214 years old. "Numerous instances are recorded of the highly deleterious effects produced by the escaping gases from coffins which had lain tranquil for many years". No conclusions are drawn.

8. DISCUSSION AND FINDINGS OF LITERATURE REVIEW

8.1 Discussion

Examination of much of the so-called evidence of environmental contamination from burial grounds shows it to be hearsay and circumstantial. Attributable and verifiable data are sparse and may be incomplete, with historic data often being anecdotal and relating to practices which are no longer carried out in the UK. There is very little information related specifically to the situation in England and Wales, although studies from other northern European countries and from parts of North America may provide acceptable analogues.

The results of the computer aided literature search and the extensive contacts made during the course of the surveys produced only twenty four sets of data related to groundwater composition beneath or adjacent to burial grounds, of which rather less than half were in hydrogeological or climatic situations which may find parallels in England and Wales. The results of the survey are summarised in Table 8.1, but are given in full in Appendix A. Results from sampling on more than one occasion are only available for a small number of cemeteries in Holland, at Branston in England and in Australia. The data set was insufficient to allow statistical analysis and quantification of the observed impacts from cemeteries.

The evidence gathered and assessed from around the world indicates that there is a potential for water pollution associated with the siting of burial grounds, particularly in those locations where burials from a large area are concentrated to a single cemetery, and where the hydrogeological conditions are such that any other potentially polluting activity would require a properly conducted risk assessment to be completed before authorisation.

The perception of the funeral industry is that there is awareness amongst their members of the potential problems, but not necessarily amongst planners in Local Authorities.

It appears that potential problems associated with intensive embalming may not be as serious in the United Kingdom as in other countries, particularly in view of the movement away from formalin to saline solution as a short term preservative, and the cessation of the use of toxic metals in embalming preparations. However, some 15% of the UK funeral industry is now owned by American interests and pressure towards more intense embalming and the securing of more "perpetual" grave sites is possible.

The situation regarding the potential emission of pathogens in water from burial grounds remains ambiguous and although further sources of information were sought, little firm field-based evidence was obtained. This is an area where more field-based research is required, particularly relating to survival of pathogens in the groundwater environment.

8.2 Findings

1. Unequivocal evidence of water pollution from burial grounds is confined principally to situations of shallow water tables, high burial rates and an area in which

hydrogeological factors favour the persistence of anoxic ground conditions. Conversely, burials in low permeability areas (non-aquifers) may lead to the prolonged presence of decay products in anaerobic conditions, which could threaten local surface waters.

2. The amount of field-based research is very limited. The most comprehensive study is currently being undertaken in Australia (Knight, 1996, Knight and Dent, 1998), and the preliminary findings are summarised below:

   - There has been widespread, low level detection of indicator and pathogenic bacteria and nutrients, in the groundwaters. However, their effects and longevity is unknown;

   - There should be prevention of direct contact of decaying remains with groundwater tables as this will provide pathways for pollution. The prevention of burials into water tables appears a sound policy;

   - Appropriate hydrogeological assessment and/or monitoring should be carried out to determine groundwater level fluctuations so that the base (invert level) of all burials is well above any fluctuations. Perched and/or seasonal water tables should also be considered;

   - Buffer zones should be mandatory in cemetery design, ideally at the cemetery boundary. If they are planted with trees this should reduce groundwater flows leaving the cemetery boundary with the trees take-up nutrients and maybe even accumulating trace metals. No burials should occur adjacent to the cemetery boundary;

   - Ideally interments should be well spread in time and position within the cemetery to reduce the impact.

3. There are no published papers, and little raw data, detailing cases of pollution from cemeteries in the UK. This may be an area for more research and a programme of monitoring boreholes located near cemeteries.

4. Although evidence from the United States has suggested that in the past soils at burial grounds may have become contaminated by toxic metals in embalming fluids, such as arsenic, current UK embalming practices are such that similar pollution is extremely unlikely in the future.

5. There is little evidence that atmospheric emissions are likely to present problems from future cemeteries.

Table 8.1 Summary of results of literature search and personal communications

Country	Site	Soil / geology	Climatic type	Comments	Source
			Europe		
United Kingdom	London	Clay	Cool temperate maritime	Water in excavated grave, ammonia and formaldehyde only	Nash, 1997.
United Kingdom	Lincs	Sand / limestone	Cool temperate maritime	2 year sequence, ammonia and COD	Environment Agency, Anglian Region 1998
Netherlands	3 sites	unknown	Cool temperate continental	Data from areas with different lapse time since burials. Analyses limited to principal anions	van Haaren, 1951.
Netherlands	Krimpen	Peat	Cool temperate continental	Sampling on two occasions. Extensive chemical parameters, no bacteriological.	van der Honing *et al*, 1988
Netherlands	Hardinxveld	Sand	Cool temperate continental	Sampling on two occasions. Extensive chemical parameters, no bacteriological.	van der Honing *et al*, 1988
Netherlands	Rotterdam	Sand	Cool temperate continental	Sampling on two occasions. Extensive chemical parameters, no bacteriological.	van der Honing *et al*, 1988
Netherlands	Westmaas	Sand	Cool temperate continental	Sampling on two occasions. Extensive chemical parameters, no bacteriological.	van der Honing *et al*, 1988
Netherlands	Zwijndretch	Sand	Cool temperate continental	Single sampling. Extensive chemical parameters, no bacteriological	van der Honing *et al*, 1988
Germany (West)	Unknown	Unconsolidated alluvium	Cool temperate continental	Samples at 5 distances from grave. Ammonia / nitrate, COD and total coliforms	Schraps, 1972

Country	Site	Soil / geology	Climatic type	Comments	Source
			Americas		
Canada	Toronto	Fine sand/silt	Cool continental	Very limited suite, some heavy metals; faecal streps.	Beak Consultants 1992
Canada	Lindsay Ontario	Sand	Cool continental	Nitrite, nitrate and phosphorus only. No bacteriological	Soo Chan *et al* 1992.
Canada	Binbrook, Ontario	Sand	Cool continental	Nitrite, nitrate and phosphorus only. No bacteriological	Soo Chan *et al* 1992.
Canada	Omeemee, Ontario	Sand	Cool continental	Nitrite, nitrate and phosphorus only. No bacteriological	Soo Chan *et al* 1992.
Canada	St Mooe, Ontario	Sand	Cool continental	Nitrite, nitrate and phosphorus only. No bacteriological	Soo Chan *et al* 1992.
Canada	Sarnia, Ontario	Sand	Cool continental	Nitrite, nitrate and phosphorus only. No bacteriological	Soo Chan *et al* 1992.
Canada	London, Ontario	Sand	Cool continental	Nitrite, nitrate and phosphorus only. No bacteriological	Soo Chan *et al* 1992.
Brazil	Sao Paulo	Tertiary sediments	Tropical maritime	Bacteriological only	Pacheco *et al*, 1991
Brazil	Sao Paulo	Weathered granite	Tropical maritime	Bacteriological only	Pacheco *et al*, 1991
Brazil	Santo	Coarse marine sediment	Tropical maritime	Bacteriological only	Pacheco *et al*, 1991
			Australasia		
Australia	Adelaide	Silts / sand / clays	Warm temperate continental	Repeated sampling. Chemical and bacteriological analyses.	Knight and Dent, 1998
Australia	Sydney	laterised clay	Warm temperate continental	Repeated sampling. Chemical and bacteriological analyses.	Dent and Knight, 1998
Australia	Melbourne	dense clay	Warm temperate continental	Repeated sampling. Chemical and bacteriological analyses.	Dent and Knight, 1998
Australia	Perth	Unconsolidated marine silty sands	Warm temperate continental	Repeated sampling. Chemical and bacteriological analyses.	Dent and Knight, 1998

9. REVIEW OF AGENCY REGION'S APPROACHES

In conducting this review, the following objective was observed:

- 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.

9.1 Outline approach to the review

This stage of the project involved visiting the Environment Agency Regions to take account of their views and experience in the area of pollution potential of cemeteries, together with their approaches taken to the problem of commenting upon planning applications for new cemeteries, or extensions to existing burial grounds. The principal areas in which information was sought during discussions were:

- Guidance (local, regional or national) which is used by the Agency officers in considering these matters;

- Examples of application of such guidance, and the responses of planning authorities and others (public local opinion, environmental pressure groups etc.);

- Any recorded instances of a contamination arising from burial grounds in each Region.

A check-list and questionnaire was developed and forwarded to each Region in advance of the meeting (shown in Table 9.1), along with a copy of the literature review and relevant sections of the first progress report. This enabled each meeting to be structured and aided both the interviewer and interviewee. The possibility of obtaining further information and views from Environmental Health Officers (EHOs) was also investigated in conjunction with the visits to the Environment Agency.

Each meeting with the Agency was attended by the Project Director, to provide consistency in the evaluation process, as well as another member of the project team.

Table 9.1 Check-list and questionnaire used for discussions with the Regions

POLLUTION POTENTIAL OF CEMETERIES

Discussion Points for Regional Visits

1. Are there regional or sub-regional policy statements on burial grounds (human and animal) with respect to:
   a) groundwater protection
   b) surface water protection
   c) protection of other environmental sectors (soil, air)
   d) mass burials (civil disasters/foot and mouth etc.)?

If so, can copies be seen or made available?

2. Are problems encountered with Planning authorities arising from comments made by the Environment Agency (or predecessors) with respect to applications for:
   a) extensions to existing burial grounds
   b) establishing new burial grounds
   c) establishing "green" burial sites
   d) establishing pet cemeteries
   e) establishing mass graves (human or animal)?

Are any reports or technical papers related to any incidents available for examination?

3. Are there any data available (preferably written, but anecdotal may also be useful) with respect to:
   a) groundwater quality in the vicinity of burial grounds (including mass burials of slaughtered animals)
   b) surface water quality (as above)
   c) drains in the vicinity of burial grounds
   d) impacts on other media (air, soil, biota)?

Can any such data be made available for analysis and inclusion in the documentation which will support the guidance document?

4. Are there other persons or groups with specific information or views on the subject who should be contacted:
   a) EA staff within the Region
   b) Local Authority Planners
   c) Environmental Health Officers
   d) Water Utilities - supply and wastewater treatment
   e) Water Supply companies
   f) Others?

Names, titles/appointments, addresses, phone and fax numbers, e-mail addresses would be very useful.

5. Are there specific areas of guidance/advice which would be welcomed by officers in your Region?

9.2 Information obtained during visits to Environment Agency Regions

All the Agency Regions were visited with the exception of the North East and North West where discussions were carried out by telephone and written contact. The discussions which took place at each of the Regions are given in full in Appendix B with pertinent details below (Section 9.2.1 to 9.2.8).

9.2.1 Anglian Region

The Anglian Region generally use the PPPG and MAFF guidelines, but each site is taken on its merit rather than any stringent conditions being enforced. No burials are allowed in saturated ground.

Regular monitoring data from a borehole located within a cemetery was made available. Chemical data (quarterly) and hydrographs (water level data) from the two nearest abstraction boreholes was also supplied. The groundwater level at the site is about 4 m below ground and the COD levels range from 23 to 461 mg l^{-1} O, with ammonia ranging from less than 0.3 to 0.8 mg l^{-1} N. The peaks in COD and ammonia do not necessarily coincide, although a peak in one or other does seem to occur, on initial inspection, about two or three months after a peak in water level recorded at nearby observation boreholes.

9.2.2 Midland Region

The policy used for guidance is the PPPG. Cemeteries are a possible bacteriological problem and are viewed in the same way as individual septic tanks (unless its a mass burial). Appendix 7 of the Severn Trent Water Authority Groundwater Protection Policy (1976, update 1989) is the only place where burial is specifically mentioned.

The area is mostly on sandstone. If there is a spring or abstraction then a 100 m restriction in Zone I applies. If there is a reasonable unsaturated zone then burial is not viewed as a problem, it is only if there is shallow gravel groundwater that a problem may occur. In relation to surface water no burials are permitted within 10 metres of land drains or surface watercourses. If a site has had a historic problem of surface water pollution, then the Agency may advise some form of cut-off trench. The Environmental Health hold the list of private supplies and the Agency rely on them, and the public, to keep them informed in relation to planning.

9.2.3 North East

The Regions procedures for dealing with cemeteries were very similar to that used at most of the other Regions. The MAFF Code of Good Agricultural Practice for the Protection of Water and the Agency's PPPG are the Region's principal guideline documents. The Region does not have its own policy on the subject. Environmental Protection staff have not reported any specific water quality problems attributed to cemeteries nor any specific monitoring carried out near them. The presence of field drains was noted as a cause for concern as their location may not be known.

9.2.4 North West

Information obtained included a proforma letter commonly used in response to enquirers seeking groundwater protection advice on burial site location in the NW Region. It is included in full in Appendix C with the main conditions summarised below:

1. *"Human or animal remains must not be buried within 250 metres* of any well, borehole or spring from which a potable water supply is drawn.*

   ** this distance may be greater if the site is within an unusually large Groundwater Source Protection Zone I - this is rare.*

2. *The place of interment should be at least 30 metres away from any other spring or watercourse and at least 10 metres from any field drain.*

3. *All burial pits on the site must maintain a minimum of one metre of subsoil below the bottom of the burial pit (i.e. the base of the burial must be at least one metre above solid rock).*

4. *The base of all burial pits on the site must maintain a minimum of one metre clearance above the highest natural water table. (Any variability of the water table should be taken into account).*

5. *Burial excavations should be backfilled as soon as the remains are interred, providing a minimum of one metre soil cover".*

The first three conditions are based on the MAFF guidelines (see Section 3.9), although these do not mention depth to solid rock (item 3 above). The letter goes on to say that:

"the combined requirements of notes 3, 4 and 5 would normally give an expectation of an <u>absolute minimum</u> distance from ground level to water table or the surface of the underlying rock (whichever is the least) of 2.4 metres for a <u>single</u> supine human graves.

If multiple burials are anticipated on any one plot this minimum clearance depth must be increased to suit the circumstances."

Should it not be possible to comply with Notes 2 to 5, the letter states "*it may be possible to seek an engineered solution by <u>permanently</u>:*

(a) diverting watercourses or drains;

(b) dewatering the ground; or

(c) raising the ground level to achieve the required clearances".

The problems with the latter course of action are then discussed, for example, option b is unlikely to be practical "*because of the cost, practical maintenance difficulties and water resource derogation potential*".

The developer is also advised to check with local Environmental Health Officers to assist in confirming the absence of any known unlicensed potable groundwater abstractions in the vicinity.

The letter concludes with an option for the Agency officer to include information from records held by the Environment Agency, such as source protection zones, recorded water table, known licensed and unlicensed abstractions of groundwater near the proposed development.

9.2.5 Southern Region

The Southern Water Policy has been superseded by the new Groundwater Protection Policy (PPPG). The old protection zones are being used at the moment until the new zones are published, most now have draft new zones. The MAFF code of good agricultural practice is also followed.

Planning applications for burial sites within Zone I are usually opposed, with Zone I based on a 50 day travel time. For surface water a common sense approach is used. In Hampshire they tend to recommend burial to be 10 m from a watercourse, although 20 to 30 m was thought preferable.

9.2.6 South West Region

It was generally felt that guidelines were needed, and that advice in terms of a protocol and risk assessment, with some background guidance, would be useful. From the risk assessment approach for small burial grounds, where a full scale, site-specific, assessment would not be feasible, it would be helpful to have an estimate of how many bodies buried a year would be likely to cause a pollution problem. When considering planning applications, it would be useful for the application to stipulate the area it will serve, and how many interments a year are likely. A better estimate of risk assessment versus rate of input would then be possible.

9.2.7 Thames Region

The Thames Region would normally make any comments on proposals to develop or extend cemeteries at the planning stage under the Town and Country Planning Acts. There are no Regional groundwater quality statements *per se*, reference is made to the policy statement in the PPPG and the MAFF guidance on Good Agricultural Practice when undertaking an initial site assessment. In general, the usual conditions requested are:

- no graves within Zone I;
- no graves within 250 m from any well, borehole or spring used for potable supply or 50 m from any other well or borehole;
- burials not normally acceptable within Zone II, but applied on a site specific basis;
- no burials in saturated ground; and
- at least 1 m unsaturated zone should remain below the base of the grave.

However, in some cases a minor extension in Zone I has been accepted. For example, at a small church which lies on the Chalk, with a substantial unsaturated zone, burials have taken place since the Middle Ages with apparently no impact on groundwater or public supply quality. Only a small number of burials were proposed each year, so overall the risks of pollution seemed minimal.

In some cases, requests for confirmation of water levels have been made, for example, over the winter period. Generally, the importance of being able to justify decisions in protecting groundwater quality was highlighted.

9.2.8 Welsh Region

No formal regional guidance is in existence but the need to establish a policy that can be applied uniformly was recognised. When planning applications are received the line of investigation generally encompasses a vulnerability survey and risk assessment with referrals to the PPPG and the MAFF guidelines. Applications are dealt with on a site specific basis with the Agency tending to do the risk assessment; the Local Authorities or churches concerned generally lack the in-house expertise and the capital to pay for it.

Attention was also drawn to a discussion document from the **Thames Region** regarding extensions to or development of new cemeteries. It was suggested that information to be gathered includes:

- rate of burials;
- areal extent;
- percentage increase if extension;
- geology.

General suggestions for guidance were:

- no graves within Zone I or within 250 m of any well, borehole or spring used for potable supply;
- not normally acceptable within Zone II unless low vulnerability conditions exist (e.g. significant thickness of clayey strata overlying aquifer; reasonable unsaturated zone; low permeability in aquifer);
- no graves within 30 m of any watercourse, spring or borehole;
- no land drainage in areas used for graves;
- where graves cited on major aquifers or "significant" areas of minor aquifers a minimum of 1 metre unsaturated ground below grave.

A planning application was forwarded to the Agency in 1997 for an extension to an existing graveyard in Llanelly. The proposed land was bordered by three other graveyards and, while no objections to the application were made, it was advised that, in order to assess the potential impacts from the new cemetery the developer should submit the following information:

1. identification of all water features within a 500 m radius (surface and groundwater);

2. thickness and type of soils and rocks underlying the site;

3. depth to water table, especially with respect to the maximum depth of burial;

4. rate of burials;

5. the quality of the local spring discharges in the vicinity of the existing graveyards.

Additionally, it was noted that if the water table would be intersected by the graves then the proposal would not be acceptable. Graves were not to be placed within 15 m of a water course or 50 m of a spring, although this distance was debatable depending on ground conditions and the use of the water feature.

9.3 Environmental Health Officers

Based on contacts suggested by staff of the Anglian Region, a number of EHO's were interviewed by telephone. Although interested in the potential for environmental pollution by cemeteries, none were able to offer direct experience of relevant problems.

9.4 Summary of findings from Agency Regions

In all Regions it has been stated that the principles incorporated in the Policy and Practice for the Protection of Groundwater (PPPG) (Environment Agency, 1998) are applied to the assessment of Planning applications related to the extension of existing, or the establishment of new, burial grounds. In those cases where guidance is given, it appears frequently to be based on that given by MAFF for the disposal of farm animals, which states that, if other ways of disposing of carcasses are not practical, and a notifiable disease is not suspected or has been ruled out, the carcass can be buried on the farm. Then:

- burials should be at least 250 metres away from any well, borehole or spring that supplies water for human consumption or to be used in farm dairies;
- burials should be at least 30 metres away from any other spring or watercourse, and at least 10 metres from any field drain;
- burials should 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 hole must be free of standing water (which may be interpreted to indicate that it must be above the local water table).

It is noted that this guidance relates to cadavers 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 9.2. 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 9.2 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 & MAFF	250	30	10	No	Initial assessment based on MAFF
Welsh	PPPG & MAFF	250	30	10	No	

All Regions oppose burials which extend below the local maximum water table levels, but only in the North West Region does the opposition appear to extend to graves into the dry rock-head.

It was noted that a higher number of planning applications related to burial grounds had been recorded in Regions with significant urban populations (Midlands and Southern), than in those of a dominantly rural character. However, even in areas such as the Midlands the majority of applications were for small extensions in the more rural parts. A number of Regions have reported an increase in planning applications for pet cemeteries and green burial sites.

Although all Regions were interested in the study, and the possible effects cemeteries may have on groundwater, only Anglian Region were able to offer pertinent groundwater quality data.

From the discussions with Regional staff there was widespread agreement that the guidance should take the form of general rules, scientifically based, but should also include an element of site specific risk assessment. Principal points which emerged from the discussions are noted below. These form the basis for drafting Technical Report P223.

* **Clarification of legal responsibilities**. There remain uncertainties over the powers and responsibilities of the Environment Agency in these matters, and in particular the relationships with Planning and Environmental Health Authorities. The place of local bye-laws and regulations by cemetery companies, Church authorities and others is also poorly defined or understood, and it is possible that this uncertainty is shared by all the bodies concerned. An introductory section, modelled on Section 3 of the Policy and Practice for the Protection of Groundwater (Environment Agency, 1998), is included in Section 1 of the guidance document. Although all Regions were interested in the study, and the possible effects cemeteries may have on groundwater, only Anglian Region were able to offer pertinent groundwater quality data (Environment Agency, Anglian Region, 1998).

* **Application of risk assessment methods**. There is widespread agreement from the regions that the guidance should be based on risk assessment protocols, in which local site specific conditions and characteristics are taken into account, rather than on a purely prescriptive approach. However, it is also recognised that there may be situations in which application of default values is more appropriate, particularly in the case of low risk proposals.

* **Small scale developments and minor authorities.** It is possible that the burden of providing environmental impact assessment data for small proposals (for example extensions to rural cemeteries with a low burial rate) may be difficult to fulfil by small authorities (Parish and Parochial Church). As a result, the guidance has developed advice on the recognition of situations in which simple default values (depth of unsaturated zone, distance from streams etc.) could be applied, or where a simplified form of risk assessment would suffice, employing only data which is widely and quickly available (average rainfall, identification of water features from 1:25 000 OS maps, simple geological/pedological maps).

* **Principal elements of the risk assessments**. The following elements are incorporated in the guidance on risk assessment:

    - *Source term, 1*. In addition to the absolute size of the proposed site, the load (rate of burial) should be considered as an important element. In the case of extension to burial grounds, the overall size and relative age of the existing area may need to be taken into account.

- *Source term, 2*. The local ground conditions, so far as they may influence the rate of release of potential contaminants (rate of decomposition of corpses), and the implications for potential loading to the appropriate receptor.

- *Pathways terms.* Consideration of the pedological, geological, hydrogeological and meteorological factors which influence the potential flux of contaminants from the burial site and the attenuation which may take place before a receptor is reached. Principal factors are expected to be the lithology (grain size and mineralogy) of soils, sediments and rocks, the influence of fissures and other discontinuities, the depth of the unsaturated zone, and the relationship of the proposed site to potential environmental receptors.

- *Receptors*. Discussion with Regional officers has indicated that the principal receptor of concern is groundwater. However, examples of problems associated with surface waters have been recorded and should be addressed. Gaseous emissions have not featured in the discussions and it appears probable that opposition to burial in waterlogged sites would prevent future examples of "corpse candles - *ignis fatuus*". Soil contamination could, potentially, arise from redevelopment of normal cemeteries. Concern over the potential for partial exhumation of remains by wind-blow of trees at "green burial" sites is not substantiated by discussions with operators of such facilities, who indicate that by the time a shrub or tree has large enough roots to re-excavate the ground to over 1 metre depth, the body would be completely decayed.

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APPENDIX A

CONSOLIDATED GROUNDWATER QUALITY DATA FROM AROUND CEMETERIES

Australia

Site	Cheltenham	Cheltenham	Woronora	Woronora	Necropolis	Necropolis
Location	Adelaide NSW	Adelaide NSW	Sydney, NSW	Sydney, NSW	Melbourne, Victoria	Melbourne, Victoria
Soil type	silts / sands / clays	silts / sands / clays	sandy clays (laterised)	sandy clays (laterised)	dense clay	dense clay
Sampling point	internal borehole	boundary borehole	internal boreholes	background borehole	internal boreholes	background borehole
pH	7.3 - 7.9	7.5 - 7.8	5.0 - 7.4	5.5 - 6.6	6.3 - 7.5	5.6 - 6.3
EC	1230 - 6200		236 - 684	509 - 922	608 - 2204	241 - 263
O_2	6 - 59%					
CO_2	135 - 220	210-325				
Amm-N	0 - 0.53	0.01 - 0.59	0.2 - 4.72	0 -0.39	0 - 0.22	0 - 0.79
Nitrite-N	0 - 0.01	0 - 0.034	0 - 0.003	0 - 0.001	0 - 0.056	0 - 0.002
Nitrate-N	0 - 11.4	0 - 0.6	0 - 1.16	0.2 - 0.3	0 - 14.3	0 - 2.2
Tot N			0.55 - 3.9	0.1 - 0.25	1.2 - 21	0.3 - 0.8
Kj-N (total)	<0.05 - 0.61	0.16 - 0.81				
PO_4 (a)	0 - 0.62	0 - 7.0	0 - 0.85	0	0.5 - 1.6	1.6 - 2.55
Cl	107 - 576	52 - 1120	24 - 41	85 - 170	42 - 390	40 - 45
SO_4	53 - 179	22 - 255	17 - 56	57 - 77	48 - 290	3.2 - 3.7
S + H_2S µg/l						
TOC	1.3 - 21.2	1.6 - 28	1.6 - 12	2 - 19	0 - 30	2 - 4
BOD	<2 - 16	<2 - 15	3 - 16	5 - 21	0 - 9	4 - 6
COD						
Ca						
K						
Na						
As µg/l						
Cd µg/l						
Cr µg/l						
Cu µg/l						
Hg µg/l						
Pb µg/l						
Ni µg/l						
Ag µg/l						
Zn µg/l						
Phenol µg/l						
Tot coli	0 - 17	0 - 2000	0 - >500	0 - 2	3 - >2400	0
Fec coli	0	0 - 1	0 - 2	0	0 - 10	0
Fec strep	0	0 - 1	0	0	0 - 22	0
Pseudom	0 - 40	0 - 1	0 - 4	0	0	0
Aerobic						
Anaerobic						
Lipolytic						
Clostridia						
Proteolytic						
Formaldehyde						
Notes	121 years use	121 years use				
Reference	Knight & Dent (1998b)	Knight & Dent (1998b)	Dent & Knight, (1998a)	Dent & Knight, (1998a)	Dent & Knight, (1998a)	Dent & Knight, (1998a)

(a) Measured as orthophosphate

All units, unless stated, are mg l^{-1} except for pH units, EC (µS/cm) and bacterial counts which are per 100 ml.

Australia and Brazil

Site	Guildford	Guildford	Vila Formosa	Vila Nova	Areia Branca
Location	Perth, WA	Perth, WA	Sao Paulo, Brazil	Sao Paulo, Brazil	Santos, Brazil
Soil type	Unconsol-idated marine silty sands	Unconsol-idated marine silty sands	Teriary sediments	Weathered granite	High porosity marine sediment
Sampling point	down-gradient boreholes	background borehole	Piezometers	Piezometers	Piezometers
pH	5.8 - 6.1	6.2 - 7.3			
EC	216 - 667	6-3 - 1127			
O_2					
CO_2					
Amm-N	0 - 0.5	0.1 - 0.45			
Nitrite-N	0 - 0.015	0.002 - 0.315			
Nitrate-N	4.1 - 33.2	0.4 - 6.3			
Tot N	18.1 - 45	1 - 4.2			
Kj-N					
PO_4	0.06 - 4.7	0 - 1.9			
Cl	20 - 33	133 - 160			
SO_4	0 - 21	66 - 95			
S + H_2S μg/l					
TOC	4 - 23	58 - 73			
BOD	<5	<5 - 22			
COD					
Ca					
K					
Na					
As μg/l					
Cd μg/l					
Cr μg/l					
Cu μg/l					
Hg μg/l					
Pb μg/l					
Ni μg/l					
Ag μg/l					
Zn μg/l					
Phenol μg/l					
Tot coli	0 - 8	0 - 8	2 - 1600	27 - 1600	2 - 1600
Fec coli	0	0	2 - 300	2 - 7	2 - 1600
Fec strep	0	0	2 - 1600	2 - 1600	2 - 1600
Pseudom	0 - 11	0			
Aerobic			$200 - 7 \times 10^5$	$2800 - 5.3 \times 10^4$	$700 - 8 \times 10^6$
Anaerobic			130 - 1200	$440 - 16 \times 10^4$	$2 - 3.8 \times 10^5$
Lipolytic			75 - 1500	160 - 36000	$80 - 1.2 \times 10^6$
Clostridia			2 - 240	2 - 27	2 - 1600
Proteolytic			2 - 1600	220 - 9000	23 - 1600
Formalde-hyde					
Reference	Dent & Knight, (1998a)	Dent & Knight, (1998a)	Pacheco *et al* (1991)	Pacheco *et al* (1991)	Pacheco *et al* (1991)

All units, unless stated, are mg l^{-1} except for pH units, EC (μS/cm) and bacterial counts which are per 100 ml.

Netherlands

Site	Cemetery X	Cemetery X	Cemetery X	Cemetery X	Cemetery X	Cemetery X
Location	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands
Soil type	?	?	?	?	?	?
Sampling point	background borehole	groundwater, old cemetery	groundwater, 8 - 10 years	groundwater, 4 - 5 years	background, ditches	old cemetery, ditches
pH	7.6	7.2	7.0	6.7	8.2	7.8
EC	1400	1550	3100	3100	1350	1300
O_2						
CO_2						
Amm-N	2.9	0.43	0	0	0	0
Nitrite-N	0	<0.05	0	<0.05	0.1	0.05
Nitrate-N						
Tot N						
Kj-N	0.4	0.65	0.98	1.2	0.47	0.84
PO_4						
Cl	295	335	760	780	265	270
SO_4	364	304	290	369	157	156
S + H_2S μg/l						
TOC						
BOD						
COD						
Ca						
K						
Na						
As μg/l						
Cd μg/l						
Cr μg/l						
Cu μg/l						
Hg μg/l						
Pb μg/l						
Ni μg/l						
Ag μg/l						
Zn μg/l						
Phenol μg/l						
Tot coli						
Fec coli						
Fec strep						
Pseudom						
Aerobic						
Anaerobic						
Lipolytic						
Clostridia						
Proteolytic						
Formalde-hyde						
Reference	van Haaren, (1951)	van Haaren, (1951)	van Haaren, (1951)	van Haaren, (1951)	van Haaren, (1951)	van Haaren, (1951)

All units, unless stated, are mg l^{-1} except for pH units, EC (μS/cm) and bacterial counts which are per 100 ml.

Netherlands

Site	Cemetery X	Cemetery X	Cemetery Y	Cemetery Y	Cemetery Y	Cemetery Z
Location	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands
Soil type	?	?	?	?	?	?
Sampling point	ditches, 8 - 10 years	ditches, 4 - 5 years	groundwater, mainly old burials	groundwater, 1930, 50 burials	ditch, 1930, 50 burials	grounwater, outside cemetery
pH	7.8	7.9	7.6	6.9	7.9	7.0
EC	1500	1500	875	1900	1150	975
O_2						
CO_2						
Amm-N	0	0.79	0.11	0.2	2.8	1.4
Nitrite-N	1.0	1.05	<0.05	-	0.25	<0.05
Nitrate-N						
Tot N						
Kj-N	1.2	1.0	0.73	1.7	0.8	1.0
PO_4						
Cl	235	240	73	290	150	165
SO_4	194	136	121	201	198	62
S + H_2S μg/l						
TOC						
BOD						
COD						
Ca						
K						
Na						
As μg/l						
Cd μg/l						
Cr μg/l						
Cu μg/l						
Hg μg/l						
Pb μg/l						
Ni μg/l						
Ag μg/l						
Zn μg/l						
Phenol μg/l						
Tot coli						
Fec coli						
Fec strep						
Pseudom						
Aerobic						
Anaerobic						
Lipolytic						
Clostridia						
Proteolytic						
Formalde-hyde						
Reference	van Haaren, (1951)	van Haaren, (1951)	van Haaren, (1951)	van Haaren, (1951)	van Haaren, (1951)	van Haaren, (1951)

All units, unless stated, are mg l^{-1} except for pH units, EC (μS/cm) and bacterial counts which are per 100 ml.

Netherlands

Site	Cemetery Z	Cemetery Z	Krimpen aan den Ijssel	Krimpen aan den Ijssel	Krimpen aan den Ijssel	Hardinxveld
Location	Netherlands	Netherlands	Southern Netherlands	Southern Netherlands	Southern Netherlands	Netherlands
Soil type	?	?	peat	peat	peat	sand
Sampling point	groundwater, 1937 - 48 burials	ditches, 1937 - 48 burials	groundwater, 14.04.86	drains, 29.04.85 & 14.04.86	canals, 29.04.85 & 14.04.86	drains, 29.04.85 & 14.04.86
pH	6.8	7.6	6.8	7.05	7.6 - 8.3	6.8 - 6.9
EC	800	1050	1080	1050 - 1100	630 - 660	890 - 940
O_2				5.7	12.3 - 12.4	4.4 - 5.1
CO_2						
Amm-N	0.11	3.3	3.8	1.4 - 1.7	0.1	1.3
Nitrite-N	0.1	0.35				
Nitrate-N			0.07	2.9 - 3.4	0.02 - 0.04	1.57 - 1.83
Tot N						
Kj-N	0.75	0.45				
PO_4			1.2	0.4 - 1.2	0.38 - 0.4	0.1 - 0.34
Cl	22	130	60	49 - 81	66	24 - 27
SO_4	38	155	39	69 - 73	66 - 71	66 - 85
$S + H_2S$ μg/l			6	<1 - 9	<1 - 9	<1 -12
TOC			11	9.6 - 12	19 - 24	5.5 - 6.6
BOD			7	3 - 4	8 - 12	2 - 3
COD			35	28 - 33	66 - 79	13 - 15
Ca			160	165	71	147 - 167
K			6.3	7.2 - 8.3	12 - 13	3.1 - 3.8
Na			50	36 - 42	39 - 41	24 - 41
As						
Cd μg/l			<0.1	<0.1 - 0.3	<0.1 - 0.2	<0.1 - 0.3
Cr μg/l			2	2 - 3	2 - 4	<1 - 1
Cu μg/l			6	5 - 12	5 - 9	5 - 8
Hg μg/l			<0.1	<0.1 - 0.2	<0.1 - 0.2	<0.1
Pb μg/l			1	<1 - 2	2 - 10	<1 - 3
Ni μg/l			<1	2 - 5	3 - 4	,1
Ag μg/l			0.3	0.3	0.3	0.2
Zn μg/l			77	44 - 60	6 - 15	20 - 24
Phenol μg/l			1	<1 - 16	2 - 8	5 - 14
Tot coli						
Fec coli						
Fec strep						
Pseudom						
Aerobic						
Anaerobic						
Lipolytic						
Clostridia						
Proteolytic						
Formalde-hyde						
Reference	van Haaren, (1951)	van Haaren, (1951)	van der Honing *et al*, (1988)	van der Honing *et al*, (1988)	van der Honing *et al*, (1988)	van der Honing *et al*, (1988)

All units, unless stated, are mg l^{-1} except for pH units, EC (μS/cm) and bacterial counts which are per 100 ml.

Netherlands

Site	Rotterdam	Rotterdam	Westmaas	Westmaas	Zwijndrecht	Zwijndrecht
Location	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands	Netherlands
Soil type	sand	Sand	sand	sand	sand	sand
Sampling point	drains 29.04.85 & 14.04.86	canals 29.04.85 & 14.04.86	drain 29.04.85	canals 29.04.85 & 15.04.86	groundwater 14.04.86	canals 15.04.86
pH	7.0 - 7.25	7.75 - 7.9	6.9	7.25 - 7.95	7.0	7.85
EC	1380 - 1480	1280 - 1320	900	910 - 1360	1500	910
O_2		16.2 - 18.0		3.2 - 14.5		9.7
CO_2						
Amm-N	1.3 - 1.5	0.1	2.8	0.1 - 1.9	2.2	0.2
Nitrite-N						
Nitrate-N	2.55 - 5.8	0.42 - 0.56	0.14	0.2 - 1.28	0.13	1.65
Tot N						
Kj-N	1.9 - 2.1	1.4 - 1.6	4.7	1.7 - 3.3	2.9	1.2
PO_4	0.42 - 1.6	0.12 - 0.22	0.42	0.08 - 0.74	0.34	0.1
Cl	135 - 185	138 - 151	49	72 - 184	24	54
SO_4	140 - 165	150 - 170	28	48 - 160	83	145
S + H_2S μg/l	<1	<1 - 10	<1	<1 - 37	13	34
TOC	7.4 - 16	10 - 12	34	13 - 20	11	9.6
BOD	1 - 5	5 - 8	27	4 - 8	-	2
COD	19 - 27	40 - 42	93	38- 93	-	33
Ca	212 - 247	158 - 170	155	141 - 168	185	144
K	5.6 - 7.6	7.7 - 7.8	3.1	3.8 - 6.1	2.0	3.2
Na	68 - 94	85 - 95	24	41 - 97	20	34
As μg/l						
Cd μg/l	<0.1 - 0.9	<0.1 - 0.3	0.3	<0.1 - 0.4	0.2	<0.1
Cr μg/l	1 - 4	2	3	1 - 2	7	2
Cu μg/l	5 - 21	4 - 6	10	6 - 9	5	4
Hg μg/l	0.2 - 0.5	<0.1 - 0.2	<0.1	<0.1 - 0.3	0.3	0.3
Pb μg/l	<1 - 6	1 - 2	1	2 - 6	8	2
Ni μg/l	6 - 8	3 - 4	21	3 - 10	7	3
Ag μg/l	0.3	0.2	-	0.2 - 0.4	0.2	0.2
Zn μg/l	11 - 105	8 - 12	49	14 - 20	135	3
Phenol μg/l	3	<1 - 3	200	2 - 17	5	5
Tot coli						
Fec coli						
Fec strep						
Pseudom						
Aerobic						
Anaerobic						
Lipolytic						
Clostridia						
Proteolytic						
Formalde-hyde						
Reference	van der Honing *et al*, (1988)	van der Honing *et al*, (1988)	van der Honing *et al*, (1988)	van der Honing *et al*, (1988)	van der Honing *et al*, (1988)	van der Honing *et al*, (1988)

All units, unless stated, are mg l^{-1} except for pH units, EC (μS/cm) and bacterial counts which are per 100 ml.

England

Site	Northwood (June 1992)	Branston
Location	London	Lincs
Soil type	Clay (Reading Beds)	Sandy over limestone
Sampling point	water in grave excavation	cemetery well 22.05.95 - 06.08.97
pH		
EC		
O_2		
CO_2		
Amm-N	408.7	<0.3 - 0.7
Nitrite-N		
Nitrate-N		
Tot N		
Kj-N		
PO_4		
Cl		
SO_4		
S + H_2S μg/l		
TOC		
BOD		
COD		23 - 461
Ca		
K		
Na		
As μg/l		
Cd μg/l		
Cr μg/l		
Cu μg/l		
Hg μg/l		
Pb μg/l		
Ni μg/l		
Ag μg/l		
Zn μg/l		
Phenol μg/l		
Tot coli		
Fec coli		
Fec strep		
Pseudom		
Aerobic		
Anaerobic		
Lipolytic		
Clostridia		
Proteolytic		
Formalde hyde	8.6	
Reference	Nash, George (1998)	Anglian Region, Environment Agency

All units, unless stated, are mg l^{-1} except for pH units, EC (μS/cm) and bacterial counts which are per 100 ml.

West Germany

Site	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
Location	West Germany	West Germany	West Germany	West Germany	West Germany	West Germany
Soil type	Unconsol-idated alluvium	Unconsol-idated alluvium	Unconsol-idated alluvium	Unconsol-idated alluvium	Unconsol-idated alluvium	Unconsol-idated alluvium
Sampling point	0.5 m down-gradient of graves	1.5 m down-gradient of graves	2.5 m down-gradient of graves	3.5 m down-gradient of graves	4.5 m down-gradient of graves	5.5 m down-gradient of graves
pH						
EC						
O_2						
CO_2						
Amm-N	6	0.75	-	-	-	-
Nitrite-N						
Nitrate-N	4.8	0.1	-	-	-	-
Tot N						
Kj-N						
PO_4						
Cl						
SO_4						
S + H_2S µg/l						
TOC						
BOD						
COD	26.7	16.4	15.4	15.4	11.4	11.4
Ca						
K						
Na						
As µg/l						
Cd µg/l						
Cr µg/l						
Cu µg/l						
Hg µg/l						
Pb µg/l						
Ni µg/l						
Ag µg/l						
Zn µg/l						
Phenol µg/l						
Tot coli (per ml)	6000	8000	8000	3600	1200	180
Fec coli						
Fec strep						
Pseudom						
Aerobic						
Anaerobic						
Lipolytic						
Clostridia						
Proteolytic						
Formalde-hyde						
Reference	Schraps (1972) in Bouwer (1978)	Schraps (1972) in Bouwer (1978)	Schraps (1972) in Bouwer (1978)	Schraps (1972) in Bouwer (1978)	Schraps (1972) in Bouwer (1978)	Schraps (1972) in Bouwer (1978)

All units, unless stated, are mg l^{-1} except for pH units, EC (µS/cm) and bacterial counts which are per 100 ml.

Canada

Site	Riverside Cemetery	Binbrook Baptist Cemetery	Emily	Wood-house United	Mount Calvary	United Church
Location	Lindsay, Ontario	Binbrook, Ontario	Omeemee, Ontario	St Mooe, Ontario	Sarnia, Ontario	London, Ontario
Soil type	Sand	Sand	Sand	Sand	Sand	Sand
Sampling point	CMF-1 6.7 m deep. In cemetery area	CMF-2 24.4 m deep.	CMF-3 32 m deep In cemetery area	CMF-4 6.1 m deep In cemeter y area.	CMF-5 Dug well	CMF-6 Dug well
pH						
EC						
O_2						
CO_2						
Amm-N						
Nitrite-N	0.005	0.005	0..003	<0.001	0.01	<0.005 - 0.01
Nitrate-N	4.25 - 4.3	0.005	0.40 - 0.415	13.8 - 14.3	1.35	8.2 - 8.3
Tot N						
Kj-N						
PO_4	0.02	<0.0005 - 0.001	<0.005	<0.0005	<0.02	<0.02
Cl						
SO_4						
S + H_2S µg/l						
TOC						
BOD						
COD						
Ca						
K						
Na						
As µg/l						
Cd µg/l						
Cr µg/l						
Cu µg/l						
Hg µg/l						
Pb µg/l						
Ni µg/l						
Ag µg/l						
Zn µg/l						
Phenol µg/l						
Tot coli						
Fec coli						
Fec strep						
Pseudom						
Aerobic						
Anaerobic						
Lipolytic						
Clostridia						
Proteolytic						
Formalde-hyde	0.0051 - 0.0058	0.016 - 0.03	0.0065 - 0.0073	0.0067 - 0.0074	0.0016 - 0.002	0.0016 - 0.0021
Notes	Sampling points 500 - 2000 m from graves	Sampling points 500 - 2000 m from graves	Sampling points 500 - 2000 m from graves	Sampling points 500 - 2000 m from graves	Sampling points 500 - 2000 m from graves	Sampling points 500 - 2000 m from graves
Reference	Soo Chan *et al*, (1992)	Soo Chan *et al*, (1992)	Soo Chan *et al*, (1992)	Soo Chan *et al*, (1992)	Soo Chan *et al*, (1992)	Soo Chan *et al*, (1992)

All units, unless stated, are mg l^{-1} except for pH units, EC (µS/cm) and bacterial counts which are per 100 ml.

Canada

Site	Mount Pleasant	Mount Pleasant	Mount Pleasant
Location	Toronto	Toronto	Toronto
Soil type	Fine sand/silt with layers medium sand	Fine sand/silt with layers medium sand	Fine sand/silt with layers medium sand
Sampling point	MW1, burials 1880 - 1992	MW2, burials 1880 - 1992	MW3, burials 1880 - 1992
pH	7.55	7.2	7.4
EC			
O_2			
CO_2			
Amm-N			
Nitrite-N			
Nitrate-N			
Tot N			
Kj-N			
PO_4			
Cl			
SO_4			
S + H_2S μg/l			
TOC	1.6	1.0	7.6
BOD	2	5	8
COD			
Ca			
K			
Na			
As μg/l	<0.002	<0.002	<0.002
Cd μg/l	<0.002	<0.002	<0.002
Cr μg/l	<0.01	<0.01	0.13
Cu μg/l	0.015	<0.005	<0.005
Hg μg/l	<0.00005	<0.00005	<0.00005
Pb μg/l	<0.02	<0.02	<0.02
Ni μg/l	<0.01	0.01	<0.01
Ag μg/l			
Zn μg/l	<0.01	0.07	0.01
Phenol μg/l			
Tot coli			
Fec coli	<4	<4	<4
Fec strep			
Pseudom			
Aerobic			
Anaerobic			
Lipolytic			
Clostridia			
Proteolytic			
Formalde-hyde	<0.2	<0.2	<0.2
Notes			
Reference	Beak Consultants Ltd (1992)	Beak Consultants Ltd (1992)	Beak Consultants Ltd (1992)

All units, unless stated, are mg l^{-1} except for pH units, EC (μS/cm) and bacterial counts which are per 100 ml.

APPENDIX B INFORMATION OBTAINED FROM THE ENVIRONMENT AGENCY REGIONS

B1 ANGLIAN REGION

A meeting was held on 25 February 1998 at the Brampton offices. Attendees from the Agency included Peter Ord (Groundwater Protection Officer), Teresa Brown (regional role in groundwater pollution), Peter McConvey (Hydrogeologist, Northern Area) and Simon Barlow (planning liaison) with Chris Young and Karen Blackmore from WRc.

It was agreed that national guidance was required. Nation-wide companies have problems as they get different guidance from different Agency Regions. The Anglian Region generally use the MAFF protection guidelines, but each site is taken on its merit rather than any stringent conditions being enforced. No burials are allowed in saturated ground.

Guidance should take the form of general rules, with a scientific basis. There is normally no blanket answer, and assessment must be of a site specific nature, based on risk assessment. Best practice guidance and basic principles are required and then there can be options to fine tune to the sensitivity of the site. How to define the sensitivity is the difficult part. In relation to size, the guidance could say that less than x number of holes is not a problem, with rate of input an important factor. There may need to be some differentiation between new cemeteries and extensions to existing ones. Clarification of other issues would be welcome including; green burial planning; what controls are placed on funeral directors and disposal of waste products; development through burial grounds and precautions to take.

Other points discussed included:

- **Planning** - there were not very many instances of planning applications, no database search was available but it was thought there was only about five applications per year (new or extensions). A small extension with two or three interments a year was recalled. A long discussion was held about the role of the Agency with the planners. The planners always push things to the Agency because they think the Agency can enforce conditions. New guidance needs to make it clear who enforces what and where and how planning relates to this. The Agency are currently statutory consultees, they want to know how the developers will protect the environment. An example was given of a plan to extend a graveyard by a Parish Council (site on the Greensand), the Agency requested a site investigation. However, next door a green burial site was to be established and it was thought no plans were needed. Copies of a newspaper article were subsequently found and sent to WRc. It appears that the green burial site has yet to apply for planning permission. The case is on-going. It was suggested WRc speak to some planners to see if they would like some guidance on burial sites, similar to the guidance they get for building on floodplains (see notes below).

- **Re-use of old graveyards** - specify that burial not to be in water-logged land. If it is an old site this may have been the practice for a number of years. However, this is probably unlikely as it is physically a difficult thing to do.

- **Private abstractions** - there is always the question of where these are located as the Agency does not have the records. These are referred to the Environmental Health Officer.

- **Mass burial** - an idea from the Southern Region was mentioned, storing bodies from a major disaster in a drained swimming pool. The pool is contained and has a recirculating drainage system so no liquid would be lost to the ground (as may happen in military sites). However, the pool would subsequently have to be demolished as no-one would go there afterwards!

The following questions were also raised:

- should burial on impermeable soils be allowed, as any leachate could come to the surface;

- does a planning application include rate of burial? If not should this be amended;

- does a regional structure plan include plans for new burial sites? If so do they take account of groundwater and surface water issues? Should or do the Environment Agency comment on long term planning issues;

- how do large animal burials affect water quality? For example, within the Region there are two large safari parks (Woburn and Whipsnade). What happens to the animals that die? Obviously a large animal such as an elephant would be difficult to transport and it is thought most of the animals that die are buried on site. Does the decay process differ for the animals with thick skins? Apparently at one of the sites there is also a bottling plant for spring water!

A few sites were discussed in detail. A completed landfill site was being used as a burial ground. This was not thought to be morally acceptable so a layer of inert material was added, and it was into this that burial took place. The site therefore may have some data as the leachate and gas monitoring boreholes are present. However, any data may be difficult to interpret.

Other information provided is summarised below:

Borehole within cemetery

At Branston Cemetery (NGR TF 023 674) there is a borehole within the grounds which is regularly sampled. Chemical data (quarterly) and hydrographs (water level data) from the two nearest abstraction boreholes was supplied. The groundwater level at the site is about 4 m below ground and the COD levels range from 23 to 461 mg l^{-1} O, with ammonia ranging from <0.3 to 0.8 mg l^{-1} N. The peaks in COD and ammonia do not necessarily coincide, although a peak in one or other does seem to occur, on initial inspection, about two or three months after a peak in water level recorded at nearby observation boreholes. There are no loading rate data available but presumably this could be found from the Parish records.

Planning advice

In Lincolnshire, there were plans to extend an existing parish cemetery, which was located less than 100 metres from a private supply. Copies of letters in connection with the planning application were forwarded to WRc.

The Agency were concerned about the pollution risk to adjacent domestic water supply sources and watercourses, but stated they would not object to the proposal providing any approval included a formal Condition and Note. The Condition stated that a full Study in respect of pollution risk shall be prepared in conjunction with the EA and submitted to the Local Planning Authority. This included the effect of the proposal on adjacent domestic water supply sources and watercourses and identifying any mitigating or compensatory works required to prevent pollution of the domestic sources or watercourses. The Note stated that the Study was to be carried out by the Applicant/Agent.

The Parish Council apparently said this was too expensive. The person who owns the well agreed that the Parish Council would support regular testing of the well water and would pay to install mains water supply to his house should his borehole become polluted. The Agency still comment that the extension is not advisable without data to prove there is no problem.

Telecommunication with Planners

The planners spoken to expect the Agency, as statutory consultees, to raise objections if needed. New cemeteries or extensions to existing cemeteries were relatively rare and Planners would not feel it worthwhile to make specific policies with respect to cemetery siting.

B.2 MIDLAND REGION

A meeting was held on 15 January 1998 at the Olton Court offices, Andrew Pearson from the Agency met with Chris Young and Karen Blackmore from WRc.

The policy used for guidance is the national PPPG. Cemeteries are a possible bacteriological problem and are viewed in the same way as individual septic tanks (unless it is a mass burial). Appendix 7 of the Severn Trent Water Authority Groundwater Protection Policy (1976, update 1989) is the only place where burial is specifically mentioned.

The area is mostly on sandstone. If there is a spring or abstraction then a 100 m restriction in Zone I applies. If there is a reasonable unsaturated zone then burial is not viewed as a problem, it is only if there is shallow gravel groundwater that a problem may occur. In relation to surface water no burials are permitted within 10 metres of land drains or surface watercourses. If a site has had a historic problem of surface water pollution, then the Agency may advise some form of cut-off trench. The Environmental Health hold the list of private supplies and the Agency rely on them, and the public, to keep them informed in relation to planning.

An example of advice given was recalled, where the site was situated on a shallow sandstone and gravel aquifer. Groundwater cut-off and lowering of the groundwater within the site was recommended. No large city burial sites could be recalled that had any form of underdrainage.

New guidance would be welcome. Reference to throughput and loading rates would be useful as would advice or discussion on necessary unsaturated zone thickness. For example, if there are x metres of unsaturated zone there will be no problem. Other areas to possibly cover include advice on emergency burial and what actions to take and the breakdown of formaldehyde and travel times.

It was noted that another Agency contract was reviewing microbiological and bacteriological contaminants and it may have some useful information to add to the subject.

Other topics discussed included:

- **Mass burial** - the National Agricultural Centre at Stoneleigh has been assigned. The River Avon flows by the site and is used for groundwater abstraction at Gloucester. The Agency have therefore agreed to only certain fields being used.

- **Planning** - the planners will forward to the Agency anything on a major aquifer, near an old well marked on a map or near private abstractions. The Agency will not necessarily see all non-aquifer applications. A copy of a database search of the planning applications had been carried out (see details below). Only 1% related to burial grounds. In 1994/95 the water table became an issue and it was stated that all burials must be above the water table. This, however, tended to cause problems so is not now used. Boggy ground is unsuitable - maybe this issue needs including in any new guidance issued. Generally there are no problems. The majority of public objections are of the NIMBY type, see Yew Tree Lane example below, which went to public inquiry.

- **Recorded instances** - not aware of any groundwater quality data in the vicinity of burial grounds but will try to find out if there are any. Wells are more likely to be affected by animal burial, this would go through the Environmental Health Officer, who would inform the Agency. There may be some anecdotal information on surface water problems but not readily available.

Copies of a number of documents were supplied, they are summarised below:

Appendix 7 - STWA Groundwater Protection Policy

This relates to the technical background to the Inner Protection Zone Concept. It summarises the technical background to the avoidance of microbiological contamination of groundwater and attempts to set out guidelines for the use of outside agencies, such as planning authorities, and operating personnel alike.

It states that the sources of microbiological contamination to groundwater are numerous but are summarised under two broad categories: a) sewage derived, and b) agriculture derived. Section b) states that "the burial of infected livestock must be treated with caution". The report goes on to state that besides the two major categories of potential pollution there are other minor, largely point, sources such as graveyards and landfill sites.

Dogs Act 1906 (6 edn. 7, C32)

The section relating to burying of carcasses states *"Any person who shall knowingly and without reasonable excuse permit the carcass of any head of cattle belonging to him, or under* *his control, to remain unburied in a field or other place to which dogs can gain access shall be liable on conviction under the Magistrates' Courts Act 1952 to a fine not exceeding £10 [Dogs Act 1906, s. 6, as amended by Dogs (Amendment) Act 1928, s. 3, and Criminal Justice Act 1967, 3rd Sched.]. In this Act, the expression "cattle" includes horses, mules, asses, sheep, goats and swine [Dogs Act 1906 s. 7].*

Proof of evidence for an appeal against refusal of planning permission for a cemetery at Yew Tree Lane, Tettenhall, Wolverhampton

The proposed site was located on the Bromsgrove Sandstone, a major source of underground water supply for the region. However, in the area there were few abstractions, the nearest located 1.1 km away (Tettenhall borehole) with no other groundwater abstractions within 2 km of the site. Groundwater vulnerability in the vicinity of the proposed site was described as low due to the nature of the loamy overlying soil and the underlying sandstone being significantly layered with interbedded sandstone and marly horizons throughout its depth.

Referring to the then NRA's Policy and Practice for the Protection of Groundwater (NRA, 1992), the potential for graveyards to cause microbiological pollution was noted, as was the opposition to the establishment of new sites or extensions within Zone I areas through the planning process. The supply borehole in question, however, had yet to have the zones drawn up, but from previous experience with other pumping stations it was believed that this zone was unlikely to extend further than 200 metres from the source. Therefore the proposal was not deemed a threat to water supplies.

The effect of surface water is also addressed. Drainage ditches about 260 m to the west of the site coincided with an outcrop of Boulder Clay. Groundwater was effectively forced to the surface here by the impermeable cover which extended towards the River Penk. The drainage ditches ultimately discharged into the River Penk (900 m from the site). The groundwater beneath the site would ultimately receive the products of degradation from deposited bodies but this was not considered a significant risk because:

1. The speed at which pollutants travel through the ground is very slow, particularly for the sandstones where there is an absence of fissuring. Microbial pollutants will not survive in groundwater for prolonged periods (the basis of the 50 day exclusion zone, Zone I in the PPPG). With the hydraulic conditions present, travel times from the boundary of the site to the drainage ditches was estimated at 1 to 10 years.

2. No records of groundwater or surface water pollution from graveyards could be found in the scientific literature. Also no pollution problems with graveyards, some close to watercourses, were known from personal experience.

The conclusion was therefore that the proposal would not give rise to significant groundwater or surface water pollution.

Planning database query, listing all the applications relating to cemeteries and burial grounds and the outcomes

Out of 10 000 planning applications, a total of 104 (1%) were made in relation to cemeteries and burial grounds between October 1989 and October 1997. This equates to an average of 13 a year, with the maximum per year being 21 in 1997. The majority of the decisions were "No objection", some had conditions stipulated, the most common being "no bodies below high water table". The largest number of applications are from small rural areas where only small extensions are required. Pet cemetery applications are increasing along with green burials. The latter number about half a dozen, they tend to be low density as a tree is planted on the site of burial.

B.3 NORTH EAST

Telephone discussions were initially held with Jeff Pacey, in which it was agreed that further telecoms or a meeting would take place once the results of visits to other Regions had been collated. Following the Regions receipt of the second progress report, detailing approaches at the Regions, a letter was received from Jeff Pacey which stated that the procedures for dealing with cemeteries were very similar to that used at most of the other Regions. The lack of response from his colleagues meant a meeting was not thought worthwhile. The MAFF Code of Good Agricultural Practice for the Protection of Water and the Agency's PPPG are the Regions principal guideline documents. The Region does not have its own policy on the subject.

Consultations made with Environmental Protection staff did not reveal any specific water quality problems attributed to cemeteries nor any specific monitoring carried out near them.

The Ridings Area office deal with around four cemetery consultations per year, the Dales Area has also averaged four per year over the last three years.

Ridings Area

Conditions to planning issued from the Ridings Area include: no burials below the water table, and no burials within 250 m of any borehole, well or spring used for human consumption. In some areas site investigations are requested to ascertain ground conditions, for example in Zone 1, although it is rare that much information is received back. In some cases the burial plots are treated as sealed systems, like individual landfills. Other comments in the Zone 1 include leaving a minimum of 3 metres of boulder clay below the deepest excavation for burial. To the knowledge of the contact in this Area, there have been no objections to cemeteries, even where the gut feeling is to object, for example Zone 1, minimal drift, as the applications have been for extensions to existing sites so the Agency would need to state that the original cemetery was causing a problem in order to justify any objection.

Yorkshire Water comments

Water Quality staff at Yorkshire Water had no knowledge of any pollution incidents associated with human burial grounds that had affected any groundwater abstractions within the company's operational area.

They do, however, have concerns regarding mass burial of animals resulting from epidemic disease. They quoted an example they would not wish to be repeated where between 300 and 1400 BSE infected carcasses were buried in an unlined quarry that was situated within the source catchment of a public water supply. Fortunately a detailed risk assessment by DNV on behalf of the Agency indicates that the overall risk of BSE infectivity are small, however, the net impact on water quality was not assessed.

The hydrogeologist from Yorkshire Water commented that the Agency PPPG appears adequate, although the trend towards larger, higher intensity cemeteries may pose future problems. It is commented that our guidance is quite lax compared to other continental countries, for example Germany, who do not allow development of new cemeteries within a 2 km radius (or within the modelled catchment zone - whichever is the smaller) of any abstraction. He commended their approach. The comment was also made that new cemeteries should be excluded from Zone II, with more attention paid to existing sites, particularly those in Zone 1 or larger sites in Zone II. A project to monitor the quality of the most sensitive sites was thought to be a worthwhile objective.

B.4 NORTH WEST

No visit was made, but communication and written correspondence was carried out with Mark Thewsey. A visit and discussion was suggested, following receipt by the Region of the Second Progress Report, but was subsequently not thought necessary. During a telephone conversation between Chris Young and Mark Thewsey reference was made to an application by the Diocese of Chester to move twenty five 18th and 19th century lead-lined coffins from vaults to a nearby graveyard. Objections were made by a local person who said if he couldn't dispose of solder to landfill, why should it be possible to bury great lumps of lead? In discussions it was agreed that the assessed risk would be very low if burial was well above the water table and that, possibly, the surrounding wood coffins should be plastic wrapped. Concern was also expressed over burials at "Woodland" sites, with an example quoted of an application for a 2000 plot site, with a proposed shallow burial depth where no consideration appeared to have been given to potential future problems of wind-blow on the trees/shrubs planted above the bodies.

Information obtained included a proforma letter commonly used in response to enquirers seeking groundwater protection advice on burial site location in the NW Region. It is included in full in Appendix B with the main conditions summarised below:

1. *"Human or animal remains must not be buried within 250 metres* of any well, borehole or spring from which a potable water supply is drawn.*

   ** this distance may be greater if the site is within an unusually large Groundwater Source Protection Zone I - this is rare.*

2. *The place of interment should be at least 30 metres away from any other spring or watercourse and at least 10 metres from any field drain.*

3. *All burial pits on the site must maintain a minimum of one metre of subsoil below the bottom of the burial pit (i.e. the base of the burial must be at least one metre above solid rock).*

4. *The base of all burial pits on the site must maintain a minimum of one metre clearance above the highest natural water table. (Any variability of the water table should be taken into account).*

5. *Burial excavations should be backfilled as soon as the remains are interred, providing a minimum of one metre soil cover".*

The first three conditions are based of the MAFF guidelines (see Section 3.9), although these do not mention depth to solid rock (item 3 above). The letter goes on to say that:

"the combined requirements of notes 3, 4 and 5 would normally give an expectation of an absolute minimum distance from ground level to water table or the surface of the underlying rock (whichever is the least) of 2.4 metres for a single supine human grave.

If multiple burials are anticipated on any one plot this minimum clearance depth must be increased to suit the circumstances."

Should it not be possible to comply with Notes 2 to 5, the letter states "*it may be possible to seek an engineered solution by permanently:*

(a) *diverting watercourses or drains;*

(b) *dewatering the ground; or*

(c) *raising the ground level to achieve the required clearances".*

The problems with the latter course of action is then discussed, for example, option b is unlikely to be practical "*because of the cost, practical maintenance difficulties and water resource derogation potential*".

The developer is also advised to check with local Environmental Health Officers to assist in confirming the absence of any known unlicensed potable groundwater abstractions in the vicinity.

The letter concludes with an option for the Agency officer to include information from records held by the Environment Agency, such as source protection zones, recorded water table, known licensed and unlicensed abstractions of groundwater near the proposed development.

B.5 SOUTHERN REGION

A meeting was held on 20 January 1998 at the Worthing offices. Attendees from the Agency included Dick Flavin and Ian Grey (Groundwater Protection) with Chris Young and Karen Blackmore from WRc.

The Southern Water Policy has been superseded by the new PPPG. The old protection zones are being used at the moment until the new ones are published, most now have draft new zones. The MAFF code of good agricultural practice is also followed.

Planning applications for burial sites within Zone I are usually opposed, with Zone I based on a 50 day travel time. For surface water a common sense approach is used. In Hampshire they tend to recommend burial to be 10 m from a watercourse, although 20 to 30 m was thought preferable.

With regard to green burials, these are usually treated like a short term septic tank.

Small scale extensions to cemeteries and single burials are unlikely to be a problem. The Region has very few completely new applications for large cemeteries. The Agency tend to get consulted at the planning stage, put in their recommendations and then hear no more. A site investigation may be specified to establish geology and/or depth to the water table.

There were no known incidents of groundwater pollution from cemeteries in the Region. Anecdotal evidence of mass burial due to anthrax at Edenbridge was noted, the site is likely to be in clay or a minor aquifer. Also, outside the region, at Buckfastleigh, Devon there is a cave (Bakers Pit Cave) which is directly beneath a church yard (and the bodies) in a Limestone Aquifer.

One site where groundwater quality data could be obtained was recalled - a borehole supply for a ferry next to a graveyard. It was planned to carry out some sampling (ammonia, formaldehyde, for example) but the data have not yet been received. The site is on Chalk, with a thin layer of gravel on top and shallow groundwater. The borehole is within 20 feet of the nearest grave, and is used to supply the ferry, originally it was licensed to British Rail.

Guidance would be useful and should consider the zone, depth of unsaturated thickness and rock type. Fissures, however, still present a problem and some guidance on how to deal with them would be helpful. It would be interesting to take the area, density of burials, timescales, groundwater flow and loading to see if there will be a problem. With regard to depth of burial, it would be preferable if there was a minimum depth of unsaturated zone stipulated, rather than the “as long as its above the water table approach”.

Advice on how necessary it is to object to graveyards in Zone I would be welcome, it was asked if there have been any known pollution cases to justify this action?

A separate section on mass animal burial would also be of value, perhaps more so than the human burial issue.

Kent Area

A list of planning applications relating to cemeteries was supplied from the Kent Area Office. There were 13 applications (10 human, 3 animal), five of which were rejected. The reasons for objections were:

- High water table, risk of pollution to watercourses;
- Public Water Supply (PWS) 400 m to the north (site in Zone I);

- Approx. 0.5 km down gradient of PWS and 1.2 km up gradient of PWS (site in Zone I);
- Burial restricted to west of site and to high ground, out of Zone I (green burial);
- Modelling needed to establish whether Zone I or II.

A few applications for pet cemeteries had also been received, but none of these were objected to.

Hampshire and Isle of Wight Area

Details of planning applications from the Hampshire Area were also received. These included:

- 10 applications for extensions to existing burial grounds;
- 7 applications for new burial grounds
- 2 applications for establishing "green" burial sites;
- 2 applications for establishing pet cemeteries on the Isle of Wight;

With regard to mass graves, there was once a MAFF query about an emergency burial site for Sparsholt Agricultural College. Apparently there are lots of designated mass grave sites in APP Zone 5 areas, in case of war or outbreaks of Anthrax or Foot and Mouth.

In this Area the standard response is that the cemetery should not be located in a Groundwater Source Protection Zone I, and that the bodies must be located above the highest annual position of the water table. The MAFF Code of Good Agricultural Practice is also referred to. It has also been recommended that bodies should not be buried within 10 metres of any water course. However, applications are considered individually.

No data on water quality was available.

With regard to guidance, they would like advice on how to respond to people who wish to bury their loved ones in their gardens.

B.6 SOUTH WEST REGION

A meeting was held on 12 January 1998 at the Exeter offices. Attendees from the Agency included Nigel Crane, Tim Jenkins and Paul Dogerty (groundwater protection), Pauline Jonstone (Senior Hydrogeologist, in charge of resources), Alan Rafelt (Cornwall Area), Colin Brown (planning), and Eileen Marshall (South Wessex Area), with Chris Young and Karen Blackmore from WRc.

It was generally felt that guidelines were needed, and that advice in terms of a protocol and risk assessment, with some background guidance, would be useful. From the risk assessment approach for small burial grounds, where a full scale, site-specific, assessment would not be feasible, it would be helpful to have an estimate of how many bodies buried a year would be likely to cause a pollution problem. When considering planning applications, it would be useful for the application to stipulate the area it will serve, and how many interments a year are likely. A better estimate of risk assessment versus rate of input would then be possible.

In the Region the ground into which burial can take place varies a great deal, for example in Ilfracombe it would be straight into rock, whereas elsewhere it could be into soil or Chalk.

An example of an application for burial a few metres from a spring was recalled at Oakford Fitzpain, the Region acted on the side of caution and the application was refused.

Other issues discussed included:

- **Private abstractions** - Devon and Cornwall have a lot of these, which are dealt with by Environmental Health. The location of these is very important and should not be overlooked in the planning process;

- **Extensions to village church graveyards** - this is an emotive issue, the extensions are required so that generations of the family can be buried together. Apparently some vicars are of the opinion that human bodies will not pollute. Often the church already own the land and do not want to buy additional land;

- **Green burial** - The implications of green burials, both on private land and commercially;

- **Mass burial** - Following a major disaster, the emergency response plan is for mass storage of bodies at military sites. It was thought this was not ideal from the risk of fluids polluting surface water or groundwater but that would probably not be the major concern at the time of a major disaster;

- **Embalming** - in North Devon there is an embalmer who travels around the area, apparently he still uses formaldehyde;

A number of questioned were also raised:

- should the EA be lobbying for certain conditions for burial which minimise the potential risk of pollution, for example; required depths of burial, burial in shrouds not coffins, type of coffin, lead lined coffins in Zone I etc.? However, it was thought it may be difficult to put restrictions on what can and cannot be carried out in a cemetery;

- should the EA be sponsoring field based research?;

- should victims of contagious diseases such as Aids be buried in body bags or will this merely contain the bacteria which may be released at a later stage?;

- do undertakers have discharge consents for the waste products from embalming?;

On the subject of any available data on pollution from cemeteries, none was available. A possible burial ground site was suggested which could be used to obtain data and assess if there was any measurable effects on nearby surface water quality. The burial ground, at Combe Martin, Devon, is on the confluence of two rivers, and it was suggested that upstream and downstream monitoring could be undertaken.

Another area discussed was burial grounds in relation to bacteriological problems and bathing beach failures. An example of a water course below a graveyard turning grey after rain was cited.

A study was mentioned that was conducted at Portsmouth Polytechnic (now University of Portsmouth) which was undertaken to try to sample an uncontaminated site in the area. Apparently the area most likely to be suitable turned out to be a graveyard but, following drilling and sampling, this too turned out to be polluted.

Another study at Bournemouth University was also mentioned, they were researching a crypt in London and were concerned about the "soup" contained in the lead coffins and what to do with it. The outcome was not known.

The Department of Forensic Science at Sheffield University was also mentioned as a possible source of information.

B.7 THAMES REGION

The Thames Region would normally make any comments on proposals to develop or extend cemeteries at the planning stage under the Town and Country Planning Acts. There are no Regional groundwater quality statements *per se*, reference is made to the Policy H statement in the Policy and Practice for the Protection of Groundwater (PPPG) (Environment Agency, 1998) and the MAFF guidance on Good Agricultural Practice (1991) when undertaking an initial site assessment. In general, the usual conditions requested are:

- no graves within Zone I;
- no graves within 250 m from any well, borehole or spring used for potable supply or 50 m from any other well or borehole;
- burials not normally acceptable within Zone II, but applied on a site specific basis;
- no burials in saturated ground; and
- at least 1 m unsaturated zone should remain below the base of the grave.

The region would normally object to development or extension of cemeteries in source protection Zone I and this approach has been successfully followed on occasion (an example is Amwell End). However, in some cases a minor extension in Zone I has been accepted. For example a small church in Hurley, lies on the Chalk, with a substantial unsaturated zone. Burials have taken place since the Middle Ages apparently with no impact on groundwater or public water supply (although few, if any, specific measurements are likely to have been made). Only a small number of burials were proposed each year, so overall the risks of pollution seemed minimal.

In some cases, requests for confirmation of water levels have been made, for example, over the winter period. At Hillingdon, sand and gravel was imported to raise the ground level to ensure that burials could remain above the water table. At Waltham Abbey, the proposed extension was to be on alluvial deposits, including sand and gravels, which could provide a pathway for contaminants to reach the nearby river. However, boreholes showed that sand lenses were present intermittently and that the pathway was unlikely to be significant, given the apparently limited hydraulic continuity. Some minor groundwater contamination was found, though it was not necessarily attributable to the cemetery. Some monitoring data have been collected and have been requested from the Officer dealing with the site.

There has been some concern from a doctor (a local resident) regarding development of a cemetery on London Clay and the possibility of spore borne diseases.

The importance of being able to justify decisions in protecting groundwater quality was highlighted - one case was mentioned where a member of staff was accused of racism after objecting to a cemetery proposal for a Muslim burial ground.

B.8 WELSH REGION

A meeting was held on 1998 at the offices. Ruth Jones of the Agency met with Chris Young and Alison Leavens from WRc.

No formal regional guidance is in existence but the need to establish a policy that can be applied uniformly was recognised. When planning applications are received the line of investigation generally encompasses a vulnerability survey and risk assessment with referrals to the PPPG and the MAFF guidelines. Applications are dealt with on a site specific basis with the Agency tending to do the risk assessment; the Local Authorities or churches concerned generally lack the in-house expertise and the capital to pay for it.

Attention was also drawn to a discussion document from the Thames Region regarding extensions to or development of new cemeteries. It was suggested that information to be gathered includes:

- rate of burials;
- areal extent;
- percentage increase if extension;
- geology.

General suggestions for guidance were:

- no graves within Zone I or within 250 m of any well, borehole or spring used for potable supply;
- not normally acceptable within Zone II unless low vulnerability conditions exist (e.g. significant thickness of clayey strata overlying aquifer; reasonable unsaturated zone; low permeability in aquifer);
- no graves within 30 m of any watercourse, spring or borehole;
- no land drainage in areas used for graves;
- where graves cited on major aquifers or "significant " areas of minor aquifers a minimum of 1 metre unsaturated ground below grave.

It was noted that groundwater resources were not utilised to a great extent in the Welsh region and therefore any effects would not be immediately known. Environmental protection has not been an issue as no investigations have taken place due to the small number of applications actually made. It is therefore impossible to comment on whether problems have occurred. Issues concerning pathogens are assumed to be dealt with in the calculation of the Source protection zones.

A planning application was forwarded to the Agency in 1997 for an extension to an existing graveyard in Llanelly. The proposed land was bordered by three other graveyards and, while no objections to the application were made, it was advised that, in order to assess the potential impacts from the new cemetery the developer should submit the follow information:

1. identification of all water features within a 500 m radius (surface and groundwater);

2. thickness and type of soils and rocks underlying the site;

3. depth to water table, especially with respect to the maximum depth of burial;

4. rate of burials;

5. the quality of the local spring discharges in the vicinity of the existing graveyards.

Additionally, it was noted that if the water table would be intersected by the graves then the proposal would not be acceptable. Graves were not be placed within 15 m of a water course or 50 m of a spring, although this distance was debatable depending on ground conditions and the use of the water feature.

Redevelopment of a graveyard in Flint resulted in some bodies being exhumed. Lead lined cadavers meant many had not decayed, and in order to exhume them the ground was sprayed with phenols and formaldehydes. This caused some local concern although subsequent monitoring found no problem.

Also discussed were issues concerned with the mass burial/disposal of cattle and swine herds. It was felt that the Agency need to adopt a pro-active approach, perhaps establishing a memorandum with MAFF to designate sites that could be used as and when the problem arose. It was also thought relevant to identify farms where animals above a certain number were held, as in many cases herds have to be disposed of locally. Ideally regions need to develop guidelines as to what would be acceptable locally.

On a more novel note was the leaflet about the Bio-digester. This is a “specially constructed container into which the whole bodies of dead animals are placed.” The digester fits into a hole 1.5 m diameter by 2.7 m deep and advertises for the safe and environmental disposal of lambs/sheep, calves and poultry, although in small print it states one should seek site approval from the Environment Agency.

APPENDIX C

NORTH WEST REGION RESPONSE LETTER

APPENDIX D INDUSTRY CONTACT LIST

Rev. Dr. Peter Jupp National Funeral College Bradden House High Street Duddington Stamford Lincs PE9 3QE	Tel: 01780 444 269 Fax: 01780 444 586	National Funeral College
Mr George Nash Institute of Burial & Cremation Authorities 157 Crescent Road New Barnet Herts EN4 9RN	Tel: 0181 449 9319	Institute of Burial & Cremation Authorities
Mr Ian Hussein Secretary Institute of Burial & Cremation Authorities City of London Cemetery and Crematorium Aldersbrook Road Manor Park London E12 5DQ	Tel: 0181 530 2151 Fax: 0181 530 1563	Institute of Burial & Cremation Authorities
Mr Boyd Dent Department of Environmental Sciences University of Technology Sydney Broadway NSW 2007 Australia	Tel: int + 61 2 95141765 Fax: int + 61 2 95141755	Extensive research in Australia
Mr David Kaye Editor Funeral Service Journal FSJ Communications PO Box IW73 Leeds LS16 9XW	Tel: 0113 284 1177 Fax: 0113 284 2152	Editor - Funeral Service Journal
Mr Allan Pentecost School of Life, Basic Medical & Health Sciences Kings College Campden Hill Road London W8 7AH	Tel: 0171 333 4481 Fax: 0171 333 4500	Ignis Fatuus

Ken West Bereavement Services Manager and Registrar Cemetery Office Richardson Street Carlisle CA2 6AL	Tel: 01228 525 022	Woodland Burials
Chris Statham Kenyon International Emergencies 231 Chaplin Street Sudbury Middlesex HA0 4UR	Tel: 0181 903 0072	Deal with large disasters
Jon Davies Midlands School of Embalming	Tel: 01527 584 654	Embalming
Adrian Haler Dodge Chemicals	Tel: 01256 893 883	Embalming fluid supplier
Fiona Melbourne Caple Melbourne Ltd	Tel: 01638 669 908	Carried out a survey of service sector requirements for funeral directors. Soon to do similar survey for embalmers.
Nick Ricketts Director Paws to Rest Pet Bereavement Service Carlisle Cumbria	Tel: 01697 472 232 Fax: 01697 472 260	Chairman of the Association of Private Pet Cemeteries and Crematoria

APPENDIX E GLOSSARY OF TERMS

Term	Definition
Aerobic	Presence of free (i.e. gaseous or dissolved) oxygen
Anaerobes	An organism that does not require oxygen
Autolysis	Self-dissolution that tissues undergo after death of their cells, due to action of their own enzymes
Cadavers	Corpse
Coccus	Globular bacterium
Corpse candles	See *ignis fatuus*
Embalm	To treat (a dead body) with preservatives
Enteric	Intestinal
Epidemiology	The branch of medical science concerned with epidemic diseases
Flaccid	Soft and limp. *Flaccidity.*
Gram-negative/ Gram- positive	see Gram's stain
Gram's stain	Stain used in bacteriology. Differentiates many kinds of (*gram-positive*) bacteria which take the stain from others (*gram-negative*) which do not.
Hepatic	Of the liver
Hypostatis	Drainage of blood under gravity
Ignis fatuus	Corpse candles - the phenomenon of pale lights across marshy ground or graveyards. Also *will-o'-the-wisp*.
Inter alia	*Latin. adverb* - among other things
Pathogen	Any agent, such as a bacterium, that can cause disease
Putrefy	(of organic matter) to rot and produce an offensive smell.
Putrefaction	Type of bacterial decomposition of protein-containing substrate (largely anaerobic) with formation of evil smelling amines rather than ammonia.
Rigor mortis	The stiffness of joints and muscles of a dead body
Will-o'-the-wisp	See *ignis fatuus*

APPENDIX F RECORDED OCCURRENCES OF IGNIS FATUUS IN THE UNITED KINGDOM

Location	**Date**
Whitbeck, Cumbria	pre 1552
Powick, Worcs.	1839
Badsey, Worcs	pre 1830
Fakenham, Norfolk	pre 1900
Bungay, Suffolk	pre 1900
Norfolk Broads, Norfolk	pre 1900
Rudham, Norfolk	1839
Syleham, Suffolk	18th C
Crowborough, Sussex	1891
Kinlochbervie, Highland Region	1980
Dunoon, Strathclyde Region	1985
Newton Steward, Dumfries and Galloway	1930
Blundellsands, Merseyside	1902
Middleton, West Midlands	c1950
Tregaron Bog, Dyfed	1984
Okehampton, Devon	1941-44
Wherwell churchyard, Hants	1991
Thorney Island, West Sussex	1935
Blo-Norton, Norfolk	1960
Dengie Marsh, Essex	1980
Eastbourne, East Sussex.	1920
Pevensey Marsh, East Sussex	1938
Morfa Bychan, Gwynedd	c1694
Leg of Mutton, Mill Hill, London	1980