THE HYDROGEOLOGICAL CONTEXT OF CEMETERY OPERATIONS AND PLANNING IN AUSTRALIA

by

Boyd B. Dent

VOLUME l

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CERTIFICATE OF AUTHORSHIP / ORIGINALITY

I, Boyd Barr Dent, certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

Abstract

The Hydrogeological Context of Cemetery Operations and Planning In Australia

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The purpose of this research has been to evaluate the potential contamination impact of cemeteries on groundwater. A comprehensive study of the groundwaters in the unsaturated and saturated zones of nine Australian cemeteries has been made, with most sampling between October 1996 and August 1998. Periodic sampling from 83 wells or ponds yielded 305 complete samples which were tested for at least 38 inorganic and 5 bacterial analytes. Other, partially complete samples were used for metals and bacterial analyses. The soils of all sites were tested for a range of analytes that might reflect or affect the presence of human decomposition products.

The within-cemetery sampling has allowed inorganic chemical characterisation of cemetery groundwaters to an amount of detail not previously attained. In the past 100 years there have been fewer than 12 sampling-based studies published on any of these matters. The forms of nitrogen feature most prominently, but three groupings of analytes are recognised as major contributors, including Na, Mg, Sr, Cl, SO_4 and forms of P; these outcomes are similar in each hydrogeological zone. This study is unique in that it has a broad focus on the environmental impacts in respect of bacterial presence and transmission, heavy metals and nutrients, and has put these into the context of cemetery management and operational practices.

Cemetery functions are best understood conceptually as a special kind of landfill but they are strongly influenced by the temporal and spatial variability of cemetery practices. Human decomposition mechanisms and products are considered in detail. This information was used to model the impacts for a large municipal cemetery over a twenty year time-frame. The previously unquantified relationship of cemetery proximity to drinking water wells has been determined and guiding principles for

cemetery location and operation have been prepared including separation distances from watertables and specification of buffer zones in different hydrogeological settings. The related issue of the disposition of cremated remains is also considered and guidelines developed for scattering of these within buffer zones.

The amounts of decomposition products leaving cemeteries are very small, and well sited and managed cemeteries have a low impact on the environment. Cemeteries should not be regarded as a detrimental landuse and the in-soil interment of human remains and re-use of graves are sustainable activities.

However, almost all cemeteries have some potential for pollution. The most serious situation is the escape of pathogenic bacteria or viruses into the environment at large. The answer to the question as to 'whether any one cemetery pollutes?' depends on the location and operation of the site in adherence to the affecting parameters. The question can only be resolved by a comprehensive geoscientific investigation with a focus on the hydrogeological setting. Such assessment needs to consider the effects if the practices and/or usage patterns within the cemetery change, or if there are unaccounted changes in impacting natural phenomena like floods.

ACKNOWLEDGEMENTS

The research work comprising this thesis has extended over 7½ years. This time-frame brings with it both opportunities and difficulties in terms of the on-going review of data and results, the search for related information, consideration and presentation of ideas; as well as changes to the breadth of the work and the people dealt with whilst conducting the research involved. Accordingly, there is a long list of people to be thanked for their inputs and help in making the work a reality and professionally and technically correct. The work has been widely promoted in Australia and overseas as the National Study of Cemetery Groundwaters.

Professor Michael Knight, Director of the National Centre for Groundwater Management (NCGM), was the Principal Supervisor for this research. He was the main protagonist for attempting the work and the skilful administrator who enabled it to happen within a complicated university administrative system and through his liaison with industry. He constantly supported and encouraged me throughout the years, overviewed my technical concerns, and facilitated interaction with key staff and others where it was needed. Thank you Michael for your support and friendship.

Dr William Milne-Home, Senior Lecturer in the NCGM was the Co-Supervisor. Bill's principal role was the provision of detailed technical support on matters like sampling techniques, chemical analysis, conceptualisation of flow models. Thank you Bill for the time spent - usually I was in a hurry.

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Whilst undertaking this work I was employed by UTS as a lecturer in the Department of Environmental Sciences (formerly the Department of Applied Geology). Adjunct Prof. Brenda Franklin (previous Head of Department) was initially responsible for employing me and then enthusiastically supported my work; she was succeeded by A/Prof. Greg Skilbeck who continued in the same vein. Other colleagues and staff helped in various ways and generally supported my absences on fieldwork or other research requirements; Mrs Leighonie Callan has been of great assistance in preparing diagrams and slides for presentations, whilst Mrs Marnie Paterson also provided liaison with staff and industry; others in respect of sampling and testing are mentioned later.

The University, and specifically the Faculty of Science, is thanked for permitting me to be employed whilst undertaking the Study. The Faculty's workshop personnel - Jim, Paul and John, were responsible for constructing all the piezometer covers and a specialised sand-sludge bailer. The University facilitated the work via the staff study scheme which funded the PhD degree costs.

The direct costs for the Study, particularly for inspections, travel, sampling point establishment, sampling, analyses, translation of papers, and more, were funded by the generous support of representatives of the Australian cemeteries industry. A Special Research Grant (reference # 907-C04-00658) was provided by the Victorian Department of Human Services and covered funding for 3 sites in Victoria, viz. Melbourne General Cemetery, The Necropolis - Spring Vale Cemetery, and Bunurong Memorial Park. The managers of the relevant Cemeteries and Crematoria Section in that Department changed over time, but specific thanks are due to Ms Pauline O'Brien who conceived of and created the Grant, Mr Bryan Crampton and Ms Jo Fox .

The trustees of those cemeteries, viz; The Necropolis, Spring Vale and Cheltenham Cemeteries, gave approval for the works in their areas of control, and through their authorised managers provided considerable additional practical help, minor materials supplies, equipment storage, and access to records. In all the cemeteries studied there were managers and field staff who participated in various ways at different times and to all I say "thank you", but specifically Mr Robert Spark, Mr Kevin Scheele, Mr Roy Latessa, Mr John Sonogan, Mr Brian Growse from The Necropolis, and Mr John Gilbertson, Mr Peter Green, Mr Peter King from Bunurong Park were involved for the whole project.

The other partners were the Boards of Trustees of Eastern Suburbs Memorial Park, Woronora General Cemetery, Centennial Park Cemetery, Enfield General Cemetery; the Launceston City Council and the Metropolitan Cemeteries Board (WA). Specifically:- from Eastern Suburbs - Mr David Blake and Mr Heiko Jacobs; from Woronora - Mr Ivan Webber, Mr Colin Smith and Mr Jim Ramsay; from Centennial Park - Mr Norm Orchard, Ms Jane Crighton, Mr Mark Ruthven, Mr Colin Platten, Mr Sam Thornton and Mr Andrew Driscoll; from Enfield - Mr Kevin Crowden, Mr Brian Bennett, Mr Phil Ambler and Mr Simon McGeorge; from Launceston - Mr Craig Saunders, Mr Austin O'Byrne and Mrs Robyn Martin; from Metropolitan Cemeteries Board - Mr Peter MacLean, Mr John Holman, Mr Brian Danby and Mr Brian Poor. Some of these staff have now left their positions and their replacements have taken over the Study's mantle at late stages, so "thank you" all.

The umbrella industry organisation - Australian Cemeteries and Crematoria Association (ACCA), and especially its incumbent President at the time of commencement - Mr David Blake, provided in-principle support for the work and encouraged its promulgation throughout the industry via presentations by Prof. Michael Knight and myself at conferences in Sydney, Adelaide and Hobart. Contact information for all these parties can be found in Appendix A.

Dr Robert McLaughlan of the NCGM was an early adviser in the study's development; thank you Robert for your challenging input about methodologies and objectives, as well as your on-going provision of reference material. Dr Kayleen Walsh, whilst wrestling with her PhD studies, was also an early adviser; she provided valuable assistance on field disinfection techniques and on testing with laboratory Hach colorimeters.

Much help was sought about the quality and methodologies for microbiological testing; particularly valuable advice was obtained from: Mrs Liz Hanko, Senior Microbiologist, Water Ecoscience Pty. Ltd.; Mrs Debbie Walters, Microbiologist, Tasmanian Department of Primary Industries, Water and Environment; Mrs Elizabeth Frankish, Consultant Microbiologist and Managing Director, Microserve Laboratory Pty. Ltd.; Mr Reg Walters, Principal Microbiologist, Australian Water Quality Centre; and Mrs Bobby Phimister, retired food microbiologist.

Groundwater solutions are difficult to analyse chemically, but thanks to the patient and expert assistance and advice of Mr Jim Keegan, Senior Scientific Officer, Department of Chemistry, Materials and Forensic Science, the hundreds of ICP analyses undertaken were of extremely high quality. Further help was provided by Ms Anthea Harris and Dr Mary Mulholland for a number of HPLC tests; and early on, Mr Roy Day helped with attempts at IC analysis.

Mr Gary Hosking, Senior Chemist, Ti-Tree Bend Wastewater Treatment Plant, Launceston, provided valuable assistance with obtaining in-time, chemical and biological analyses for groundwater samples taken in Launceston. This became extremely urgent when the local, government testing laboratory closed half-way through the sampling program.

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The field and laboratory data was subjected to numerous statistical examinations. The general methodology and applicability was reviewed by Dr Peter Petocz, Senior Lecturer, Department of Mathematical Sciences, UTS, who gave copious amounts of encouragement and support for the matters tackled.

A number of documents and journal papers needed to be translated in order to complete the Study's literature analysis. Mrs Cornelia Pulvermacher and others translated from German, Mrs Jackie Van Helden form Dutch including an especially difficult but historical paper; Mr Pablo Lara and Ms Balbina Arsenio and others translated papers from Portuguese.

In 1991 Ms Geraldine Hodgson commenced related research into in-grave anthropological taphonomy at Centennial Park Cemetery. Geraldine provided invaluable encouragement with my Study, was a source of fruitful technical discussion on various issues and provided samples of soils and adipocere, gave much assistance in meeting people in the Australian "death industry", as well as promoting my work and involvement in broader matters like forensic geology.

Mr Bolivar Antunes Matos is a PhD researcher at the Institute of Geological Sciences, University of São Paulo, Brazil, and is also working on in-ground transmission of necro-leachate. We have had a number of valuable discussions about our mutual interests. Bolivar also acted as a guide to the cemetery sites where he and Prof. Alberto Pacheco have studied, when I visited Brazil in August, 2000.

Attempting to juggle work commitments including supervision of senior students, the needs of immediate and extended family, as well as the necessary travel for fieldwork, long hours in the lab or at the desk, has been a demanding task. It would not have been possible to do this work without the significant backing of my wife, Annette, and son, Nicholas, and all my family both near and far; I thank them for their patience, encouragement and love.

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CHAPTER ONE

THE AUSTRALIAN CEMETERY

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DISPOSAL OF THE DECEASED

Deceased human bodies in the normal course of dealings after their death follow one of five pathways, or a combination of these, in the final passage to complete decomposition:

(1) aerial emplacement, i.e. the body remains in its place of disposition exposed in a variety of ways to natural processes;
(2) burial in land - the cemetery
(3) entombment, i.e. essentially emplacement in a vault or crypt significantly removed from interaction with the non-aerial environment - a cemetery function
(4) burial at sea
(5) cremation with various disposal routes for the ashes including, in cemeteries.

With time, which can be extremely lengthy in say the case of naturally mummified bodies from desserts or frozen ice fields or tar pits, the body is reduced to its primordial component parts. This reduction happens via a very large number of intermediate decomposition products, a large range of chemical and microbial reactions, direct consumption by lower trophic level scavengers, or by rapid vaporisation.

Almost immediately upon death the human body starts to decompose, yet at the same time a number of cellular functions continue, replacement biochemical reactions occur and growth in fact continues in tissues like hair and nails (Janssen, 1984, Wilkins, 1992). Very significant destructive biochemical reactions begin to occur bringing about gross changes to the appearance of the cadaver. One of the significant drivers of the process is the rapid consumption of the body's oxygen. This element is taken from cells by remnant biochemical reactions, the needs of resident aerobic organisms, and also that oxygen which is able to be harnessed by redox reactions. Consequently, from within the body, the decomposition activity becomes anaerobic (Janaway, 1993). This anaerobic phenomenon is an important factor in understanding the later appearance of decomposition products in the environment.

Whatever the final passage is for the deceased's remains, in one way or another there will be continuous contact and/or interaction with elements of the natural environment. This interaction is slow, limited in size and probably of little significance in the case of the mummified and to some extent the entombed, but assumes a large scale significance in the case of the buried and cremated. The reason for this is the number (i.e. volume) of bodies disposed of by regulated crematoria or cemeteries. There seem to be very few civilisations that practise uncontrolled disposal of the deceased so that the assumption of a regulated and, to a degree orderly, disposal is a reasonable starting point.

The work described in this thesis concentrates on exploring the relationship of cemeteries to the environment. In particular it explores the practice of burial of the deceased (interment) from a hydrogeological viewpoint. A fundamental premise is that everything that society does in some way interacts with the hydrological cycle: cemeteries are no different. The research concentrates on characterising the nature of cemetery groundwaters and elucidating how cemeteries work.

In a cemetery, essentially organic waste is disposed of by burial - without necessarily creating new land, but in a way that it immediately interacts with the sub-surface environment; it is orderly, regulated and final to different degrees. Cemeteries thus represent a special kind of landfill (Dent and Knight, 1998) and can really be viewed as a "black box" - a significant land area interacting with rainfall, infiltrating water and ultimately with permanent groundwater systems. They are controlled by planning and legal policies, and they have significant management and operational needs and attributes. Although cemeteries may be operated by private, or many kinds of government concerns; they are 'big business'.

Within the 'death industry' of more advanced societies like Australia, UK (United Kingdom), France (Vidallet, 2000) and many more, there is considerable competition for the right to dispose of remains by cremation or burial. Despite long term trends in many countries to a preference of cremation over burial (ACCA, 1997, Davies and Shaw, 1995, Dunk and Rugg, 1994, Environment Agency, 1999) cemeteries are a present, future and permanent aspect of the landscape. In some areas, beyond normal religious rites and beliefs, cemeteries are a growth industry e.g. the trend to woodland burials in the UK (West, 2000) and USA (United States of America) (Memorial Ecosystems Inc., 2000, and Campbell pers. comm.).

People with certain religious affiliations, e.g. the Muslims in southwest Melbourne and northeast Perth, Macedonians in northeast Perth, Jewish adherents in eastern Sydney, are also demanding increasing numbers of burial spaces. The previous examples are mentioned because they have been considered in this Study at SPR (The Necropolis), NEW (Bunurong Memorial Park), GUI (Guildford Cemetery) and BOT (Botany Cemetery). On the other hand the trend lines for burial suggest that some people of all religious affiliations and belief systems will demand some burial space, forever.

> "In Australia in 1996 approximately 46% of all funeral services resulted in interment ... of the deceased ..... the proportion opting for interment means that significant grave space needs to be found.

> Using average death rates and "Low Case" population projections, as per the Australian Bureau of Statistics (ABS, 1996), then about 1.34 million Australian adults (>15 years) will die in the next 10 years (1998-2007). If just 40% of these are interred, and 75% of them occupy new graves of an average size 1.1m by 2.4m; then 106 ha of land will be consumed.
>
> Most of this consumption, 67 ha, will occur in the greater metropolitan areas of the capital cities, since this is where approximately 63% of the population lives. This is roughly equivalent to 1100 standard building blocks of 600 m^2 each, and makes no allowance for associated paths, roads, gardens and other infrastructure. Clearly this is a significant urban space requirement ....." (Dent and Knight, 1998).

It is also worth noting that Government policy clearly reflects this demand and trends. See for instance submissions by the Australian industry to various Enquiries (e.g. Department of Lands, 1989) and examine the trends by industry to re-use grave space - in South Australia at CEN (Centennial Park) and HEL (Cheltenham Cemetery), at GUI, and the development of new sites e.g. at NEW (Dent and Knight, 1998, Crowden, 1996). It is a piece of industry folklore that successive New South Wales' Governments have and will not move on making more space available by grave re-use - existing graves are sacrosanct; "in perpetuity" means just that - forever. The situation is similar in the UK which has vast areas dedicated to 'burial grounds' within the context of an otherwise quite restricted land availability (Davies and Shaw, 1995, Dunk and Rugg, 1994, Harrison, 1984).

The issue of cemetery land consumption and re-use seems to occur ‘over and over’. The approaches taken to solving it vary considerably, see Chapter Three for a discussion of worldwide cemetery studies. Very few other calculations of the actual amount of space required have been published. For the USA it has been estimated that at current death and cremation rates, approximately 2 square miles (518 ha) of burial space (2.4 m x 1.2 m) alone is required (Iverson, 1994). These are raw figures and assume one interment per site, and don't allow for roads, paths and other infrastructure, but they serve as a guide.

A STUDY IN THE AUSTRALIAN CONTEXT

This Study reports upon unique research into the relationship of cemeteries to the physical environment in the Australian context. The issue of what cemetery decomposition products can be recognised in the vadose and saturated zones of cemeteries is addressed, with focus primarily on the inorganic chemistry and indicator bacteriology. In excess of 300 complete analyses of groundwaters from 9 cemeteries each of a unique hydrogeological character are reported. Many of the samples comprise limited time series (up to 7 sampling events at any site) over a period of 2 years. The site soils themselves have also been characterised (except for detailed chemistry) so that their primary relationship/s to the percolating groundwaters can be assessed.

An effort has been made to relate the results to cultural aspects of interments where possible and to consider any resultants of the effects of coffin construction and interment artefacts. Consequently this expansive work has led to the primary characterisation of cemetery groundwaters. Consideration is also given to the quantitative effects of disparate interments in time and space; the workings of the "black box" which is the total cemetery.

The work is original, the only other studies in the World which have been of any consequential size in terms of number of samples are those by Pacheco et al. (1991) in Brazil, and van Haaren (1951) in The Netherlands. In the former, 67 samples were taken from 3 cemeteries, in a different climatic and cultural context to the present, and concentrated on microbiological aspects. In the latter, 17 groundwater samples were taken from 3 cemeteries, and together with nearby drain waters were examined for their inorganic chemistry. Other international literature and studies are reviewed in Chapter Three to establish the known extent of relevant knowledge.

On a broader scale, the sample results have to be considered in many contexts: for example, the aspects of cemetery operations, religio-cultural aspects of interment, as well as aspects of cemetery management, policy and legal issues. These are drawn together into considerations and discussions of cemetery planning and operations.

The issues discussed have been presented by the Researcher at several national and international forums (Knight and Dent, 1995, and 1998, Knight and Dent, 1998, Dent, 1999, 2000a, 2000b and 2000c) and at smaller professional gatherings and seminars in Australia, Brazil and the UK. The Researcher has also contributed significantly and especially to studies by others (WHO, 1998, Environment Agency, 1999) which have attempted to represent the wider context of the role of cemeteries in society. This Study is a new contribution to knowledge and a distinct focus for the benefit of other professionals, regulators and industry members.

The Study was funded by substantial tied grants from Contributing Research Partners (Appendix A) within the Australian industry including a research grant from the Victorian Department of Human Services. It was also widely supported by other participating cemeteries, the Australian Cemeteries & Crematoria Association (ACCA) and the industry generally. Because of the need to work within the management paradigms of the various facilitating cemeteries and the sites under the direct control of the Contributing Research Partners, the Researcher had only a limited influenced over the choice of sites. Consequently the Study was done where and how it could be (Figure 4.1). The value and amount of information from each site varies, the hydrogeological setting encountered is what it is, and is not necessarily the most suitable for any vadose or saturated zone work in all instances.

Furthermore, the work involved was restricted to the cemetery sites proper. In no cases did the cemetery operators have direct responsibility or operational use for land beyond their boundaries. Background and final downgradient sample concepts as they relate to groundwater sampling were thus confined to the cemetery sites. This aspect has had both positive and negative consequences in the understanding of the data (see Chapters Five and Six).

A NOTE ABOUT THESIS STYLE

A Study of this kind is expansive in terms of the areas of information that must be examined in order to pull together all the threads that make the story. It is truly interdisciplinary and as such begets a unique and convoluted jargon which can be confusing to those reading it from any perspective. The Study also involved an expansive consideration of sites around Australia (nine are reported on directly) and was enhanced by overseas visits to Brazil, the UK and USA, as well as a wide range of discussions, and internet and other correspondence with participants, researchers and workers in the "death industry".

In order to simplify the work and avoid tedious repetition of identifier statements some words are given special implied meanings, and an abbreviation symbolism is used throughout the text. These words and abbreviations are listed in Appendix A. The cemetery sites are referred to by a 3-letter acronym; those not yet introduced are: WOR (Woronora General Cemetery), MEL (Melbourne General Cemetery), and LAU (Carr Villa Memorial Park at Launceston).

Some words like "body", "remains", "cadaver" are used interchangeably and usually are chosen for best fit in their context. The word "interment" is the correct term for the burial of human remains, but like in the preceding, "burial" is used interchangeably. In a similar way "coffin" may be interchanged for "casket" but not vice versa: the casket being a relatively large, clearly rectangular container for burial.

The term "Study" is also a representative for all the work reported on in this thesis. Groundwater sampling was undertaken in up to seven "events" at each cemetery; accordingly a sampling event is designated by symbols and numbers e.g. CEN/1. The Candidate and Researcher of this thesis was responsible for the collection of all groundwater and soil samples as well as the consideration and analysis of the results; for simplicity he is referred to throughout as the "Researcher".

CHEMICAL COMPOSITION OF INTERRED WASTES

This Study is about the processes and products of decomposition and their interaction within various environments. In order for these to be properly understood their derivation must be first understood. In the cemetery context this is reasonably straightforward because the bulk composition of the buried waste is confined within a relatively narrow range of possibilities.

The primary material is that of the bodies themselves. These vary in size, age, sex, and degree of decomposition at the time of interment and a few insignificant aspects for this Study like skin colourings and other factors of genetic makeup. A matter of importance is the assemblage of microbiological agents present in and on the remains, particularly if these agents are in excess of the normal range e.g. if they represent the cause of death like in cholera, salmonella poisoning, staphylococcal infections, tuberculosis, hepatitis or other viral agents. Typical human compositions are discussed in Chapter Two.

Furthermore, the degree of completeness of the remains is a factor, e.g. if they have been autopsied the normal decomposition processes are affected, as well as if certain parts are damaged or missing or decayed or burnt. In the context of a cemetery, however, these variations are likely to represent only a tiny fraction of the total waste load. Therefore, with the exception of highly specialised burial areas and perhaps some for which special disease considerations are important (see for instance Sly, 1994, and Medical Waste Committee, 1994), these effects are not further considered.

Embalmed bodies represent another avenue of significant variation. The practice of embalming as it occurs in the usual pathway of cemetery interment, seeks to keep the appearance of the remains in a 'living' or 'as remembered' state, for a short - but variable amount of time. It is a preservative process that seeks to partially disinfect the body and also prevent some biochemical reactions. The whole issue of embalming contains a number of variables, but essentially these devolve to two key ones, namely: how the embalming is done, for example, a full or partial arterial and visceral replacement of body fluids; and, the type of embalming materials used.

These matters also turn on whether the remains are to be cosmetically treated for short-term viewing after death or whether a long-term, religio-cultural preservation requirement attains.

A large number of participants in the Australian industry have been questioned on this aspect. The evidence is that in the Australian context embalming is little practised, that which is done is generally for short-term cosmetic reasons for viewing of the body, and probably amounts to less than 2 or 3 percent of all interments (Blake, MacLean, Bennett, Hodgson, and others pers. comm.). Another perspective, likely based on some limited discussion with funeral directors and reported in a newspaper article (Santamaria, 1997), claims that "around 30%" of all corpses in Australia, whether cremated or interred, are embalmed. There are significant cultural divides in the maintenance of the practice, for example it is the most common amongst persons of Italian and Greek descent.

In other countries, particularly the USA, Canada and the UK (Environment Agency, 1999, assumes up to 50% of interments), embalming is a widely practised procedure and considerable quantities of embalming fluids are thus interred with the remains. There is a corresponding loss of body fluid - mostly salt and iron rich blood, but also water and cells; in addition, many microbiological agents are lost - killed by the embalming process. Typically the lost fluids (remains) are sent into the ruling sewage system and are well removed from the cemetery context (see e.g. discussions and papers by the National Funeral Directors Association - USA, 2001).

The matter is exacerbated by the now-defunct embalming practice of using arsenic as the main preservative. This practice has led to the occurrence of some groundwater contamination by arsenic in the vicinity of civil war era cemeteries in the USA (see e.g. Spongberg and Beck, 2000, Hayden and Rayne, 1996). Other investigations have sought, albeit in a small scale way, to either detect methanal (formaldehyde) in groundwater (Beak Consultants Limited, 1992, Chan et al., 1992) or to raise questions about the pollution potential of embalming fluids. This latter aspect has been the context of a few recent commentaries e.g. see Cook (1999) and Holleman (2000); and is further discussed in Chapter Three.

Secondary factors also play a significant part in determining what sort of decay loads can enter the soil and water. These fall into two more groupings:

- firstly the funereal aspects of the interment, for example, whether the remains are included in a coffin or not, the coffin construction, encapsulation of the remains in plastic, the presence of clothing and artefacts in and around the coffin;

- secondly, other aspects that may relate to cultural attitudes, burial rites, and post mortem examinations.

At the request of the Victorian Department of Human Services, the likely effects of non-coffinated burials (i.e. the remains are not placed in a coffin or body-bag before burial) were specifically considered in the Study. The relevant results were principally derived at GUI and are discussed later. The usual situation, however, is that the remains are buried in a coffin. Hence the construction and lining materials of the coffin become relevant as they will eventually breakdown.

In Australia today, the preferred coffin fabrication is from chipboard or particle-board type product with various coatings and finishes like wood and plastic veneers, paint and lacquers. These are typically adorned with plastic ornamentation and handles and are held together by steel staples. They are lined with various plastics - usually PVC sheeting, wood and paper fibres, poly-cotton and cotton type fabrics.

Sometimes the coffins are manufactured with brass ornamentation and fittings, including screws, hinges and catches. A much less important category of coffin is a metal-lined or full-metal variety. Information from various industry representatives suggests that the full-metal coffins that are actually interred might be as high as 2% of all burials for some cemeteries and some cultural groups, although the pattern appears inconstant (Danby, Thornton, Hodgson and others, pers. comm.). It is not really practical to assign even average numbers to such widely disbursed occurrences; although at a few cemeteries, of which CEN is one, a specific lawn area is used for large, metal, American-style caskets.

In the case of metal-lined coffins these aren't always identified to the cemetery, they are interred randomly in some cemeteries but in others would principally be found in above-ground vaults and mausolea. Once again their usage is generally low overall and it is not really satisfactory to think of them in terms of average numbers for interment. The materials used vary from copper sheet to zinc sheet, possibly lead but generally not. There have been market-driven and health regulation changes with time that have affected these aspects (Smith, pers. comm. 1998).

In some cemeteries, probably in portions at least one hundred years old, it might be expected that steel and lead coffins could be found. Such construction materials have been reported for coffins in the UK (Janaway, 1993, Environment Agency, 1999), USA, and have been seen by the Researcher coming from the exhumation of a substantial Victorian era crypt in London, UK.

Finally, the actual amount of material interred in the grave (and by extension to the cemetery) has to be considered. Figure 1.1 illustrates composite size data for a representative grave derived from examinations at the Study's sites, and some data about the nature of the materials interred. There are some variables like coffin size, density parameters for soils, depths and other matters that can be changed to suit various perspectives, but nevertheless the model adequately illustrates the concept of waste disposal in the cemetery. The resultant is, that although cemeteries consume vast tracts of land and a very large volume of graves is dug, the interred remains take up only about 10% of this volume and only 5-6% of the allocated grave space: spatial consumption by the organic wastes is small. This utilised volume may contain about 70 kg of remains and maybe 15 kg or so of coffin and funereal artefacts; that is about 0.8% of the original grave mass is organic waste. After excavation and backfilling the density, specific mass and volume relationships of the grave alter from these representative values.

cemetery organic waste numbers

assumptions:

grave space 1.1m x 2.4m	$2.64m^2$
grave excavation 0.7m x 2.0m x 2.1m	$2.94m^3$
volume of grave space 1.1m x 2.4m x 2.1m	$5.54m^3$
coffin volume 0.45m x 1.9m x 0.35m	$0.3m^3$
weight of organic waste to be buried (coffin +)	85kg
in-situ bulk density of soil	$2000kg/m^3$

then:

• waste weight % of allocated grave space	0.8%	(1.4%)*
• waste volume % of allocated grave space	5.4%	(10.2%)*

* of excavated space

Figure 1.1 Model of Amount of Material Actually Interred

*

CHAPTER TWO

HUMAN DECOMPOSITION

Contents

DECOMPOSITION PROCESSES

This section outlines the various processes that the deceased human body undergoes in its final passage when its primordial elements are merged with the natural environment. In all of the written literature that has been examined these processes have never been comprehensively delimited for the context of interred remains and their interactions in the cemetery. There are significant summaries of the main aspects - Mant (1987), Corry (1978), Janssen (1984), Polson et al. (1985), Gill-King (1997) and Clark et al. (1997) with particular respect to forensic and medical applications which are most useful, whilst other authors have dwelt on individual aspects as necessary. Consequently there is some, but not greatly important, diversion in the presentation of the order in which the various processes occur, and a little variation in the manner of these. In respect of discussions about individual processes and their effects these are very dependent upon the individual circumstances being described e.g. Janaway (1993 and 1996), Galloway (1997), Owsley and Compton (1997). Forbes (2000, pers. comm.) is currently studying adipocere formation as an aspect of decomposition and has provided some important additional insights into the following understanding.

Decomposition commences almost immediately after death and is characterised by spontaneous postmortem changes. Soft tissue that has not been naturally or artificially preserved is subject to the postmortem processes of autolysis and putrefaction . Following putrefaction, the decomposition process continues through liquefaction and disintegration, leaving skeletonised remains articulated by ligaments. Skeletonisation proceeds until eventually only the harder resistant tissues of bone, teeth and cartilage remain. These remains are then subjected to inorganic chemical weathering (Figure 2.1).

Putrefaction is characterised by the breakdown of soft tissue and alteration of the protein, carbohydrate and fat constituents. van Haaren (1951) indicated that the body composition is approximately 64% water, 20% protein, 10% fat, 1% carbohydrate and 5% minerals. The breakdown is due to the action of many enzymes that are already present in the tissues, or are otherwise derived from micro-organisms and fungi (Evans, 1963), with the resultant that considerable amounts might be expected from the protein and fat contents. A further exposition of compositional details is given in the following section.

Normally, putrefaction is initiated by autolytic processes (Janssen, 1984) and occurs in variable timeframes (usually 48 – 72 hr) depending on the surrounding environmental conditions, but is the most likely in-grave process. After death, the micro-organisms present migrate from the intestines and respiratory tract to invade the body tissues. Aerobic organisms deplete the body tissues of oxygen as well as setting up favourable conditions for the anaerobic micro-organisms that take the remains through the putrefactive stages. These anaerobic organisms are usually derived from the intestinal canal but may also migrate from the soil and air into the remains in the later stages of decomposition (Evans, 1963).

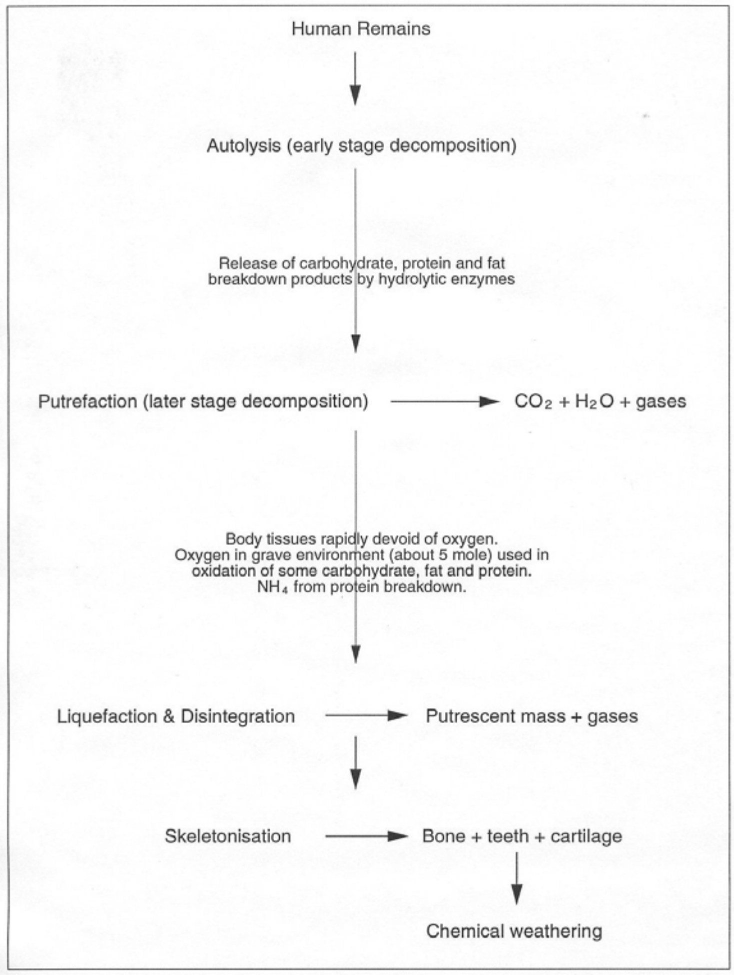


Figure 2.1 Overview of Human Decomposition Process

An oxygenated environment will increase the rate of decomposition. It has been noticed for example that bodies lying in wooden coffins will putrefy much more rapidly than those in leaden shells, due to the freer access of air to the body as the wood coffin disintegrates (Henderson, 1987). However, in the grave, the amount of oxygen available to the remains is limited and its continual involvement depends on gas diffusion in the grave and attendant soils. This is discussed in more detail later.

Fungi are commonly found on the skin and exposed surfaces of decomposing remains. In some cases, they can also be found growing in the intestines and other body cavities. However, most fungi encountered are aerobic and are therefore restricted to surfaces whereby little or no penetration of the tissue takes place. In a sealed coffin the fungal growth is usually slowed and arrested because of the reducing conditions present (Evans, 1963).

Body Chemistry

A more succinct understanding of the body's chemistry is provided by Forbes (1987) who has documented the approximate elemental composition of the human. Forbes' data are for the representative lean male of 70kg mass. It needs to be borne in mind that females have a lower body mass typically 2/3 - 3/4 of that of the male. The exact water content is not quantifiable and is regarded as about 70 - 74% of body mass (Forbes, 1987). The data is summarised in Table 2.1.

Table 2.1. Summary of Elemental Composition of Representative Lean Male (70kg) (after Forbes, 1987)

Element	**Amount (g)**	**Element**	**Amount (g)**
Oxygen	43000	Fluorine	2.6
Carbon	16000	Zinc	2.3
Hydrogen	7000	Copper	0.07
Nitrogen	1800	Manganese	0.01
Calcium	1100	Strontium	0.32
Phosphorus	500	Bromine	0.2
Sulfur	140	Lead	0.12
Potassium	140	Aluminium	0.06
Sodium	100	Cadmium	0.05
Chlorine	95	Boron	<0.05
Magnesium	19	Nickel	0.01
Silicon	18	Molybdenum	<0.01
Iron	4.2	Chromium	<0.002

The nature of the trace elements is a matter of considerable study and interest because of their role in bodily disorders. They are, however, also difficult to quantify; indeed to define. Moynahan (1979) pointed out that different researchers have denoted the same elements variously as trace, major, essential and/or toxic, or even as a vitamin; so that, irrespective of the ability to chemically analyse the element of interest - mainly metals, they must be simply demarcated for the relevant context. The information available also does not seem to be referenced to a standard like the 70kg lean male. Tables 2.2 to 2.4 summarise some relevant data from various sources.

Table 2.2. Other Elements in Human Composition

Iodine	0.011 g in adult (1)
Cobalt	0.0015 g in adult (1)
Selenium	ca 125 μg/L in blood (2)
Manganese	13.4-13.9 ppm in bone (3)
Copper	20 - 26.0 ppm in bone (3)
Cadmium, Mercury, Arsenic	<1μg/g of bone (4)

Sources for Table 2:

(1) Moynahan, 1979

(2) Gissel-Nielsen, 1988

(3) Keeley et al., 1977 reporting data by others

(4) Waldron, 1987; see also the discussion in Chapter Three where a European Union concentration of 4 g/body has been reported

Table2.3. Typical Components of Fresh Bone (after Goffer, 1980)

Component	Weight %	Component	Weight %
Calcium	20 - 22	Nitrogen	6
Phosphorus	10	Iron	traces
Fat	10	Fluorine	traces
Water	10	Lead	traces *

* Lead is a bone-seeking element; about 90% of the body's total lead burden is found in the skeleton (Waldron, 1987).

Table 2.4. Indicative Trace Components of Some Human Fluids

A. Median reference and European values (after Minoia et.al., 1990)

Concentration in μg/L

Element	Urine	Blood	Serum
As	16.7-20	5-7.9	3.5
Cd	0.8-0.86	0.6-1	~0.1-0.2
Cr	0.4-0.61	0.23-2.8	0.17-0.19
Co	0.57(1)	0.39-20	0.21-0.29
Cu	23-38	960-1225	987-1100
Pb	11-17	123-157.7	0.3-<1
Mn	0.6-1.2	8.8-13.6	0.6-0.63
Hg	3.5-4.3	5.3-9.5	2.1-5.8
Ni	0.9-2.5	2.3	1.2-7.5
Se	22.1-40	105-107.5	81-96
Zn	449-456	6340-6400	922-930

(1) where there is only one value comparative data were not available.

B. Data for selenium in similar tissues (after Aaseth and Thomassen, 1988)

Selenium - Concentration in μg/L

Group studied	Blood	Serum
All except China (2)	60-200	50-150
China	20-3200	10+
Australia	150	85
New Zealand	60	50

(2) different population groups in China have been treated with Selenium enhanced diets (Moynahan, 1979)

C. Representative compositions of faeces and urine (after Polprasert, 1989)*

	Faeces	**Urine**
Quantity (wet) per person per day	100 – 400 g	1.0 – 1.31 kg
Quantity (dry solids) per person per day	30 – 60 g	50 – 70 g
Moisture content	70 – 85 %	93 – 96 %
Approx. composition (dry weight percent)	**%**	**%**
organic matter	88 – 97	65 – 85
Nitrogen (as N)	5.0 – 7.0	15 - 19
Phosphorus (as P_2O_5)	3.0 – 5.4	2.5 – 5.0
Potassium (as K_2O)	1.0 – 2.5	3.0 – 4.5
Carbon (C)	44 - 55	11 - 17
Calcium (as CaO)	4.5	4.5 – 6.0
C/N ratio	~6 - 10	1
BOD5 content per person per day	15 – 20 g	10 g

* adapted from 1956 and 1983 studies of some European and USA cities.

Whilst the preceding data are all very useful for understanding the nature of the chemistry of interred remains, and can certainly be used for broadscale work in terms of elemental loadings of a cemetery, it must be remembered that it would be incorrect to slavishly apply any of the data to any one investigation or site. The nature of the human, their environmental associations and lifetime exposures to various chemicals will influence their composition, as will also gender, genetic and cultural matters. For example, the general anatomical or fluid-metabolic models basically relied upon here are not commonly used in human composition research (Heymsfield and Waki, 1991, Heymsfield and Yasumura, 1993).

Furthermore, in any attempt to explain cemetery loadings for any element or elements, the ratio of females to males, children to adults, and typical body weights of remains for cultural groupings also need to be considered. The data of Tables 2.2 to 2.4 also suggest that averages for some elements may be attended by wide variances.

Bacterial and Viral Components

The microfauna and flora of the human shows many similarities for worldwide populations; this is, for instance, why excreted bacteria are widely used for indicators of faecal pollution. There are in addition, indigenous variations and variations where disease and sickness occur. Most people also carry organisms which can be pathogenic in other persons or in different concentrations, or in the same person when the organism is not in its usual environment (Lewis-Jones and Winkler, 1991, Singleton, 1999). An individual if infected with an organism of the gastro-intestinal tract will then go on to secrete large amount of the organism in faeces.

Corry (1978) points out that "Almost all the organisms that have been isolated post-mortem have also been isolated from faeces or intestines". Furthermore, about 90% of these are anaerobes (like *Bacteriodes spp*., bifidobacteria, eubacteria; and lesser amounts of enterococci like *Lactobacillus, Streptococcus spp*.; and Enterobacteriaceae). Other groups often detected include: *Bacillus spp.,* yeasts, *Staphylococcus spp., Pseudomonas aeruginosa* and *Clostridium perfringens* (Corry, 1978).

The similarities are important in the present context because they indicate the organisms that are part of the remains after death; as well as some of the organisms involved in decomposition processes. The presence of organisms is usually assessed from faecal matter, and sewerage has been the most widespread medium thus examined, although Corry (1978) has assembled much useful data on post-mortem microbial populations.. Table 2.5 indicates the range of common organisms found. The information given is re-treated in Chapter Six to include environmental survival data for different organisms.

Table 2.5 Typical Bacterial and Viral Components of the Human

A. Bacteria (after Singleton, 1999)

Body Part	**Typical Inhabitant Genera**	**Body Part**	**Typical Inhabitant Genera**
Colon	*Bacteriodes* *Clostridium* *Escherichia* *Proteus*	Nasopharynx	*Streptococcus* *Haemophilus*
Ear	*Corynebacterium* *Mycobacterium* *Staphylococcus*	Skin	*Propionibacterium* *Staphylococcus*
Eye (conjunctiva)	*Staphylococcus* *Corynebacterium* *Propionibacterium*	Stomach	*Helicobacter pylori**
Mouth	*Actinomyces* *Bacteroides* *Streptococcus*	Urethra	*Acinetobacter* *Escherichia* *Staphylococcus*
Nasal passages	*Corynebacterium* *Staphylococcus*	Vagina	*Acinetobacter* *Corynebacterium* *Lactobacillus* *Staphylococcus*

* this species believed to be present in significant numbers of human population

B. Bacteria and Viruses from Sewerage (after Lewis-Jones and Winkler, 1991)

Bacteria	
excreted by a healthy person	Enterobacteria Enterococci *Clostridium perfringens (Cl. welchii)* (1) Faecal streptococci
bacterial genera found in faeces >40 pathogenic species have been isolated	*Brucella* *Campylobacter* *Clostridium* *Klebsiella* *Mycobacterium* *Pseudomonas* *Salmonella* *Shigella* *Staphylococcus* *Vibrio* *Yersinia*
Viruses	
common viruses in sewerage	Echovirus Enterovirus Hepatitis A Poliovirus Rotavirus

C. Summary of Organism Groups Isolated from Human Blood, Tissues and Lymph Nodes, Post-Mortem (after Corry, 1978)

Major Groups (studies 1934 – 1974)
Enterobacteriaceae (incl. *Escherichia coli*) Micrococcaceae Streptococci (excl. diplococcus) *Clostridia perfringens (welchii)* Yeasts Bacillus Bacteriodes
Presence in various lymph nodes (healthy individuals)
Streptococcus Enterobacteriaceae (*Escherichia, Aerobacter, Serratia, Proteus*) *Micrococcus/Staphylococcus*

D. Bacteria of the Healthy Intestine (after Corry, 1978)

Family	Genera Represented	Prominent Species	Other Species
Pseudomonadaceae	*Pseudomonas*		*P. aeruginosa, P. faecalis*
Enterobacteriaceae (1)	*Klebsiella* *Enterobacter* *Proteus*	*Escherichia coli*	*K. pneumoniae, E. aerogenes, P. mirabilis*
Bacteroidaceae	*Bacteriodes* *Fusobacterium*	*B. fragilis*	*B. capillosus, B. oralis,* *B. clostridiformis, B. putredin, B. coagulans, B. ruminicola, F. mortiferum, F. necrogenes, F. fusiforme, F. girans,*
Neisseriaceae	*Neisseria* *Veillonella*		*N. catarrhalis, V. parvula,* *A. alcalescens*
Micrococcaceae	*Staphylococcus* *Acidaminococcus* *Sarcina* *Peptococcus*		*S. albus, P. asaccharolyticus,* *S. ventriculi, A. fermentans*
Streptococcaceae (Enterococceae)	*Streptococcus*	*S. faecalis* (2)	*S. sangius, S. viridans (mitior), S. faecium*

Lactobacillaceae	*Lactobacillus Leptotrichia Bifidobacterium Ruminoccus Peptostreptococcus*	*L. acidophilus, B. adolecentis, B. longum, R. bromii*	*L. casei, L. catenaforme, L. fermentum, L. leichmanii, L. plantarum, Leptotrichia buccalis, Bif. bifidus, Bif. breve, Bif. cornutum, Bif. eriksonii, Bif. infantis, P. intermedius, P. productus*
Propionobacteriaceae	*Propionobacterium Eubacterium*	*E. aerofaciens*	*P. acnes, P. granulosum, Eu. contortum, Eu. cylinderoides, Eu. lentum, Eu. limpsum, Eu. rectale, Eu. tortuosum, Eu. ventriosum*
Corynebacteriaceae	*Corynebacterium*		*C. pseudodiptheriticum, C. xerosis, C. ulcerans*
Bacillaceae	*Bacillus Clostridium*	*Cl. perfringens (welchii)* (3), *Cl. paraputrificum*	*B. cereus, B. subtilis, Cl. cadaveris, Cl. innocuum, Cl. malenominatum, Cl. ramosum, Cl. sordellii, Cl. tertium, Cl. bifermentans, Cl. sporogenes, Cl. indolis, Cl. sphenoides, Cl. felsineum, Cl. difficile, Cl. oroticum*

(1) The Enterobacteria are mostly reported as Total Coliforms. However, Total Coliforms is comprised of E. coli (about 90%, Lewis-Jones and Winkler, 1991) and other non-faecal coliforms like; species of *Klebsiella, Citrobacter* and *Enterobacter aerogenes*.

(2) *Streptococcus faecalis* is now called *Enterococcus faecalis (Singleton, 1999*); other bacteria have also been reclassified in recent times.

(3) *Clostridia perfringens* is also called *Clostridia welchii.*

Availability of Oxygen

This Study has shown that the presence of the decomposition products - nitrite, nitrate, orthophosphate, ammonium, sulfide, sulfate and others, can be readily associated with the interred remains in both sandy and clayey soils (Chapter Five and Appendix L). However, these occurrences have also to be put into the context of the decomposition and in-grave processes; or the micro-cemetery function (see Chapter Six), in order that a fuller understanding can be had. To do this, in turn, requires an explanation of oxygen availability for those decomposition processes involved in protein, fat and carbohydrate reduction - the ones where oxidation by oxygen is most likely to occur if hydrolytic splitting of these substances has occurred during the autolytic process (Janssen, 1984).

Figure 2.2 illustrates a representative grave with comments regarding oxygen availability. The data for grave size are derived from a composite of representative sizes examined throughout the sites. These, like any of the details of the model can be manipulated by small degrees to skew the discussion but suffice here to illustrate the concepts. The percentage of available airspace in the coffin is nominal.

Because the usual physical procedures of interment require a hole to be excavated, the remains (encapsulated or not) emplaced, and then backfilling with site soils, there is a considerable disruption to the normal gas (and water) infiltration and diffusion pathways into the grave. At the commencement of the procedures the diffusion/infiltration is easy and unobstructed, excess of the atmosphere is present at the grave invert; however, as backfilling proceeds, air is progressively displaced and excluded by soil. The soil is, in the typical model, looser than that surrounding the grave (grave walls) even if wetted-down to increase its compaction, so that its effective porosity and permeability are both greater than equivalent undisturbed material.

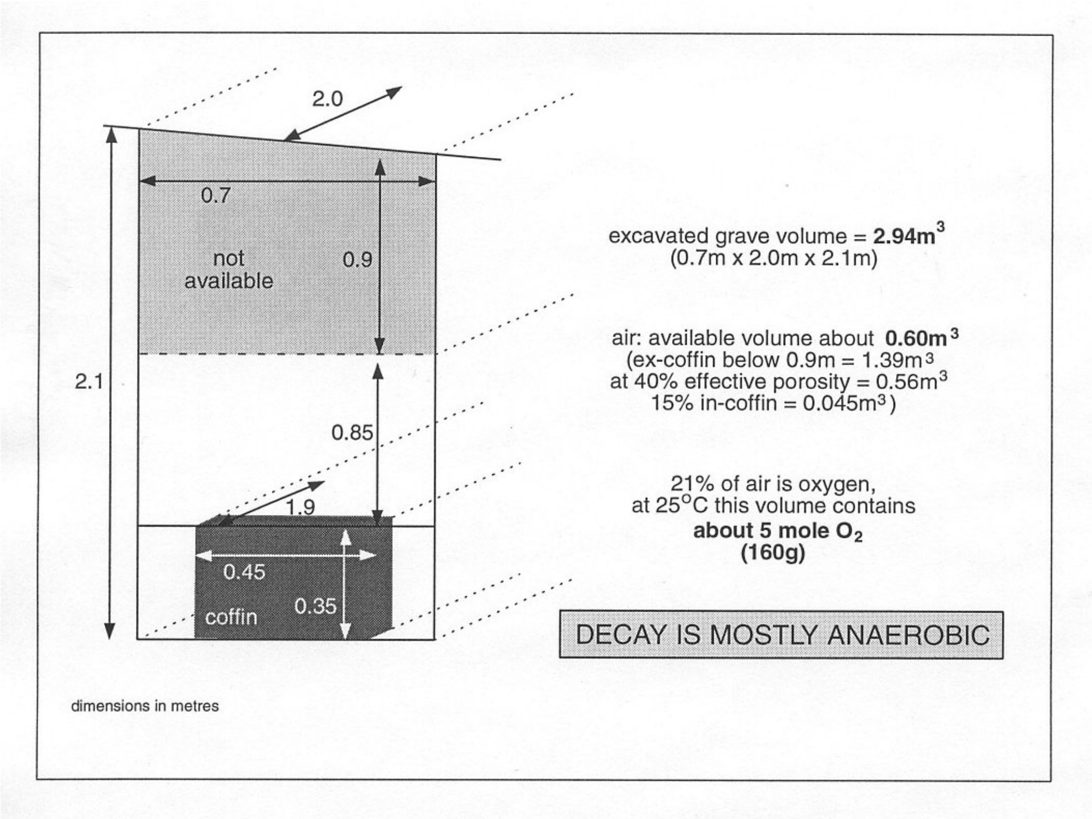


Figure 2.2. Oxygen Availability for In-grave Decomposition

Accordingly, excess oxygen (as 21% of air on average) is entrapped close to the coffin and certainly in the lower parts of the backfill. Closer to the grave's surface level the density of the soil fill increases: this is as a result of the physical presence of gravediggers completing the backfill or because of machine tamping (e.g. a backhoe bucket use to induce compaction by battering). In the latter case the machine is careful not to be directly in contact with the coffin. The density increase is certainly carried out by design. Therefore, in the model (Figure 2.2) the upper soil volume is considered to make little contribution of oxygen available for consumption in a short timeframe.

It could be expected that oxygen availability would be higher than that for the natural soil or for other graves where there is a relative equilibrium of compaction and finalisation of decomposition. However, the corollary to this is that when the interment is complete the soil compaction processes continue of their own accord and are aided by infiltrating rainfall and subsequent water percolation. Except for very special grave systems and vaults, it is most unusual for a grave's surface to be completely sealed over in a short timeframe. Whatismore, the gravediggers universally report that the coffin lid collapses inward very quickly - often at the time of backfilling.

The typical cemetery has heaped earth above recent graves to allow for these compaction processes which can last many years - this is widely seen in lawn burials (e.g at BOT, WOR, CEN, LAU) and has been observed at woodland burial sites in the UK. Ultimately a shallow depression (up to 0.3m has been observed) is created, and unless this is continuously maintained this depression becomes a collection centre for concentrating precipitation and runoff. With time, just as water can, oxygen can readily diffuse from these ponded areas through macropores or by other pathways if conditions are right; but the increased soil bulk density seems to generally work against oxygen diffusion.

In typical studies of the unsaturated zone, workers are usually little concerned with oxygen diffusion beyond one metre depth as it decreases rapidly, irrespective of soil porosity (Bouwer and Chaney, 1974, Domenico and Schwartz, 1990). Oxygen dissolved in groundwater itself is another source of the gas for decomposition reactions. It is, however, near impossible to determine how much of any percolating groundwater will directly contact the decomposing remains or to predict the aerobic state of any waters when they first reach such remains. Moreover, except for continuous rainfall from the commencement of interment, the grave soils are likely to be less than saturated or receiving copious percolation quickly. Whatismore, as depth of percolation increases the dissolved oxygen will be less and less inclined to leave its hydrated state; thus it will be more readily available for in-solution reactions and for reaction with soil particles at the edge of any water film or droplet. It is well known that dissolved oxygen influences the redox characteristics of shallow groundwater.

Calculations for the grave model suggest that only about 150 g – 200 g (about 5 mole) of oxygen gas is available for short timeframe, chemical decomposition processes, and any direct respiration needs of micro-organisms. Consequently it is clear that in-grave decomposition processes are mostly anaerobic after a very short period of time.

There is an important opposing effect to also consider. With time, and for variable amounts of time, decomposition gas products like carbon dioxide, methane, hydrogen sulfide, ammonia, cadaverine and putrescine diffuse upwards from the remains; preferentially in the looser soils of the grave volume. These gases will compete for space with oxygen diffusing downward with unknown effects; suffice to expect the blocking of downward diffusion and displacement of entrapped gases (e.g. air) upwards. Hodgson in 1997 commenced a study of in-grave gases at CEN but the studies were prematurely terminated. To this Researcher's knowledge there are no other relevant studies concerning this phenomenon.

DECOMPOSITION PRODUCTS OF PROTEIN

After death, proteins are broken down by the action of enzymes via a process known as proteolysis (Evans, 1963). This process does not occur at a uniform rate and hence some proteins are destroyed in the early stages of decomposition while others are destroyed in the later stages. The proteins of the neuronal and epithelial tissues are usually the first to be destroyed, including the lining membrane of the gastro-intestinal tract whilst those which are more resistant to decomposition include epidermis, reticulin, collagen and muscle protein.

Keratin, an insoluble fibrous protein found in skin and hair is resistant to attack by most proteolytic enzymes. The integrity of this substance - which is the reason that hair remains amongst skeletonised remains for a long time - is due to the disulfide bonds between its component cystine molecules. Its destruction is eventually aided by physical or microbial damage; *Strepomyces spp*. bacteria enhance this decomposition (Gray and Williams, 1971).

The rate at which proteolysis proceeds depends largely on moisture, temperature and bacterial action. In general terms the proteins break down into proteoses, peptones, polypeptides and amino acids. Continuing proteolysis leads to the production of phenolic substances (eg. skatole and indole) and the evolution of gases such as carbon dioxide, hydrogen sulphide, ammonia and methane (Evans, 1963), Figure 2.3. The common proteolytic bacteria genera are: *Pseudomonas, Bacillus* and *Micrococcus* (Higgins and Burns, 1975).

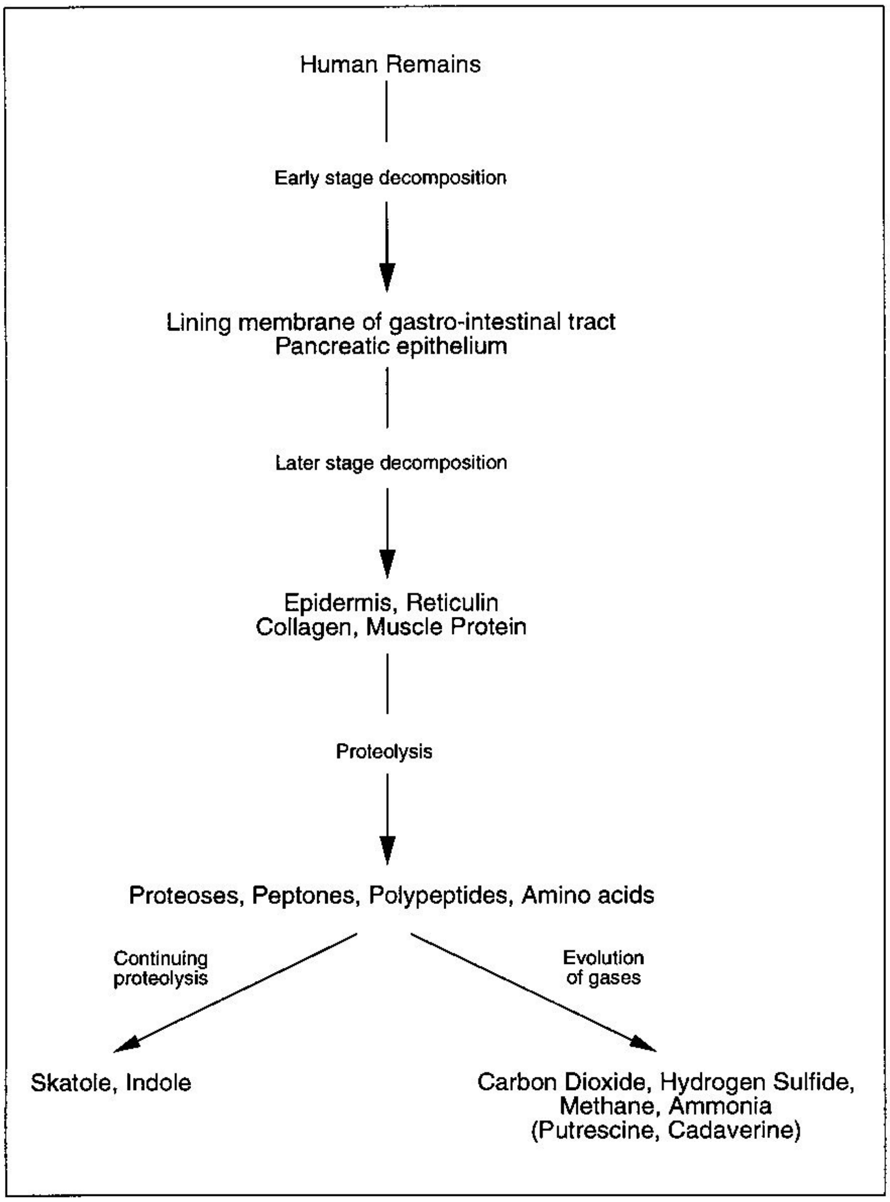


Figure 2.3 Changes to Protein During Decomposition

The constituent amino acids can undergo deamination, decarboxylation and desulfhydralation (Gill-King, 1997). For example, the deamination of L-phenylalanine yields phenylpyruvic acid and ammonia. Phenylpyruvic acid combines with ferric iron from the soil or circulatory tissues to form a greenish complex often identified on the skin of the entire body. The same coloured fluid is frequently observed in necro-leachate as it seeps through walls of adjacent graves.

Two prominent decarboxylation products include the gases putrescine and cadaverine. Both are highly toxic with a foul odour (part of a well-known group of diamines) and together with hydrogen sulfide and methane, are usually present in soils where bodies may be decomposing.

The decomposition processes result in the production of a range of organic acids and other substances that become bacterial metabolites. These are generally of low or moderate molecular weight, anionic or non-ionic, and are susceptible to rapid breakdown by bacteria (Santoro and Stotzky, 1967). These compounds may produce several effects that might be observable in cemetery vadose zones or watertable aquifers; including alterations of pH or providing a nutrient source for bacteria along groundwater pathways. In addition they may have an effect on altering electrokinetic potentials of clays so that bacteria are assisted in being adsorbed to them (Santoro and Stotzky, 1967). This latter idea has not been developed significantly in the literature, wherein bacteria to clay adsorption is mostly explained in terms of the nature of the charged surfaces of the clay itself or of the bacteria. These matters are considered further in Chapter Six.

The sulfur containing amino acids of the proteins, for example the essential Methionine (Hart and Schuetz, 1966), undergo desulfhydralation and decomposition by the action of bacteria to yield hydrogen sulfide gas, sulfides, ammonia, thiols (see below ^**)** and pyruvic acid. In the presence of iron, hydrogen sulfide will produce the familiar black precipitate, ferrous sulfide, often associated with decomposing remains. The anaerobic conditions of the grave favour sulfide production in considerable quantities (Waksman and Starkey, 1931).

^ Thiols or mercaptans are decomposition gases containing the –SH (sulfhydryl group). They are notable for their disagreeable odour. They are acidic and form insoluble solutions with heavy metals, for example mercury. Many thiols form from aromatic molecules and are often eventually converted to disulphides (Hart and Schuetz, 1966, Alexander, 1999). The term 'mercaptans', although common in discussions of landfills, is very infrequently used in the context of cemeteries.

Under anaerobic conditions, the sulfide is not transformed further. However, under aerobic conditions it soon disappears and is oxidised to elementary sulfur and then rapidly to sulfate through a series of steps producing sulphurous acids which are variously detectable in groundwater. This process is in common with standard chemical weathering of sediments. Various specific bacteria, mainly belong to the *Thiobacillus* group, are also capable of bringing about these processes in the soil.

The nitrogen of proteins is present as amino acids. The amino acids are readily used by most of the soil microbes as a source of energy. The nitrogen, however, is liberated by chemical reactions as ammonia. The ammonia produced may in turn be used by higher plants or various microbes, may be converted to nitrate, may accumulate in the soil or move through the groundwater system (Waksman and Starkey, 1931).

In the presence of low soil pH, ammonia (NH_3) is converted to ammonium ($NH_3 + H^+ \rightarrow NH_4^+$) which is readily utilised by plants. Under alkaline conditions, part of the ammonium entering the soil may revert to ammonia and undergo volatilisation ($NH_4^+ \rightarrow NH_3$). Furthermore, ammonium may become incorporated into microbial tissue, thus re-entering living organisms.

Alternatively, ammonium not intercepted through one of the above mechanisms can undergo nitrification and denitrification. Nitrification can occur directly (by light) or during the metabolism of some heterotrophs (Gray and Williams, 1971), but is more usually accomplished by various species of soil organisms that convert ammonia to nitrate. Two autotrophic bacteria are the most important: the first oxidises ammonia to nitrite (*Nitrosomonas spp*.), and the second transforms nitrite to nitrate (*Nitrobacter spp*.) (Waksman and Starkey, 1931). None of the bacteria belonging to either group is capable of transforming ammonia directly to nitrate; each is confined to merely one stage of the reaction. There are also other, less widely known, nitrifying bacteria - *Nitrosococcus spp*., *Nitrosocystis spp*., and *Nitrospir spp*. (Gray and Williams, 1971) whose roles are not fully established.

The conditions suitable for the formation of nitrite and nitrate by nitrifying bacteria (ie. nitrification) include an inorganic medium containing salts of ammonia, aerobic conditions and a neutral reaction. The nitrifying organisms, however, unlike the denitrifiers are very sensitive to environmental pH. *Nitrobacter spp*. prefer a pH between 5 and 8, whilst *Nitrosomas* specie*s* have optimum conditions at pH 7 to 9. In the right medium, transformation of ammonia gives rise to nitrite, and once a large part of the ammonia has disappeared, nitrate is then formed. Nitrification normally occurs above the water table in the soil zone where organic matter and oxygen are abundant; the reactions are inhibited by high pH or added lime, and stop altogether at pH less than 5 (Gray and Williams, 1971, Higgins and Burns, 1975, Bolt and Bruggenwert, 1978).

Denitrification refers to the reduction of nitrate to nitrite, gaseous nitrogen or nitrous oxide. The conditions necessary for denitrification (ammonification) to occur include a prevalence of nitrate, an energy source and anaerobic conditions. The organisms known to be denitrifiers include *Achromobacter spp., Bacillus spp., Micrococcus spp*. and *Pseudomonas spp*. (Bolt and Bruggenwert, 1978) but not *Pseudomonas aeruginosa*. This last bacterium is important as a waterborne pathogen and is further considered later.

The remaining ammonium that does not undergo any of the above processes, will be displaced through the soil subject to several types of adsorption and fixation processes. These processes include regular cation exchange, intra-lattice fixation and direct adsorption by organic matter. In this way, ammonium may leach to deeper layers and eventually reach the groundwater.

When nitrifying bacteria or organisms capable of oxidising ammonia are absent, the ammonia will accumulate in the soil.

Many kinds of anaerobic bacteria are able to split off ammonia from amino acids thus producing large amounts of ammonia in oxygen deficient areas. Furthermore, while ammonia can be oxidised to nitrate under aerobic conditions, nitrification is completely inhibited under anaerobic conditions, causing a greater accumulation of ammonia in anaerobic environments than where there is freer access of oxygen. Denitrification is inhibited in the presence of oxygen. Waterlogged soils experience the highest denitrification rates.

In cemetery groundwaters it would be expected that ammonium concentration decreases with distance from graves, or as groundwater moves from newer to older interment areas. Conversely, nitrite and more particularly nitrate, should increase in these circumstances. In clayey soils ammonia would be expected to denitrify to nitrogen gas and nitrous oxide accompanied by higher amounts of ammonium and low nitrate concentrations: suggesting that lower total nitrogen would be observed compared to the situation in more permeable soils.

Phosphorus is another important element that is conveniently considered here. In the body the phosphorus store is found in a number of components: in proteins comprising nucleic acids and coenzymes; in sugar phosphate; and in phospholipids (fats) of the brain and spinal cord. As phosphorus is liberated during putrefaction it does not follow simple pathways nor does it remain in elemental form.

The mobility of phosphorus is far from simple. Phosphorus leaching in its oxidised forms - orthophosphates, appears to be tightly controlled by slight soil acidity within the range pH 6 – 7, yet these forms are the most thermodynamically stable and hence most mobile (Hem, 1989). Above pH 7 and certainly below pH 5 the phosphorus is locked up into insoluble components (Cook and Heizer, 1965, Reimann and Caritat, 1998). In most soils, the phosphorus is likely to exist as insoluble inorganic complexes, probably associated with iron, calcium, magnesium and aluminium (Higgins and Burns, 1975); this is especially likely for grave soils. Consequently little leached phosphorus is expected in cemetery groundwaters in a general sense, but it will be very dependent on the hydrogeological context. The situation may be complicated by addition of lawn and garden fertilizers containing phosphates.

Soil micro-organisms also play a role in phosphorus transformations from insoluble organic complexes to soluble ones and its release from mineral forms as well as its incorporation in new protoplasm. "A great many microbes (*Pseudomonas, Mycobacterium, Micrococcus, Flavobacterium, Penicillium, Aspergillus* and others) have the ability to solubilize inorganic phosphorus compounds" (Higgins and Burns, 1975). The common process of adsorption of phosphorus by metal oxides – notably those of iron and manganese, might also imply that any released phosphorus may be continuously recycled within parts of some cemeteries with suitable environments; and/or there may be a net migration off-site. This is further considered in Chapter Five.

Phosphorus derived from body decomposition has had an interesting association with evidence of burial. This is the phenomenon of burial silhouettes/pseudomorphs wherein the former body is outlined with a dark stain/deposits at the level of interment. It has been suggested that in sandy and gravelly, acidic conditions that the organic phosphorus complexes further attract soil metals, notably manganese, in order to make the dark stains. The phenomenon is still not fully explained but has been well considered for inhumations at Sutton Hoo, UK (Bethell and Carver, 1987). Interestingly, the phenomenon has also been noted in a tropical setting – Tonga (Spennemann and Franke, 1994), but the chemistry was incompletely considered in this example.

DECOMPOSITION PRODUCTS OF FAT

The body's adipose tissue typically comprises, by weight, 5-30% water, 2-3%

proteins and 60-85% lipids (fats), of which 90-99% are triglycerides (Reynold and Cahill, 1965). Triglycerides are composed of one glycerol molecule attached to three fatty acid molecules. Of the numerous fatty acids that may be attached, monounsaturated oleic acid is the most widespread in adipose tissue followed by linoleic, palmitoleic, (both unsaturated) and palmitic (saturated) acids.

The neutral fat of decomposing remains can undergo hydrolysis to yield fatty acids which may subsequently undergo either hydrogenation or oxidation. Neutral fat is hydrolysed by intrinsic tissue lipases shortly after death to produce a mixture of saturated and unsaturated fatty acids. Hydrogenation of oleic, linoleic and palmitoleic acids yields stearic, oleic and palmitic acids respectively. More extensive hydrolysis and hydrogenation increases the mixture of saturated fatty acids while decreasing the relative amount of unsaturated fatty acids (Evans, 1963). Hydroxy-fatty acids may also be formed at this stage in small amounts (Figure 2.4).

Providing there are sufficient water and enzymes available the process will continue until no neutral fat remains and the original adipose tissue is reduced to a mass of fatty acids. These fatty acids can react with sodium and potassium ions present in tissue fluids at neutral or slightly alkaline intracellular pH to form salts of fatty acids. Once the body is deposited in a grave the sodium and potassium may be displaced by calcium or magnesium ions present in the soil (Gill-King, 1997). The result is the formation of water insoluble soaps of the saturated fatty acids that are known to comprise adipocere.

The fatty acids can also undergo oxidation by the action of bacteria, fungi and atmospheric oxygen. Oxidation occurs under aerobic conditions and the exposure of fatty tissues to visible and ultraviolet light will accelerate their breakdown. If the neutral fat has been hydrolysed to produce a large concentration of unsaturated fatty acids, oxidation of these fatty acids can thus result in the production of aldehydes and ketones (Evans, 1963).

Within a closed coffin, oxidative changes are less likely than hydrolytic changes because the human remains are being continuously exposed to the reducing conditions. These conditions will slow and eventually halt the oxidative process. If the burial conditions keep the oxygen levels low then the fat degradation products will remain as adipocere (Mant, 1987, Henderson, 1987). The intrinsic bacterium - *Clostridium perfringens (welchii),* which derives from the intestine produces a powerful enzyme which significantly aids the anaerobic hydrolysis and hydrogenation of the fat under warm conditions (Corry, 1978, Polson et al., 1985).

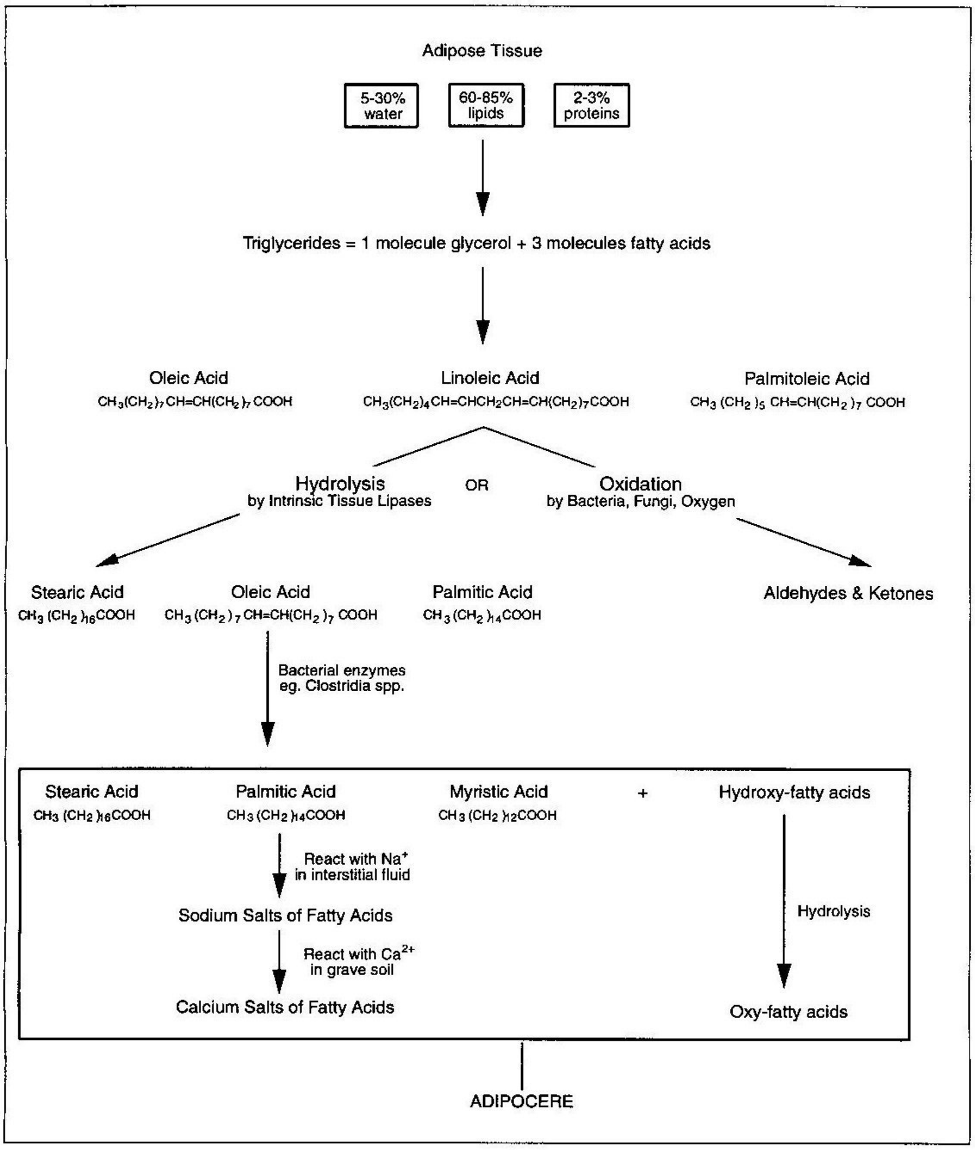


Figure 2.4 Changes to Fat During Decomposition

Both hydrolytic and oxidative processes generated by various fungi and bacteria will continue to decompose the adipose tissue in the soil. The glycerol and fatty acids breakdown giving shorter-chain saturated fatty acids and eventually carbon dioxide and water. However, little is known about which specific micro-organisms bring about lipid breakdown in soil (Gray and Williams, 1971, Cabriol et al., 1998). In the Brazilian cemetery studies (see Chapter Three) the presence of significant numbers, but unspecified types of lipolytic bacteria (possibly *Clostridia spp*.?) was reported for the groundwaters examined (Martins et al., 1991); these were said to be directly related to the decomposition of the interred remains.

The bacterium - *Clostridium perfringens* has been widely implicated as a major agent for anaerobic decomposition of cadavers because it is a resident of the human intestine and has strong saccharolytic, proteolytic and lipolytic capabilities as well as being able to grow at a relatively high Eh (Corry, 1978). Whilst it is doubtlessly important, its reproduction and activity is very limited to favourable environmental - mainly warm temperature, conditions. The optimum conditions are 15°C to 45°C (Corry, 1978); whatismore, *Cl. perfringens* is a common inhabitant of soils (Lewis-Jones and Winkler, 1991, WHO, 1993) so that its participation in decomposition may in fact derive from the surroundings as well. The Clostridium genus is a ubiquitous inhabitant of soils (Haagsma, 1991). The *Cl. perfringens* bacterium is discussed in later Chapters in the context of a bacteriological indicator in groundwater.

DECOMPOSITION PRODUCTS OF CARBOHYDRATE

The carbohydrates in the soft tissues also break down during the decomposition process (Evans, 1963). For example glycogen, a complex polysaccharide, will break down into sugars (glucose monomers) by the action of micro-organisms. This destruction occurs in the early stages of decomposition and is evidenced largely in the liver. Some of the sugars are completely oxidised to carbon dioxide and water while some are incompletely decomposed for example by *Clostridia spp*. to form a number of various organic acids and alcohols.

Fungi decompose the sugars to form organic acids including glucuronic acid, citric acid and oxalic acid (Waksman and Starkey, 1931). Bacteria decompose sugars in a different manner to fungi and the resulting end products are determined principally by the presence or absence of free oxygen in the organisms' environments.

Under anaerobic conditions lactic acid, butyric acid and acetic acid are produced as well as alcohols including ethyl and butyl alcohol, as well as acetone. In the presence of oxygen, the glucose monomer is broken down through the pyruvic acid, lactic acid and acetaldehyde stages to form carbon dioxide and water (Waksman and Starkey, 1931). Other gases produced through bacterial carbohydrate fermentation include methane, hydrogen and hydrogen sulfide, Figure 2.5.

The comprehensive understanding of organic decomposition products of the cemetery needs to also take into account natural processes. A number of studies of rocks and soils report native carbohydrate components. In the case of soils, carbohydrates as polysaccharides generated by microbial action to decompose vegetative material are found in the deeper subsoils. Whereas in the upper soil horizons monosaccharides predominate and can comprise from 9 – 24% of the total organic carbon fraction (Folsom et al., 1974). In the cemetery situation, where there is a mixing of soils as a consequence of grave excavation and refilling processes, some small variation to the carbohydrate loading could be induced. This is then likely to be further decomposed anaerobically.

In another study, Whitelaw and Edwards (1980) reported the presence of natural carbohydrates in the chalks of England. The implications of this work also have a minor consequence for the understanding of cemetery processes because their results indicated that the natural carbohydrate content affected pore-water nitrate concentrations in the unsaturated zone. That is, the mere presence of carbohydrate in the grave environment (natural and interred), and its support for nitrate-reducing and ammonia-oxidising bacteria, is likely to lead to the alteration of forms of inorganic nitrogen leaving the gravesite. Most probably there will be an additional loss as nitrogen gas, thus influencing any stoichiometric calculation of nitrogenous oxides or ammonia groundwater products.

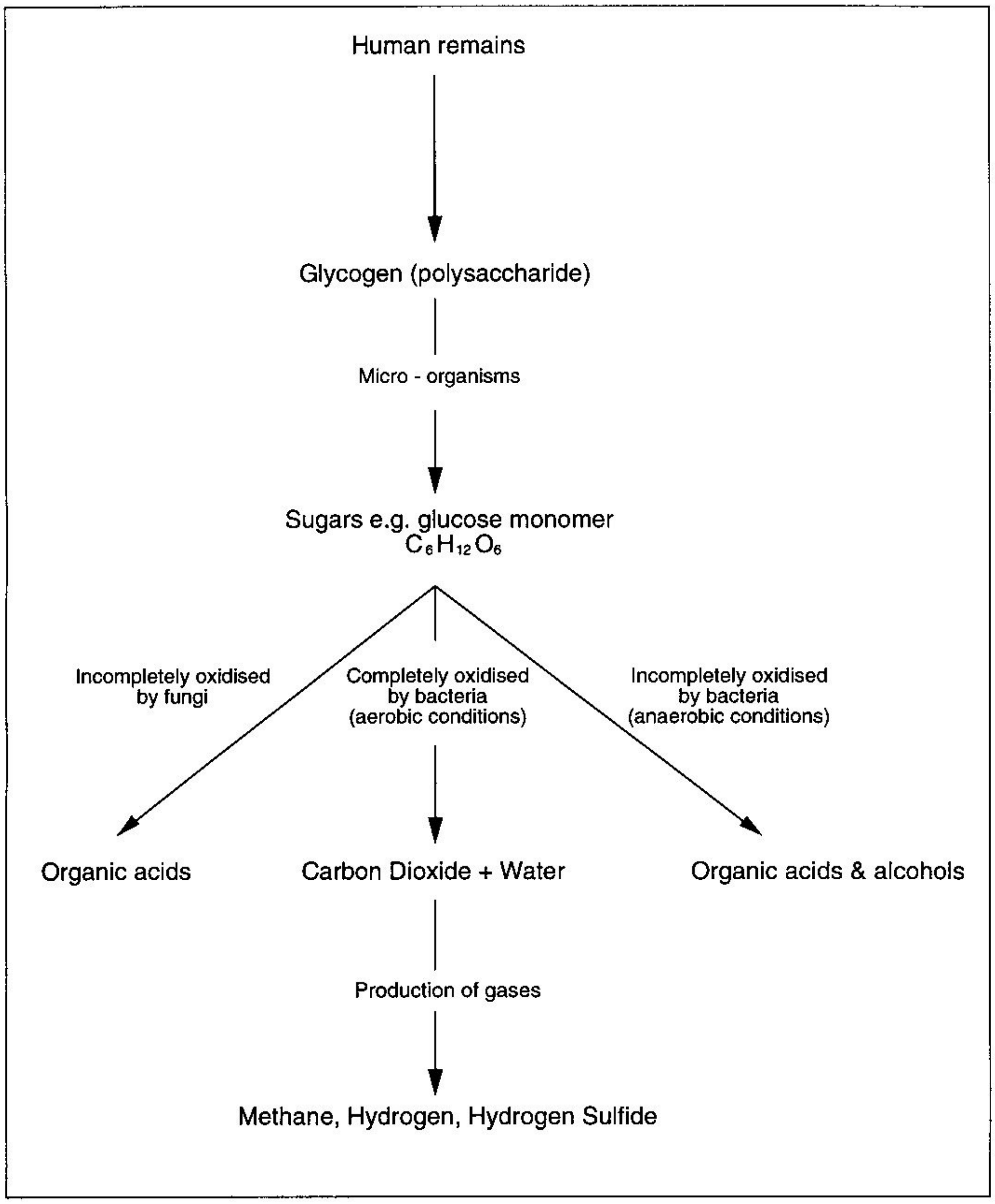


Figure 2.5 Changes to Carbohydrate During Decomposition

LIQUEFACTION

The body's tissues and organs soften during decomposition and degenerate to a mass of unrecognisable tissue that under continued decomposition becomes liquefied. This liquefaction is aided by the breakdown of proteins to simpler units thus allowing a greater range of micro-organisms to grow on the substrate and to subsequently be dispersed throughout the tissues. Discoloured natural liquids and liquefying tissues are made frothy by the gases forming within the decomposing remains. Some of these liquefaction products may exude from the natural orifices, forced out by the increasing pressure of the gases (Janaway, 1997) (see below*).

In the case of a body buried directly in the soil, a mucus sheath will form around the corpse consisting of liquid body decomposition products and the 'fines' soil fraction (Janaway, 1997). Coffin burials, on the other hand, often produce a semi-fluid mass consisting of water and putrefied tissue with a powerful ammoniacal odour. This mass is only retained in sealed coffins (see below**).

Ultimately, liquefaction and disintegration of the soft tissues leaves behind skeletonised remains. At this stage the skeletonised body will be held together by ligaments and surrounded by a putrescent or liquefying mass. Eventually the liquefaction products will be washed down by percolating water and enter surrounding soil and groundwater systems.

* Much folklore surrounds the occurrence of gaseous decomposition products and their effects on coffins - mostly concerning explosive disintegration of the coffins at sometime during their storage. The issue is discussed in detail by Lewis (1851) and also reported on by Evans (1963), Polson et al. (1985) and Wilkins (1992). The occurrence of any such phenomenon is rare, and only in a few cases has gaseous bulging been detected or gas composition measured.

** The recordings of various researchers who have studied mass exhumations of sealed coffins, mostly in the UK, report on occasions that these coffins contain soft tissue and liquor; but the reports are infrequent. It appears that "sealed" coffins are eventually breached by either mechanical stresses during storage or chemical reactions from within or without (Lewis, 1851, Mant, 1987, Polson et al., 1985, Janaway, 1993). Consequently it is more common to find skeletonised remains with extensive adipocere formation; often burial and funereal artefacts and textiles are quite intact (Janaway, 1993).

DECOMPOSITION PRODUCTS OF BONE

Skeletonisation refers to the removal of soft tissue from bone. The process is considered ‘complete’ if all soft tissue is removed and ‘partial’ if only portions of the bone are exposed. Under appropriate conditions, a partially skeletonised body can proceed to complete skeletonisation.

The rate at which skeletonisation proceeds depends on depth of burial, soil type and surrounding environment (Mann et al., 1989, Clark et al., 1997). For example, a body buried in a warm environment may skeletonize as quickly as an exposed body in a mild environment. The arresting effects of a cold or dry burial environment on decomposition are well known and documented (Polson et al., 1985, Janaway, 1997), so that in some instances skeletonisation can take a very long time. This matter is consequential for the future of cemeteries in today's cold and/or dry climatic zones: when climate changes occur the ground condition will vary and decomposition rates will increase. These phenomena will be attended by release of decomposition products.

Skin, muscle and internal organs are generally lost to the environment well before a skeleton becomes disarticulated. Bone is broken down over time by physical breaking, decalcification, and dissolution due to acidic soil or water. Bodies which are not buried in tombs or coffins may disappear completely, or under the right conditions may become fossilised and preserved for tens of thousands of years (Clark et al., 1997, Galloway, 1997).

Bone is a composite tissue and is composed of three main fractions: a protein fraction consisting mainly of collagen which acts as a supportive scaffold; a mineral component consisting of hydroxyapatite to stiffen the protein structure; and a ground substance of other organic compounds such as mucopolysaccharides and glycoproteins (Hare, 1976, Goffer, 1980, Janaway, 1997). The collagen and hydroxyapatite are strongly held together by a protein-mineral bond that gives bone its strength and contributes to its preservation.

The organic collagen phase of bone is eliminated predominantly by the action of bacterial collagenases by reducing the proteins to peptides, which in turn break down to their constituent amino acids and leach away in groundwater. Collagen degradation is also thought to be affected by the activity of the *Clostridia* bacteria that operate in a pH range of 7-8 (Janaway, 1997).

Following elimination of the collagen phase, the loss of mineral hydroxyapatite proceeds by inorganic mineral weathering. The calcium ions in the apatite crystal migrate into the soil solution when they are replaced by protons at low pH. Not only is there removal of proteins and minerals but also substitution, infiltration and adsorption of ions which serve to undermine the protein-mineral bond leaving the bone susceptible to internal and external reactions.

Bone preservation in all manner of physical condition is dependent on the burial environment. Bone excavated from aerobic, non-acidic environments often appears to be in good condition but demonstrates surface coarsening in fine sands and further cracking may occur upon drying. In calcareous sand or loam where it is damp and there is more oxygen present, the bone surface will be rougher and may crack, warp or laminate upon drying. Bone buried in coarse calcareous gravels will lose large amounts of collagen and have the consistency of powdery chalk, while bone from acidic peat deposits is pliable and will harden on drying. Acidic soils are the most destructive as they work by dissolving the inorganic matrix of hydroxyapatite which produces an organic material susceptible to leaching by water (Goffer, 1980, Henderson, 1987).

In general, bone preservation is best in soils with a neutral or slightly alkaline pH, and is worst in acid conditions. Dry sand assists preservation because of reduced bacterial action yet elsewhere sandy and permeable soils assist decomposition because of the free exchange of water and gases (Hare, 1976, Janaway, 1987).

During life, the body's bones accumulate trace amounts of non-primary elements - notably strontium and fluorine (Tables 2.2 and 2.3) so that these are available to be released during the later chemical weathering of decomposition. But bone serves another important role in archaeology and possibly in the management of cemeteries (see Chapter Seven). Bone has an unexplained attraction for many metals and selected other elements form the soil and groundwater.

DECOMPOSITION PRODUCTS OF OTHER RELEVANT SUBSTANCES

In the burial environment there are other important substances present that will, during their own decompositonal pathway to primordial elements, ultimately mix with the decomposition products of the remains themselves. Thus they need to be given some expression since they will influence the composition of cemetery groundwaters.

Coffins made of wood are comprised of cellulose, hemicellulose, lignin, starch, paints, lacquers and metal or plastic ornamentation and fittings.

The corrosion of any metals or metal oxides in or on coffins and remains may release the element, oxides, organic or hydrated forms, directly to groundwater pathways: this is very dependent on the subsurface environment and the volume of interred metals. This Study has sought a comprehensive set of base metal analytes in the groundwater analyses (Appendix L) and these are discussed in Chapter Five. Very particular attention was also given to the search for mercury that was presumed to derive form dental amalgam; this is also discussed in later Chapters.

Cellulose is hydrolysed by a complex set of enzymes (called cellulase) that are possessed by a variety of fungi, actinomycetes and bacteria including species of *Bacillus, Pseudomonas*, and *Clostridia*. If the decompositional environment is aerobic the breakdown will lead to glucose and carbon dioxide: if anaerobic, the end products will be organic acids and alcohols. Other environmental factors will also have effects; for example, increased pH say due to the addition or presence of lime will slow the bacterial action, whereas phosphate addition will increase this rate

(Gray and Williams, 1971). Filamentous fungi and yeasts are likely to play the greatest roles in cellulose decomposition where present (Lee, 1980); their possible absence with increasing burial depth, and maybe together with the degree of moisture present, might explain observations of variable coffin breakdown rates. Also important, and initially investigated for cellulose in landfills, is the physical association between lignin and cellulose (Stinson, 1993), which for the cemetery context probably reflects the type of coffin wood.

Hemicelluloses occur in the thickened walls of cells in plant stems, roots, leaves and seeds. The main types - pectin and xylans; are decomposed by bacterial species of *Cellulomonas, Cellvibrio, Clostridia, Pseudomonas* and *Bacillus* genera and others. A related compound – lignin, is even slower to decompose - about three times as slow as cellulose: its decomposition is mostly achieved by fungi, although species of *Pseudomonas* and the actinomycetes can also achieve this. The decomposition of lignin releases phenols and tannins which can be toxic or repellent to some soil organisms (Lee, 1980). This might be another significant influence on total rates of coffin decomposition in some cemetery settings and explain apparently retarded rates – as reported by cemetery staff: as such, these are matters which represent an area of future research.

A very small additional source of plant tissues occurs as undigested food waste within the remains themselves. Studies of sewerage effluents which specifically examined these materials, have shown that lignin is a particularly resistant and prevalent waste product. Lignin can contribute less than 10% of the total weight of young plants (and hence their food products) but it can be from 20% to 40% by weight of mature woods (as in coffins) (Higgins and Burns, 1975).

Starches typically undergo a two-fold breakdown, firstly to dextrins and then to simpler compounds (Gray and Williams, 1971). The end products are variants of those for cellulose, i.e. simpler organic compounds that will ultimately breakdown to water and carbon dioxide.

The organic acids that are derived as well as carbonic acid - from the in-ground dissolution of some carbon dioxide, are available for reactions along any in-soil or groundwater pathways that present themselves. These are, however, relatively weak acids (low K_a) so that their effects, for example on minerals or tissues, are influenced by their intrinsic nature as well as that of the soil or grave environment. Doubtlessly, organic acids are a part of the measured pH for cemetery groundwaters.

Under aerobic conditions the organic acids are weakly persistent compared to anaerobic conditions where they may persist for some time (Waksman and Starkey, 1931). Waksman and Starkey (1931) report a German study that showed that simple organic acids have a significantly increased dissolving power for various phosphate minerals (cf. bone) compared to carbonic acid. Such occurrences are likely to be part of the reason why bone is attacked in cemeteries.

The nature of paints and lacquers used to finish coffins, and plastic ornamentation and fittings, has not been investigated for this Study. It is known that these materials contain mixtures of various organic compounds, fillers like clay minerals and silica, and colourants like titanium oxide. It was assumed that there is some commercial variation in these products, just like there would be with metal coffin fittings and fastenings, and coffin linings of plastics and textiles. Generally speaking, the ultimate fate of complex organic molecules is to end up as water and carbon dioxide through a set of intermediate steps driven by enzyme- and equilibrium-activated reactions. These are accompanied by the release of special compounds e.g. chlorine or organochlorides say in the case of PVC (polyvinyl chloride) plastic linings. All of these products are free to move in the cemetery environment. On the other hand, relatively inert materials like clay minerals, silica and various metal oxides will mostly be incorporated into the soil substrate.

In the funereal artefacts e.g. the clothing or paper products, the presence of detergents with boron or phosphate loadings, or bleaching agents like chlorine, for instance, may also be significant. The list of variants could be quite extensive, but on balance the total amount is relatively small compared to the amounts of the remains themselves or the coffin materials. They are all part of the "black box" products.

The case for the future study of organic decomposition products relating to the remains and all these other substances can easily be made out. A particular effort could be made in respect of PVC and other plastics' breakdown. However, this was generally well beyond the scope and resources of the current Study. It is certainly considered desirable in relation to this group of compounds, but in other respects it is considered that such knowledge would not be consequential on a satisfactory understanding of cemetery operations' effects or groundwaters.

CREMATED REMAINS

Sometimes cremated remains are interred or scattered in cemeteries. Typically they will be buried in a garden or entombed in a purposeful vault whilst contained in an urn. However, many sets of remains are also scattered in memorial gardens or other designated areas. Where very large concentrations of cremation ashes exist there is the possibility of a metallic geochemical anomaly being created: the data on human body composition suggest that cremated remains may be rich in metals within a calcium and phosphate base.

Only **two** chemical analyses of cremated remains are known to the Researcher and are reproduced in Table 2.6. The origins of the samples, the ethics and the details of their collection are unknown. The first was analysed in 1951 by Hehner & Cox, consulting analysts and chemists of London. The second sample was analysed in 2001 in the USA by TEI Analytical Inc., from the cremated remains of an 84 year old male (Douthit, 2001).

The results are reported in differing determinand forms, as various combinations in weight %. The USA results are reported with an error of +/- 10%. For ease of comparison the results have been converted to the elemental form, and some assumptions made about the form of the analysis.

The results differ considerably in the key determinands; Ca, P, Na, K, S, Mg, Cl, Fe. They vary non-uniformly from 1.15 times for Mg to 12.9 times for Fe. From the data and collection information there is no way to explain these differences. They may relate to contamination, for example by coffin materials or residues in the cremators, or may be due to differences in the age, sex and lifetimes of the deceased. The composition of cremated remains is a matter in need of urgent, dedicated investigation; it has a particular relationship to the role of these remains when scattered (in large numbers) within the hydrologic cycle.

A related aspect is the examination of effects due to any residue radiological isotopes. A discussion paper from the Cremation Association of North America (2001) has examined the risk posed by ^{89}Sr and concluded that it is extremely low. In the case of remains that are scattered this is likely to diminish the effects; whilst those interred are likely to have only very short periods of very low level radioactivity. The North American report makes use of a study for the National Radiological Protection Board of the UK (Cooper, et al., 1989); which although it states that it is difficult to make the necessary calculations, arrives at the conclusion that there is negligible risk in almost all likely cremation-related situations.

The primary effects of cremation ashes within the cemeteries' soils are in the enhancement of element movement in: stormwaters moving over scattered remains, for example on gardens and lawns; groundwaters percolating through open/decaying urns, ash pits from crematoria, or buried uncontained ashes. These effects are likely to vary for dispersed ash disposals (scattering) to possibly being inseparable from other cemetery concentrations when the ashes have been interred in large quantities. It is, however, considered more likely that concentrations of ashes form geochemical anomalies in the vadose zone. This is thought to be significant for crematoria ashpits. The investigation of this aspect was initially considered for this Study but later abandoned because of the difficulties occasioned by diverting resources to this matter and ethical problems associated with the analysis of cremation ashes.

Table 2.6 – Analysis of Cremated Remains

(with conversion to elemental forms)

Compound (1, 2) **UK**(upper) **USA** (lower or only)	**weight %** **UK 1951 (3)** **(5)**	**weight %** **USA 2001 (4)** **(5)**
calcium oxide (CaO) calcium	28.90 (20.66)	 25.3
phosphoric acid (P_2O_5) phosphate **(6)**	27.48 (5.999 P)	 47.5 (10.37 P)
potassium oxide (K_2O) potassium	14.83 (6.16)	 3.69
sodium oxide (Na_2O) sodium	6.50 (2.41)	 1.12
acid insoluble matter silica	5.56	 0.9
loss on ignition	4.78	
carbon dioxide (CO_2)	4.45 (1.21)	
sulphate (SO_3) *sic.* sulfate **(7)**	2.26 (0.906 S)	 11.0 (4.41 S)
iron (Fe_2O_3) iron oxide	1.52 (0.532)	 0.118 (0.0413) **(8)**
chloride (as NaCl) chloride	1.17 (0.710)	 1.00
magnesium oxide (MgO) magnesium	0.80 (0.48)	 0.418
aluminium oxide		0.72 (0.19)
zinc		0.34
titanium oxide		0.0260 (0.0156)
barium **(9)**		0.0066
antimony		0.0035
chromium		0.0018
copper		0.0017
manganese		0.0013
lead		0.0008
tin		0.0005
vanadium		0.0002
beryllium		<0.0001
mercury		<0.00001

Notes to Table 2.6

(1) The compound names and forms have been retained in the manner in which they were provided to the Researcher.

(2) Other qualitative determinations were made for the UK sample and showed the presence of: boron, aluminium, copper, lithium, manganese, silicon, zinc, and trace amounts of arsenic, lead and strontium.
(3) Reproduced with the permission of the Cremation Society of Great Britain (Arber pers. comm., 2001).
(4) Analysis as re-reported in Pharos International (Douthit, 2001).
(5) The value in brackets is the conversion of the analysed form to the elemental form which permits better comparison.
(6) Phosphate is the oxidised form of phosphorus (P) – assumed to be the pent-oxide.
(7) Sulfate is the oxidised form of sulfur (S) – assumed to be the tri-oxide.
(8) The iron is assumed to be fully oxidised to the Fe III state.
(9) Barium was reported in a high level: apparently the deceased had undergone radioactive barium X-ray imaging two years prior to death.

*

CHAPTER THREE

REVIEW OF WORLD CEMETERY KNOWLEDGE

Contents

Were There Ill-effects? An Analysis of USA Court Cases (Table M1)
Embalming Problems and Soil Issues
Cemeteries in the Community

OVERVIEW

Scientific research regarding the relationships of cemeteries or crematoria to the physical environment has not been a popular pursuit. Since 1994 and the Researcher's original work (Dent, 1995) he has scoured electronic databases and cross-referenced articles from journal and newsletter reports for any published information regarding the broader aspects of this Study. E-mail and other contact has been made with present-day and previously active, like-interested researchers around the World:- in Brazil – Pacheco, Matos and Silva; in South Africa – Croukamp; in UK – Trick, Mitchell, Young; in USA – Campbell. In the same timespan tens of enquiries have been fielded from academics, government regulators – in numerous countries, and students in Greece, Portugal, the UK and USA; parts of investigations and theses have been reviewed for Students – D. Harden (Aberdeen University, 2000) and M. Lemma (University of Reading, 2001) in the UK.

A diligent effort has been made: to uncover relevant sources of printed information or studies, and, to discuss the Researcher's and other's investigations and understandings with industry practitioners. The outcomes of these endeavours have been a relatively small collection of investigative reports and journal papers, and the knowledge that the topic area generally is completely under-explored, under-reported and little understood - worldwide. Some of the publicly available material is extremely difficult to procure, especially the earliest articles from Germany. The papers and documents have been written in a number of languages – German, Dutch, Portuguese, Spanish – and these have been translated into English where possible.

The experience from the UK through contact with Trick (pers. comm., 2000), Mitchell (pers. comm., 2000) and Jessett (pers. comm., 2001) and the report by WRc (2000) has suggested that there may easily be some relevant material held in government archives for example, departments of health; but at the same time none of these are likely to be comprehensive investigative reports. Many newspaper articles and reports are useful providers of information related to cemetery or burial practices and effects in/on the community.

The initial focus of reported studies was the health danger posed by decomposing bodies – such as "exploding coffins" in UK crypts (see Lewis, 1851) and likely injurious effects on groundwater supplies for example in Germany (there is a reference cited in Keller, 1966 to an investigation in Berlin since 1903). The significant amount of litigation from the USA regarding groundwater pollution (Appendix M) is another fruitful source dating from the 1860s. For the sake of completeness, a record is also made herein of negative search results of published legal case records concerning groundwater and cemeteries in other jurisdictions. In contrast to the USA the relevant litigation records are 'blank' for other countries where it was possible to readily review the information.

More broadly focused work has derived from Germany (see Schraps, 1971), The Netherlands (see van Haaren, 1951) and Brazil (see Pacheco et al., 1990). In more recent times, other published work has focused on archaeological aspects of burials from an historical, histopathological, sociological, dietary or a pollution (for example lead content of bones) perspective; or disease aspects causing deaths in populations; or cemeteries' affects in society today as open places, flora reserves or parks, records of history, or as sites for disease vectors (insects); or gross pollution as in respect of arsenic in soils and groundwater due to American Civil War embalming practices.

In the following discussion, the known work and relevant findings are presented in the context of the country of origin. The work presented is not exhaustive of all published documents, but it does capture all the principal works related to this Study and many other peripheral matters related to the role of cemeteries and crematoria in society, or their management and operational aspects. For example, under 'Australia' can be found a short list of early cemetery site investigations: it is likely that a great many of these kinds of reports exist Worldwide in government archives and consultants' files, and with investigations predicated on generalized geological concepts like:- deep soils which are easily excavated and are then stable after excavation in the short-term, reasonable drainage, no elevated watertables.

Another issue which can be pursued quite widely in international literature is that of the relevance and correctness of chemical studies of bone; see the text by Behrensmeyer and Hill (1976) for an introductory overview of these matters.

ARGENTINA

There have been several studies of cemeteries being sources of disease spreading vectors. Primarily this relates to the favourable breeding conditions of mosquitoes in stagnant vases' and other receptacles' water. Understandably, the situation seems to be most prevalent in warmer, more humid areas. What is unclear is whether the decomposing remains themselves are a source of the diseases carried by these vectors or whether the spread is from other community sources. To be related to the former implies that there are very lax hygienic conditions, as well as management and operational difficulties within the cemeteries.

Vezzani et al. (2001) report a study of over 22000 water receptacles in 5 Buenos Aires' cemeteries, wherein *Aedes (Stegomyia) aegypti (L.)*, a vector of yellow and dengue fevers, was found in 5.55% of cases. However, their results cannot be positively correlated with the cemeteries acting as the foci for the proliferation and spread of the vector or whether they are merely a favourable location for the vector's development.

The Researcher has been contacted by Mr Rúben Torrente (pers. comm., 2001) regarding a number of technical details for a new cemetery development in Buenos Aires. The site lies in very gently sloping, unconsolidated, silty-sandy alluvium with a watertable between 1.6 and 2.2 m. Advice was sought as to how this site might be acceptably developed with respect to groundwater influences and so that it would comply with the requirements of the prevailing code of the Sanitary Works Department: this code requires a 1 m separation of the watertable from the grave invert level.

AUSTRALIA

New proposals for cemeteries in Australia are handled at local government level and subject to a considerably variable range of legislative requirements. In South Australia for instance, interments can be for as little as 50 years (since 1949) by default in the legislation which prescribes a period of exclusive licence to be buried. Prior to this the time was 100 years. In the area of control of the Metropolitan Cemeteries Board, Perth, Western Australia, the possibility of 25 year licences for graves was introduced in the mid 1990s. Otherwise, burials are usually – i*n perpetuity* – with a non-revocable licence to be buried been conferred on the grave's purchaser.

It is not intended in this Study to review local legislative requirements, except where they are relevant to the research results. In the case of South Australia they are relevant because of the economic pressures on the cemetery trusts for continued effective operation of some cemeteries. The Enfield General Cemetery Trust first employed the concept of "lift and deepen" for large-scale re-use of grave space when it took control of an abandoned, full, near-city cemetery at Cheltenham (HEL) from the late 1980s (see Appendix I). In the "lift and deepen" process {which seems to have been first applied at Centennial Park Cemetery (CEN) (Crowden, 1986, Nicol, 1986)}, the grave site is carefully re-opened and any remnant remains are gathered-up, placed in an ossuary bag or box, and re-buried beneath the new proposed invert level of the grave – at about 2.2 m; funereal artifacts are generally included, but remnant coffin materials are discarded. New interments then proceed in the reclaimed space. Since HEL had over 121 years of interments and an assemblage of 'new' ones it was an ideal candidate for this Research.

This Study thus represents the first known evaluation of such a practice and preliminary findings have been presented in Knight and Dent, 1998. The issues of grave re-use in Australia generally have been under consideration for some time (see for example Department of Lands, 1989), however, the arguments have lacked a scientific underpinning which can state whether the practice would be hygienically and environmentally acceptable; this is discussed further in Chapter Seven.

The previous work by the Researcher (Dent, 1995) is the first scientific study of the relationship of a cemetery to its environment, in terms of decomposition products and groundwaters, in Australia. However, it not the first geoscientific evaluation of a proposed cemetery site. Some relevant reports have been uncovered in the annals of various State Departments of Mines (or equivalent); they principally relate to finding new sites with suitably deep soils (to 2m), effective drainage and acceptably positioned above any permanent watertables.

The following list is not necessarily exhaustive for Australia: those known include:

- For NSW: Pogson and Chestnut, 1968
- For Victoria: Esplan, 1959, Dahlhaus, 1984, Neilson 1986 and 1988;
- For Tasmania: Leaman, 1971a, 1971b and 1974, Moore, 1973, Cromer, 1975 and Moore, 1980.

In 1995 a consulting company – Woodward-Clyde, undertook an extensive desktop study of groundwater contamination issues with respect to the operation of the Rookwood Necropolis, NSW (Woodward-Clyde, 1995). This cemetery is the largest in the Southern Hemisphere at 314.4 ha (Weston, 1989); its land is flat to shallowly sloping and the relatively deep, residual soils comprise clays and sandy clays over shale/laminite bedrock. There are likely to be perched aquifers at the soil/rock interface. The study concluded that the likelihood of contamination from the cemetery was very low; that bacterial and viral contamination would diminish in 3 – 5 m, and any groundwater contamination would mainly comprise nitrate (Woodward-Clyde, 1995).

Pate (1989) undertook a geochemical study of postmortem changes of Australian Aboriginal bone from an indigenous burial site in South Australia. This study was interesting because of the relatively uncomplicated chemistry of the host interment soils – being siliceous dune sand. The conclusions made were that the evaluation of palaeo-societal aspects from the analysis of bone is considerably complicated and needs to be approached cautiously.

At UTS, studies of adipocere have been proceeding since 1999. In Australia it is difficult to obtain such human material for examination, however, it has been made available to the Researcher from forensic specimens and been found in soil materials reclaimed from “lift and deepen” processes at CEN. The studies have been initially concentrated on characterization of the substance and its identification in soils (see Stuart et al., 2000) but are now proceeding to further delineate the factors of its formation. This latter work by Forbes is likely to help resolve some of the difficulties so far encountered in the management of this intermediate decomposition product.

In 1999, MacGregor from the University of Queensland concluded research of pig decomposition products in soils. The setting for the fieldwork was alluvial and residual soils in the Brisbane area (sub-tropical climate). MacGregor's results do not appear to have been publicly released.

A review of relevant legal case records for Australia and its States (via AUSTLII, 2001, and other sources) did not yield any results of interest in this context.

BOSNIA

As a result of the civil war in Sarajevo a critical shortage of cemetery space occurred, to the point where bodies were being buried in town parks and neighbourhood playgrounds (Shenon, 1996). This newspaper report also contains a note of foreboding by a local medical representative that potential problems with water supply contamination and disease spread occur when too many corpses are buried in one hole, or are buried less than six feet (1.8 m) depth, or at high density, or uncoffinated, or near water supplies. Although such reporting serves to highlight a degree of ignorance relevant to decomposition processes and the need for a coffin, it also serves to highlight the need for orderly public management of cemeteries and their correct siting in relation to ground- and surface- water supplies.

BRAZIL

Other than the Dutch, the most intense relevant research has been conducted by Brazilians – Pacheco, Matos and others. The Brazilians have had an interest in in-grave decomposition processes because of the frequent appearance of adipocere in their interred remains, and because of the pressure on grave space in major cities. In larger cities like São Paulo where graves are re-used at 3 – 5 year intervals, the previous remains when recovered are frequently well converted to adipocere; this is a function of wetter climate, shallow burials (0.8 m measured by the Researcher) and likely soil and site drainage aspects.

Pacheco et al. (1991) carried out a study focussed on microbiological aspects; they examined 67 samples of the groundwaters in three cemeteries in the São Paulo area. Their paper is one of the mostly widely cited works regarding the effect of cemeteries on groundwaters. Their central claim is that cemeteries which are improperly managed, or which are not located according to sound geoscientific principles, are a potential threat to groundwater. The original study with its multitude of authors lead to a number of further reports; those that are available, emphasize different aspects of the work, were mostly published locally and written in Portuguese, and include:- Pacheco (1986), Mendes et al. (1989), and Martins et al. (1991).

Since that time Pacheco (pers. comm., 2000) has continued to advise on and consider decay processes in cemeteries (see Pacheco and Bastello, 2000), the occurrence and difficulties presented by the amount of adipocere encountered, and, the role of soil type in the selection of cemetery sites and their processes. He has also supervised a PhD student – Bolivar Matos, who studied soil/groundwater/microbiological relationships in one of the originally studied cemeteries (Cemitério Vila Nova Cachoeirinha). This further work has lead to at least the following publications;- Bastianon et al. (2000), Matos and Pacheco (2000) and a website developed by Matos (1999 – 2001).

Pacheco's Work

In August 2000 the Researcher had the opportunity to visit Brazil where he met with Pacheco and Matos, discussed their current research interests and, over two days, visited the three cemeteries originally studied. At two of these (Vila Nova Cachoeirinha and Areia Branco), the Researcher observed remnants of the original piezometers from this 1989 study. The visits to Cemeteries Vila Formosa and Aeria Branca were quite rushed but allowed for a better understanding of their geographical and likely hydrogeological settings.

The published works (Pacheco et al., 1991 and others) raise important issues for consideration particularly relating to the integrity of groundwater supplies. However, from a purely scientific perspective they all have a quantifiable degree of inadequacy in terms of methodology, rigour and conclusions that gives a considerable degree of concern. **The Brazilian results are at odds with data and conclusions from all other studies, Worldwide.**

Their data is specifically targeted at microbiological parameters and the specific analytes determined were: Total coliforms, Faecal coliforms, Faecal streptococci, *Clostridia spp.,* proteolytic bacteria, aerobic and anaerobic heterotrophic bacteria, salmonella and lipolytic bacteria. The measurement of proteolytic and lipolytic bacteria (specifically related to tissue decomposition) is the only known study of such organisms in this context. Their detection in considerable numbers likely indicated the presence of decomposition products in the sampled waters.

Some measurements of nitrate levels were also made (Martins et al., 1991); they apparently ranged from 0.004 – 75.70 mg/L and were found in all but Cemetery Vila Formosa sampling points, but are not otherwise presented. Another difficulty with the nitrate measurements is that they appear to have been misinterpreted in terms of whether NO_3 or NO_3-N is considered.

The primary issues concerning evaluation of the work relate to:

(1) the failure to specify background levels of measured parameters so that the results can be interpreted in context;

(2) inadequate explanation of sampling technique including installation of piezometers; precautions for maintaining bacteriological integrity;
(3) the disposition of sampling sites to interments, and, dates and sequencing of samples;
(4) the description of the sites and an understanding of the hydrogeological settings.

An investigation of the matter of background values suggests that these were not properly formulated. Although sampling of a piezometer in the most elevated part of the Cemetery Vila Nova Cachorinha occurred, this point is still well within the influence of interments. Other sampling points distant from interments were used but suffer the same consequences. For a complete understanding, the "normal" state of the groundwaters is required. Both Pacheco, and later Matos, experienced the same difficulties that this Researcher found in determining backgrounds for sampling in highly developed sites without the benefit of external sampling points.

There is no discussion of the technique used to ensure the integrity of bacteriological samples between sampling points, or successive samplings. The piezometers, which appear to have been 65 mm o.d., may or may not have been purged. They were sampled with disinfected bailers but how this was done, how the bailers were handled, and all relevant protocols, except for the testing methodologies are unknown.

Matos (pers. comm., 2000) pointed out that a topographically high, natural, drainage system – a stream called "Côrrego", associated with the eastern part of the Cemetery Vila Nova Cachorinha, had until sometime about 1998 been an open sewer and stormwater drain for slum dwellers on the fringe of that cemetery. In addition, Matos (2000) suggests a direct hydraulic connection (beneath and across the cemetery) between this stream and a river (Rio Cabuçu de Baixo) which is located topographically below and east of the cemetery. This hydraulic connection may not exist in such deeply weathered granitic landscape, and the distances between slum dwellings, stream and original sampling points is considerable; however, if true, then this is likely to have been an inestimable influence upon the original data obtained by Pacheco et al. (1991). If the link and relationships are not true, then in any case, this has a bearing on the general surface sanitary conditions of the cemetery and may have been an influence on sampling techniques for the reported study.

The sampling points were initially chosen on the basis of geophysical investigations, principally electromagnetic surveying, which was completed with the aim of detecting "salty" seepage or soils that might at least have the possibility of reflecting the presence of necro-leachate. Although such techniques seem to have been thoroughly applied the relevant background studies necessary to make the required judgements are never reported. In some cases the geophysical work was completed in parts of the cemetery not subsequently sampled and hence used to 'reflect' or 'transmit' relevant properties to the sampling locations. The geophysical work was substantially relied upon to determine the underlying geology.

When the published works are considered as a whole it is difficult to formulate an exact picture of the hydrogeological nature of the sites, especially Cemetery Vila Nova Cachorinha. The subsurface of this latter site is variously described as unconsolidated heterogeneous sediments and residual clay soils over weathered, possibly faulted, granite. It also seems apparent that numerous perched watertables occur in that site and that there are a number of shallow, probably ephemeral, groundwater systems (with short travel distances and emerging at springs) present. The Cemetery Aeria Branca is founded on an infilled embayment hosting fluvio-marine sediments and clearly with a high, probably tidally-influenced watertable (the area is generally surrounded by estuary). The Cemetery Vila Formosa hosts a significant, natural drainage system along its central axis and evidenced a number of wet areas when visited by the Researcher; this is likely to have some effect on groundwater systems and their interpretation. Subsurface investigations (Mendes et al., 1989) also detected perched watertables at this cemetery.

Matos' Work

Matos' principal investigations were in connection with his PhD thesis (2001). At this time Matos' data has not been published and the following is reported from personal discussion between him and the Researcher during the latter's visit to Brazil in 2000, as well as consideration of the paper by Matos and Pacheco (2000) and some review of the data (Matos, 2001). His main objectives were the quantification of bacterial and viral transport inactivation and adsorption rates, their modeling, and the relationship of this data to the percolation of necro-leachate. He established a series of 13 piezometers (50 mm PVC) in the lowermost part of Cemetery Vila Nova Cachorinha where he intersected both permanent and perched watertables. A portion of this part of the cemetery was too wet for burials all year round. He sampled the groundwaters on six occasions for bacterial parameters and four times for inorganic parameters, and used the site soils for laboratory column experiments to study retardation rates of bacteria and viruses. The soils were chemically and physically characterized and found to contain at least 40% clay, which was mainly kaolinitic, with little variation at the general sampling location except for some peaty layers which had a high CEC.

Additional work in the field included, further geophysical investigations of potential sampling sites, slug tests (withdraw style interpreted by Horslev's methods), and three tracer tests to determine groundwater velocity. K was determined at about 1E-7 to 1E-6 m/sec, and groundwater velocity at about 2 – 3 cm/day (although only one of the three tracer tests worked). A mostly permanent watertable was found at about 4 m, however, some ephemeral, perched watertables were also tapped. A correlation was detected between rainfall events and watertable replenishment. Some interred remains are apparently in frequent contact with these watertables.

Two piezometers were established within the cemetery in a nearby grove of eucalypt trees. These were used to provide some indication of background groundwaters in that their locations were hopefully little influenced by interments. The groundwater from these piezometers typically showed pH about 5.5 and EC <=100 µS/cm, whereas the main site's groundwater typically had pH >6 and EC >= 400 µS/cm.

Bacterial sampling was conducted with separate acrylic bailers for each sample. These were disinfected prior to use with 70% alcohol solution. Each piezometer was bailed for 2 – 3 volumes before sampling; the piezometer top was also disinfected before sampling. Some disinfection control samples were run – they were found to contain heterotrophic bacteria in small quantities (10 – 20 CFU/100 mL). Some 5 L samples were obtained for measurement of viruses, however there was no particular additional protocol used for this sampling.

The virus sampling occurred on 3 occasions over a period of 5 months. On the first (October) and last (March) samplings, Matos detected respectively ardenovirus and then enterovirus in each of two piezometers, the same ones on each occasion, located within interment areas in widely separated parts of the cemetery. However a third sampling point slightly downgradient of one always showed no detections (Matos, 2001).

In the bacterial sampling program, Matos collected 56 samples from a total of 16 piezometers: many piezometers were sampled 5 times (including one generally used for 'background' values), one 8 times. The analytes tested for each water sample (224 tests) were; heterotrophic bacteria generally, Total Coliforms, Faecal Coliforms, proteolytic bacteria generally, and sulfur reducing *Clostridia spp.*. The results are very variable, but heterotrophic bacteria, proteolytic bacteria, Total Coliforms and *Clostridia spp.* were always present, except for 1 sample of proteolytic and 1 sample of Total Coliforms where the results were below the detection limits. In 8 piezometers, representing 33 tests, Faecal coliforms were not detected (Matos, 2001).

The presence of Faecal coliforms and proteolytic bacteria in some of the piezometers probably indicates that decomposition products are present in the groundwater systems.

A comprehensive range of inorganic analytes and trace metals was also determined. A time change in chemistry was found such that in summer it appeared that the dissolved salt content was diluted. In general the groundwater was found to be Al and Fe rich. These results are consistent with shallow recharge from summer rains and the weathering of granites. São Paulo receives abundant summer rainfall (October to March) and about 1420 mm of rain per annum (Encyclopædia Britannica, 1998).

Others

In March 2000 a Brazilian cemetery - Cemitério Parque São Pedro, in Curitiba attained ISO 14001 certification (Vanzo, pers. comm., 2001). The principles underlying this attainment, which is being heralded as a world first, included the need to ensure that necro-leachate was not discharged directly to nearby rivers. The work undertaken in the cemetery development stressed the need for proper geoscientific evaluation of cemetery sites and their operations. Complete details of the site are not available, but the following information has been obtained from a worldwide media release, personal communication (Vanzo and Silva, 2001) and other sources (Encyclopædia Britannica, 1998).

Curitiba is in the State of Paraná, about 325 km southwest of São Paulo. It is a city of about 2.5 million people and enjoys a temperate climate with a dry summer. The existing cemeteries in the city were old and often regarded as inappropriately located from a geoscientific perspective, with likely contamination of groundwater in places where bodies have been buried in contact, with at least ephemeral, perched watertables. At the cemetery mentioned these soils are clayey with low permeability. Interments, which are always coffinated, are up to three per grave, to 3 m depth. The municipal law requires that remains be exhumed after 3 – 5 years. The whole site of about 120000 m^2 is drained by subsoil drainage which leads to a collection tank wherein leachate undergoes active biological activation and filtration before being discharged.

The geoscientific work for the Cemitério Parque São Pedro was carried out under the direction of Professor Silva from the university of São Judas Tadeu. Silva (pers. comm., 2001) claims to have carried out many evaluations of potential and existing cemetery sites and developed systems for “decontamination of the underground of cemeteries”. The Researcher has not yet had the benefit of reviewing this work, and none is known to be published in international literature.

CANADA

Two studies that are commonly referred to in the Industry and literature arose from concerns about formaldehyde (methanal) (derived from embalming) in groundwaters and soils in Canada. The first was by Soo Chan et al. (1992) of the Ontario Ministry of Environment, who investigated chemical and bacteriological parameters in six drinking water wells downgradient of cemeteries. They included possible chemical load modelling for formaldehyde and nitrate-nitrogen, but found no attributable evidence of contamination. The matter of formaldehyde is further considered in the following discussion on the USA. This study was one of the few that has recognized the variable nature of decomposition processes within cemeteries.

The second study was by Beak Consultants (1992) and investigated similar aspects in one large (200 acre (81 ha)) and older (about 120 years) cemetery in Toronto, however, a suite of environmentally harmful metals and other elements was also included. The cemetery soils are comprised of fine sands and silts hosting a watertable at about 12 – 13 m, except for probable perched watertables at about 3 – 5 m (however, these were not identified in the study). For the most part the testing of soils and groundwater yielded no results of concern, or which could be convincingly linked to cemetery decomposition products.

In a completely different pursuit, Carlson (1993) studied the lead content of bones from a 19th Century cemetery in Alberta. Her conclusions showed the measurable affinity of human bone for environmental lead.

A review of relevant legal case records for Canada and its Provinces (Lexis-Nexis, 1999, CanLII, 2001, and other sources) did not yield any results of interest in this context.

EUROPEAN UNION

> "Target 23: Waste Management And Soil Pollution
> *By the year 2000, public health risks caused by solid and hazardous wastes and soil pollution should be effectively controlled in all Member States.*

> Most existing cemeteries were sited without thought being given to potential risks to the local environment or local community. The impact of degradation products from seepage waters from cemeteries has only been studied by a few researchers."

(from the Introduction and Abstract, WHO, 1998)

The quotations above indicate the first comprehensive review of cemetery operations and impacts in the European Union; it drew heavily on the Researcher's findings. Although this was a preliminary study it contains several significant recommendations which will serve to guide Member States in future cemetery locations. These include:-

- graves to have a minimum 1 m of soil below invert level and above solid rock;
- graves should be at least 250 m (more in certain hydrogeological circumstances) from any well, borehole or spring used for a potable water supply;
- graves should not lie closer than 30 m to any spring or watercourse;
- graves should lie at least 10 m away from any subsoil drain;
- the invert level of any grave must be at least 1 m above any level to which a watertable may be found or rise to;

(WHO, 1998).

The report goes on to suggest that there are a number of other matters relating to funereal materials, micro-organisms of decomposition, hydrogeological settings, and the relationship of cemeteries to disease outbreaks, which also need to be studied.

On another matter – cremation products in the air – the European Union has also taken a strong stand. It was reported that on average in Europe a cremated body yields 4 g of mercury in cremation gases (Copeland, pers. comm. 2000); this is more than the usual figure used for the body content of mercury – see Chapter Two. The application of new regulations to limit these discharges will have major impacts on the economic operations of many crematoria and is becoming a significant political issue (Copeland, pers. comm. 2000).

FRANCE

In France in mid 2000 there were just 5 crematoria, however this was expected to grow to 85 in 2001 as a continued trend to cremation in Europe generally became more apparent (Vidallet, pers. comm. 2000). A special significance can be attached to this kind of data because it focuses the need to apply environmental standards to the operations and products of crematoria. In many countries, for example, Australia and the European Union, such standards are in effect. As far as this Researcher can tell however, there has been little thought given to, and no investigation of the effects of, ash pits which are used for the bulk disposal of cremated residues collected from cremators and their flues.

GERMANY

German research represents the earliest known, systematic study of cemetery processes. The Germans have made limited investigations of the inorganic and bacterial nature of decomposition products, the movement of these products into municipal drinking water and aquifers, and particularly - the suitability of various soils for interments. Probably the first systematic collection and analysis of relevant samples was made by Matthes (1903) for the Ohlsdorf Cemetery in Hamburg for the period 1888 – 1901.

Keller (1966) and Schraps (1971) both report that a study of the chemical and bacterial composition of water from a well within the Ohlsdorf Cemetery has been conducted, but their reportage is incomplete. Additional information may have been reported at least up until 1928 – there are 3 references cited: apparently there have been no adverse contamination aspects recorded (Keller, 1966, Schraps, 1971). The soils in the cemetery are described as alternating layers of clay and fine sands; however no other details of the well can be found.

The chemistry in the original reference (Matthes, 1903) is a little difficult to interpret, and the identification of the "germs" (Kleim) reported on is unclear. Certainly TDS, COD, nitrate (nitrous acid), ammonia (-ium?) and chlorine (-ide?) were examined as well as other oxidizing reactions and many measurements of germs. Eight wells were regularly sampled, about once per year, between 1883 and 1901; presumably these were shallow drinking water or irrigation wells. The wells seem to be located in all the major sections of the cemetery, and the market garden/nursery (?meaning unclear), and one just outside the cemetery. Later-on, 7 subsoil drains were also sparsely sampled. From 1893 to 1901 the germ analyte was determined; a result is usually reported and the overall range is 0 (once) to 1117 per cubic centimetre; for the drains 0 (once) to 1820 per cubic centimetre. A limited amount of rainfall data is reported but there does not appear to be any correspondence of germ values to rainfall events.

Braun (1952) from the Institute for Hygiene of the Westphalian State University, Münster, conducted an investigation to establish the likelihood of cemetery decomposition products migrating to a municipal drinking well located in unconsolidated floodplain deposits overlying karstic limestone. A reasonable hydrogeological investigation showed that the well was recharged from the karst with a possible minor connection to the nearby river. It was concluded that, despite the nearby presence of the cemetery which occupies an area of about 8000 m^2 and at its closest point is 150 m from the waterworks, there is no hydraulic connection to the drinking water source and that "germs" from the cemetery can't contaminate. It was further pointed out that the "practical conditions can not be judged schematically" (Braun, 1952) and that the cemetery's location must be interpreted in its hydrogeological context. The soils investigation in the cemetery showed that the graves were underlain by about 1m of clayey loam.

Molleweide (1983) produced a theoretical re-evaluation of Braun's (1952) work and in doing so used the soil classification system of Schraps (1972) which seems to be supported as a solution for the location of cemeteries.

Keller (1966) approached the idea of cemetery location from the perspective of considering soil textures and the ability of the soils to promote "dry decomposition". Keller's findings were that a sandy soil with particle sizes between 0.2 and 2.00 mm diameter represented an optimum; this soil permits ready water and gas percolation with little likelihood of perched watertables and is usually sufficiently self-supporting to permit grave excavation. The considerations here also addressed topographic location relative to permanent watertables, drainage, and the separation distance between grave invert level ("sole") and watertables.

At the time of writing, Keller (1966) pointed out that cemetery location or extension was still effectively controlled by Prussian guidelines dating from 20.01.1892, but that the principles embodied in those guidelines demanding proper evaluation of the soils were sound. Keller also considered the concept of protection areas for municipal drinking wells. On this issue it was stated that the location of a cemetery within a well's protection area depends upon an effective groundwater travel time of 60 –80 days in all directions. Furthermore, it was concluded that a separation of 0.5 – 1.0 m from watertables below grave invert ("sole") was sufficient to provide filtration of decomposition products for the preferred soil type, and as little as 0.4 m in clay-silt soils (Keller, 1966). There are difficulties with such considerations based just on size, however, as they ignore too many other factors about decomposition, cemetery operations and percolation of bacteria and viruses.

Schraps (1971 and 1972) explores the texture and composition of soils and their ability to work as filter media in the context of cemeteries. Schraps argues that proper geoscientific evaluation of proposed cemetery sites is required to prevent the spread of disease and contamination of water supplies. Schraps (1971) sets out the likely performance characteristics of different soil types in respect of permeability and decomposition processes, although at the same time pointing out that these processes are themselves not fully understood. The time for complete decomposition of remains is cited as 10 years in well aerated sandy soils, and up to 50 years in clay soils with high water retention and minimal aeration.

In Schraps (1972) the filtration effects of soils and groundwater composition in cemeteries is further explored. It is proposed that different soils require minimal separation distances below grave inverts and watertables: 70 cm (as required in government regulations) in sandy loam substrates is considered sufficient but not so in gravels and sands, where the situation is considered more difficult to evaluate. In any case, land with a permanent or perched watertable at a depth shallower than 2.5 m is considered unsuitable for normal burials (using a 1.8 m interment depth as a guide). Attention is also drawn to unsatisfactory interment in contact with porous rock: karstic limestone was of particular concern.

Schraps (1972) reports an examination of seepage water into a drainage ditch within a cemetery in the Oberbergische region. The soils are reported as up to 2 m of loess overlying a gravelly/cobbley clayey soil above limestone. After pumping out, the drainage ditch collected seeping groundwater which was then sampled at different down-gradient distances from the last nearby row of graves. The ages of the interments and many other relevant descriptors of the site are not given; however, the waters were found to initially contain ammonia (to 6.0 mg/L), nitrate (to 4.8 mg/L) and oxidisable dissolved carbon (to 26.88 mg/L), after which they became more diluted along the drain. The results also included measurements of "germ" colonies, which also decreased with distance; but apart form these "germs' not being coliform types, no other details on identification or technique are given.

Schrap's (1972) work is reported in Bouwer's (1978) "Groundwater Hydrology" a significant text in hydrogeology. The report therein contains some small differences to the original paper. Bouwer's text is important to note because this is one of the readily available books in the field of hydrogeology and one of the very few that mention cemeteries as having a potential impact on groundwater.

GREECE

"The serious problems of land use in Athens suburbs sometimes leads to unprecedented solutions" (Stournaras, 1994). In this case it has been proposed by municipal authorities that a former domestic waste landfill be used to host a graveyard. This brief report identifies some environmental risks associated with the proposed development but is more concerned with the appropriateness of the development – "the sanctity of a cemetery's environment" (Stournaras, 1994) and does not adequately explain the difficulties. However, the report serves to highlight the continual pressure on municipalities to provide burial space as well as the need for proposed sites to be properly evaluated geoscientifically.

In 2000 the Researcher was contacted by A. Kalliorus, a PhD student at the University of Xanthi. Kalliorus is studying other aspects of hydrogeology, but has noted the importance of potential cemetery pollution to situations particularly in Greece and has developed an interest in this.

NETHERLANDS

van Haaren's Work

A comprehensive investigation of cemetery groundwaters was conducted by van Haaren (1951) in the Netherlands. Van Haaren studied a graveyard adjacent to a church in an unidentified location of that country, and designated it 'X'. This cemetery covered about 4 ha and was encircled on two boundaries and near the third with drainage ditches which are most likely to have received effluent groundwater from beneath the cemetery. The motivation of the study is stated as determining the influence, from a hygienic perspective, of cemeteries on nearby surroundings and determining any effects on groundwater and surrounding surface waters.

Seven sampling points of unknown construction were established in and around the projected down-gradient perimeters of the cemetery. The sampling points are described as being in the incline (the slope to the ditches) at the phreatic surface; they may represent exposure of the watertable in a small excavation. These were all sampled at least twice together with adjacent drainage ditch waters. Two sampling points ('D' and 'E') were sampled 3 times, but in different sequences; firstly after one week, then after 3.5 - 4 months in an effort to examine variation with time. Two other similar cemeteries (designated 'Y' and 'Z') were also sampled once (3 months after X's second sampling) each at two points, and a nearby drain, within the cemetery area except for point 'B' in cemetery Z which resembles the setting of G at X. The soil conditions at X were described as "sandy" and later as "clean sand filling".

The sampling points were established with regard to the duration of recent interments. These varied: for ‘A’ nearby to graves > 9 year old, ‘B’ near graves 9 – 7 years old, ‘D’ near graves 4 –3 years old, ‘C’ was in an unused area as were later ‘E’ – 150 m from D, and ‘F’ – 50 m from D, ‘G’ was adjacent to E but on the opposite side of the drainage ditch. For cemeteries Y and Z interment durations nearby to the sampling points were up to 20 years; the information about these sites is very limited. All the sampling, except the third round at X, took place after periods of heavy rain. There are no other clues of methodology, site conditions or procedures; and only brief indications of some analytical methods. However, it was pointed out that cemetery X had not been subject to fertilizer applications.

van Haaren’s (1951) approach to consideration of the issues was based on the mass-balance of likely inputs from the breakdown of human remains by total oxidation. The work is one of the earliest known to give some idea of the composition of the human body. However, van Haaren concluded that this approach isn’t necessarily satisfactory and could not obtain any correlation between groundwater chemistry and potential decomposition products. With the benefit of newer knowledge, it is now clear that there are errors in the methodology, considerations, concept of decomposition by oxidation and other factors in this work. Van Haaren was unable to definitively link cemetery groundwater composition with that of the drainage ditches and was only able to say that both lots of water were polluted.

Re-evaluation of van Haaren’s Work

van Haaren’s (1951) work is difficult to procure, difficult to translate (it’s written in a formal old-Dutch style), and extremely important in the context of cemetery studies. For these reasons his raw data, re-worked for better interpretation and with updated terminology is included as Table 3.1. The data has then been re-interpreted.

van Haaren (1951) listed typical general properties of in-cemetery groundwaters compared to the drainage ditch waters, since his primary focus was on trying to demonstrate the link between the two. The degree of analysis presented, however, was quite limited although the conclusions are correct. The results have been reconsidered by the Researcher and some conclusions, from the perspective of more closely considering the in-cemetery composition are following.

- Results for in-cemetery groundwaters: close to newer graves the EC is generally higher than for older/more distant sites; NO_3 is very low but organic nitrogen is generally present as well as NH_4 but only at modest levels; SO_4 is relatively high and so is Cl and these generally match elevated EC, however the results are variable throughout; COD doesn't specifically identify with any grouping.
- Comparing groundwater to drainage ditch waters:

  1st round: Cl about 1/2 to 2/3 of 'g' samples; SO4 about 1/2 'g' samples; EC similar to lower; NH_4 similar to higher; organic N generally higher; NO_3 much higher;

  2nd round: Cl and EC generally lower; COD a little lower; NO_3 higher; NH_4 similar (except Eg); organic N similar except Eg;

  3rd round: Eg is marginally worse than 'w' samples; otherwise drains are worse - more N.
- Comparing Y and Z cemetery results to X: these show little difference between within-cemetery and drainage waters; if anything, the drains are more influenced by free nitrate and sulfate. Site Ag in Y shows higher levels of EC and Cl and organic N and COD - possibly indicating decomposition products.

Although the results are inconclusive and show considerable variety, in the light of newer data from this Study and others, it appears that decomposition products have been identified in the cemeteries; as evidenced by EC, Cl, SO_4, NH_4 and organic N measurements. The influence of soils possibly containing organic matter or sulfide minerals cannot, however, be discounted.

Table 3.1 Restatement of data obtained by van Haaren (1951)

Cemetery X

Date	10/05/50	10/05/50	10/05/50	10/05/50	13/10/50	15/3/51	13/10/50	13/10/50	24/10/50	15/3/51	13/10/50	24/10/50
Sampling Point*	Ag	Bg	Cg	Dg	Dg	Dg	Dog	Eg	Eg	Eg	Fg	Gg
interments	>9 years	9 - 7 years	unused land (1)	4 -3 years				unused land (2)			unused land (3)	unused land (4)
EC (uS/cm equiv)	1550	3100	1400	3100	3200	1850	3200	1700	1650	725	1450	1050
pH	7.8	7	7.6	6.7	7.4	7.2	6.6	6.6	7.3	7.4	7.2	7.5
colour (mg Pt/L)	50	70	cloudy	90	cloudy	105	cloudy	n/a	cloudy	160	95	cloudy
COD (mg/L) (7)	55	55	55	90	80	65	80	250	150	100	80	60
Cl (mg/L)	335	760	295	780	780	340	770	n/a	66	25	295	180
NO3 (mg/L)	<0.05	0	0	<0.05	<0.05	n/a	<0.05	n/a	<0.05	n/a	<0.05	<0.05
SO4 (mg/L)	304	290	364	369	384	n/a	331	7	399	n/a	80	130
HCO3 (mg/L)	280	525	350	455	465	345	565	n/a	730	475	400	220
NH4+ (mg/L)	0.43	0	2.9	0	0	n/a	0	47	13	n/a	1.8	0
organic N (mg/L) (8)	0.65	0.98	0.4	1.2	1.2	n/a	1.2	3.4	4.1	n/a	0.2	1.1
bicarbonate hardness**	12.8	24	16	20.9	21.3	15.8	25.9	14.8	33.4	21.8	18.4	10

Date	10/05/1950	10/05/1950	13/10/1950	10/05/1950	10/05/1950	13/10/50	13/10/1950	24/10/1950	13/10/1950	24/10/1950
Sampling Point*	Aw	Bw	Bw	Cw	Dw	Dw	Ew	Ew	Fw	Gw
interments	>9 years	9 - 7 years		unused land (1)	4 -3 years		unused land (2)		unused land (3)	unused land (4)
EC (uS/cm equiv)	1300	1550	1500	1350	1500	1500	1500	1500	1500	1500
pH	7.8	7.8	8	8.2	7.9	7.6	7.9	7.9	7.9	8
colour (mg Pt/L)	55	65	80	50	60	80	75	70	80	75
COD (mg/L) (7)	46	47	55	48	90	55	55	50	55	50
Cl (mg/L)	270	235	240	265	240	240	245	250	240	260
NO3 (mg/L)	0.05	1000	0.3	0.1	1.05	0.45	0.35	0.15	0.4	0.15
SO4 (mg/L)	156	194	285	157	136	290	293	271	294	282
HCO3 (mg/L)	240	335	315	250	340	325	325	315	325	320
NH4+ (mg/L)	0	0	0	0	0.79	0	0.38	0.2	0	0
organic N (mg/L) (8)	0.84	1.2	1.1	0.47	1	1.2	0.69	1.2	1.4	0.99
bicarbonate hardness**	10.9	15.3	14.4	11.4	15.6	14.9	14.8	14.4	14.9	14.7

(1) sampling point C was on unused land but near a pond; (2) sampling point E was about 150 m from D; (3) sampling point F was about 50 m from D; (4) sampling point G was on the other side of the drainage ditch to E

Cemeteries Y and Z

Cemetery	Y	Y	Z	Z	Y drain	Z drain
Date	28/2/51	28/2/51	28/2/51	28/2/51	28/2/51	28/2/51
Sampling Point*	Ag	Bg	Ag	Bg	Aw	Aw
interments	30 – 20 years	older graves(5)	13 – 2 years	outside (6)	30 -20 years	13 – 2 years
EC (µS/cm equiv)	1900	875	800	975	1150	1050
pH	6.9	7.6	6.8	7	7.9	7.6
colour (mg Pt/L)	cloudy	140	120	290	120	120
COD (mg/L) (7)	100	85	65	70	65	70
Cl (mg/L)	290	73	22	165	150	130
NO3 (mg/L)	n/a	<0.05	0.1	<0.05	0.25	0.35
SO4 (mg/L)	201	121	38	62	198	155
HCO3 (mg/L)	725	325	505	285	315	305
NH4+ (mg/L)	0.2	0.11	0.11	1.4	2.8	3.3
organic N (mg/L) (8)	1.7	0.73	0.75	1	0.8	0.45
bicarbonate hardness**	33.1	14.8	23.2	13.1	14.4	13.9

(5) Site Y-Bg was adjacent to section where graves inferred to be older than 30 years, but some were 5-0 years old

(6) Site Z – Bg was located outside the cemetery beyond a drainage ditch

(7) COD = oxidation of sample by $KMnO_4$ (8) assumed to be Kjeldahl nitrogen

* suffixes: g =groundwater sample; o = nearby extra D site 3 m separation from original; w= drainage ditch sample – taken adjacent to groundwater sampling point

** hardness reported in 'G. degrees' - local scales based on amounts of equivalent $CaCO_3$: this is likely to be German degrees where 1 German degree = 17.8 mg/L, after Hem (1989)

All sampling followed a period of rain except for 15/3/1951 when it was dry.

van der Honing et al.'s Work

In 1985 several government authorities and research institutes in southern Holland decided to re-investigate the influence of cemeteries on surface-, drain- and groundwaters (van der Honing et al., 1986). The primary concerns were the low-lying nature of the countryside, the inevitable surrounding of many cemeteries by surface waters, and the possibility of adverse influences on agricultural plots adjoining the cemeteries.

A number of cemeteries were chosen for investigation and eventually sampling took place within and adjacent to five. As far as possible the sampling locations were chosen to be close to a series of interments about 3 years old. The cemeteries were of vastly different ages and sizes, varying from about 67000 interments at Rotterdam (since 1940) to 750 at Westmaas (since 1888). The samples consisted of groundwaters from piezometers and sub-soil drains, drainage ditch waters, and surface drain waters. Three samples of the latter were used as reference waters for interpreting the effects of the cemeteries. The published report is significantly lacking in detail about sample collection and testing methodologies, however, it refers to more detailed purposeful reports. The researcher was unable to obtain those reports.

Two piezometers were installed one month before sampling, one in each of two cemeteries. They had screens straddling the watertable; each was only sampled once, after a period of pumping designed to provide representative samples.

Samples were also tested for the presence of thermotolerant coliforms, but again the details are incomplete. The second set of the reported results (after 48 hours) appears to be comparable with the techniques reported later for this Study. A significant range of simple organic acids was also determined. Very little data of this kind has ever been reported for the cemetery context. Furthermore, the dissolved gases cadaverine (1,4-diaminobutane) and putrescine (1,5-diaminopentane) were determined; these are organic, decomposition products.

A range of the various water samples was also used for short duration (48 hour) environmental toxicity tests using the species; *Daphnia magna* (water flea) and *Poecilia reticulate* (gup). It was concluded that there were no "strong indications for acute toxicity in the water samples" (van der Honing et al., 1986).

van der Honing et al.'s (1986) general conclusions were that there were no increased concentrations of physio-chemical, microbiological, and toxicity parameters near cemeteries; and "that none or hardly any influence has been observed". However, a suggestion that the waters should not be used for recreation or irrigation of consumption crops was added.

Re-evaluation of van der Honing et al.'s Work

van der Honing et al.'s (1986) work is difficult to procure, is written in Dutch, and is an important report of a comprehensive study of cemetery sites and their 'watery' connections. For these reasons some of the raw data, re-worked for better interpretation is included as Table 3.2. The data has then been re-interpreted in the following.

Compared to the background waters, the cemetery groundwaters:-

- contain more dissolved salts, but are closer to neutral pH; have a lower BOD and COD;
- are higher in total N load and the same or higher in total P load; Cl and S results are also inconclusive and are about the same or sometimes a little higher;
- calcium and sodium are slightly elevated; the trace metal suite shows an increase;
- there is a noticeable decrease in common organic acids and putrescine (which is a surprising result);

The results for thermotolerant coliforms are inconclusive and are high values, the sampling techniques are unknown; they suggest that the surrounding waters are more contaminated than the groundwaters. The samples from the cemetery at Westmaas show considerable alignment with the surface samples and it seems likely that they are contaminated by factors related to their sampling from a ditch. The elevated EC, total N load, near neutral pH (in this situation), Ca, Na and metals suite, total P and possibly Cl indicate the presence of decomposition products. In many respects the in-cemetery groundwaters are cleaner than the reference surface waters.

Others

A set of instructions purporting to be from the "Inspectorate for the Environment" an organisation based in The Hague and available on the internet (Inspectorate for the Environment, 2001) provides some guidance for the structure and layout of cemeteries. It has not been possible to verify the internet address of this website, or of the existence of the organisation; the documents are made available through third parties. Most of the information accords with good practices promulgated elsewhere with the exception of the 30 cm distance between grave invert level and any watertable. The documents state that cemetery design and function should aim to encourage complete decomposition of the remains within ten years without the formation of adipocere.

NEW ZEALAND (NZ)

During the course of this Study the Researcher became aware of only one cemetery investigation about potential cemetery impacts in the New Zealand landscape. This was in a matter raised by Ross (1997, pers. comm.) at a local IAH meeting. The substance of the enquiry was as to whether cemetery decomposition products in groundwater could be satisfactorily differentiated from those of a nearby abattoir. The circumstances of the investigation were not revealed so that it is hard to comment. Detailed organic molecule profiling – e.g. for prescription drugs or caffeine, or comprehensive inorganic chemistry of the groundwaters, may be useful, but this is by no means certain. Decomposition products are typically identified by their nitrogen species initially (see also Chapter Four).

Table 3.2 Restatement of data obtained by van der Honing et al. (1986)

Cemetery	Kr. a.d. IJssel*	Rotterdam		Westmaas	Zwijndrecht	Kr. a.d. IJssel*	Westmaas	Zwijndrecht
Type of sample	groundwater	sub-soil drain		s/soil drain**	groundwater	representative surface water		
Date	14/04/1986	29/04/1985	14/04/1986	29/04/1986	14/04/1985	14/04/1986	15/04/1986	15/04/1986
EC µS/cm	1080	1380	1480	900	1500	490	960	550
pH	6.80	7.00	7.25	6.90	7.00	8.00	8.05	8.45
temp °C	n/a	8	8	n/a	n/a	6	7	8
COD mg/L	35.0	27.0	19.0	93.0	n/a	81.0	46.0	35.0
BOD mg/L	7.0	5.0	1.0	27.0	1.0	9.0	8.0	4.0
dissolved Organic Carbon mg/L	11.0	16.0	7.4	34.0	11.0	24.0	12.0	9.2
kjeldahl N - as N mg/L	4.3	2.1	1.9	4.7	2.9	2.7	2.9	1.0
ammonium - as N mg/L	3.8	1.3	1.5	2.8	2.2	0.1	1.1	0.1
NOx - N mg/L	0.07	5.80	2.55	0.14	0.13	0.03	1.83	0.01
orthophosphate – as P mg/L	0.01	0.01	0.01	0.01	0.01	0.02	0.09	0.04
total P mg/L	1.20	1.60	0.42	0.42	0.34	0.36	0.36	0.16
Cl mg/L	60	135	185	49	24	41	78	91
S mg/L	39	165	140	28	83	74	125	41
Ca mg/L	160	247	212	155	185	51	124	55
K mg/L	6.3	5.6	7.6	3.1	2.0	8.9	7.7	3.8

Na mg/L	50	68	94	24	20	27	57	42
HCO3 mg/L	685	495	577	575	706	175	410	155
Cd µg/L	<0.1	0.9	<0.1	0.3	0.2	<0.1	<0.1	<0.1
Cr µg/L	2	4	1	3	7	2	2	2
Cµ µg/L	6	21	5	10	5	6	6	4
Hg µg/L	<0.1	0.2	0.5	<0.1	0.3	0.3	<0.1	0.2
Pb µg/L	1	6	<1	1	8	2	2	1
Ni µg/L	<1	8	6	21	7	2	3	<1
Ag µg/L	0.3	n/a	0.3	n/a	0.2	0.2	0.3	0.3
Zn µg/L	77	105	11	49	135	7	6	1
phenol µg/L	1	3	3	200	5	<1	4	2
acetic acid mg/L	290	n/a	240	254	310	935	755	1855
proprionic acid mg/L	46	n/a	50	4.3	30	135	165	325
butyric acid mg/L	6	n/a	n	n/a	n/a	25	83	43
cadaverine µg/L	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
putrescine vial 1 µg/L	3	2.3	n/a	9.2	6.6	8.3	9.7	5.7
putrescine vial 2 µg/L	1.1	2	n/a	9.9	0.4	22.1	9.3	6.1
Thermotolerant coliforms (48 hr @ 37 °C) /mL	140	60	27	860	590	590	580	1600

Details of sampling methodology not available; samples were taken from places nearby to interments 3 years old.

* cemetery at Krimpen a/d IJssel ** the Westmaas drainage water was subsoil seepage trapped in a ditch drain n/a - no data given

A diligent search has been made of reported NZ court cases mostly in the Butterworth's series of reports (Wily, 1968 and subsequent, and AUSTLII, 2001), however, no records relating to cemeteries and surface- or ground- waters' interaction were found.

PACIFIC ISLANDS

A review of relevant legal case records for the following nations, territories or protectorates (via PacLII, 2001, AUSTLII, 2001, and other sources) did not yield any results of interest in this context: American Samoa, Cook Is., Federated States of Micronesia, Fiji Is., Kiribati, Marshall Is., Nauru, Niue, Norfolk Is., Palau, Samoa, Solomon Is., Tokelau, Tonga, Tuvalu, Vanuatu.

A study of burial mounds and the possibility of remnant decomposition products in Tonga, has been discussed in Chapter Two.

PORTUGAL

In late 2000 the Researcher was contacted by Luisa Rodrigues (pers. comm., 2000) a student in Portugal. Rodrigues has undertaken some kind of postgraduate study into cemetery chemistry for an unknown number of sites and unknown location/s in Portugal. She has also been advised by Pacheco from Brazil. Every effort to obtain further information about her work, or copies of reports or theses, has been unsuccessful.

SOUTH AFRICA

The CSIR in South Africa conducted some sort of cemetery investigation/s (probably since the early 1990s) and via an internet site (CSIR, 2000) promote themselves as experts on the location of cemeteries. It has proved impossible to obtain specific information about these studies or copies of any reports, although Knight (pers. comm., 2000) has seen some of the data. The website claims that 21 well-points were established about a cemetery and examined on 15 occasions over summer and winter. Microbial pollution was detected and has been directly attributed to the cemetery.

On another website, the Environmental-, Engineering- and Marine- Geoscience Division of the Council for Geoscience (Geoscience, 2000), also promotes themselves as experts in the assessment of land for cemeteries and claims to have developed considerable expertise in this area for over eight years. The hosted discussion partly compares cemeteries to conventional landfills and points out that the "pollution emanating from a cemetery site" differs from that of conventional waste disposal sites. It has also proved impossible to obtain further information, or copies of reports or studies completed by this group.

In Durban there is a looming, critical shortage of burial space. This city lies in the heart of an area affected by the AIDS epidemic and it is reported that 16 of the city's 24 cemeteries are now full (SMH, 2001). Innovative burial practices, for example a vertical coffin, are being proposed as a means to better utilization of space in a situation where burial is preferred over cremation. It is projected that 241 ha of cemetery space will be required in the next 10 years at the current death rate (SMH, 2001).

An archaeological investigation of a cemetery near Vredendal during the course of the site's re-development, has permitted recording of some data on decomposition aspects, but with a particular focus on coffin woods (February, 1996). The study occurred at least 72 years after the last interments (the cemetery was believed to be active from 1837 – 1920), but only recovered some coffin material from 15 of the 45 burials. The wood turned out to be forms of pine. Some of the burials were apparently also not coffinated. Unfortunately further site details, for example climate and soils, are not given.

SPAIN

Like the Brazilians, the Spanish have had an interest in "putrefactive" products from cemeteries, the need to re-use graves and some difficulties that this produces, as well as the need to protect water supplies. It is known that Pacheco (pers. comm., 2000) (from Brazil) has done some studies and worked with a group of researchers in Spain on these matters. However, no published reports are known or have been made available to this Researcher.

It is also known that a Spanish company, in operation since 1996, (I.C.A.T., 2001) orientated to "technical solutions" and consulting (?) has been making capital about cemetery processes and the need to properly investigate cemetery placement. This company maintains a website that discusses a number of issues about groundwater pollution including cemeteries and is known to be behind contributions to industry magazines (see Oritz, 1997).

A paper by Arche et al. (1982) is an important early work in identifying the need for potential cemetery sites to be properly assessed geoscientifically. The discussion here includes some limited understandings of cemetery processes and simplistic interpretations of hydrogeological phenomena, but correctly explains the level of interments relative to watertables. The paper discusses grave re-use within the context of space pressures in Spain and favours a switch to cremation. A key recommendation is that "Processes that speed up the putrefaction processes and avoid the proliferation of pathogenic bacteria should be encouraged: cremation, burying corpses without wrapping in plastic bags" (Arche et al., 1982).

Arche et al. (1982) also record that relevant legislation – Mortuary Legislation Act 2263/1974 of 1974 prohibits the establishment of new cemeteries on permeable terrain within 500m of an urban area and that no dwellings will be permitted in such an area.

UNITED KINGDOM

Various researchers, government agencies and industry members in the United Kingdom have been concerned about the impact of cemeteries on the environment, their place in society in terms of care and re-use, and numerous aspects of archaeology and socio-medical history encapsulated within them. There is much anecdotal evidence of disease spread from cemeteries and likewise numerous personal reports of tests on drinking water from wells in graveyards and nearby which all show obnoxious substances.

Holmes (1896) reported that many "wells, conduits, and pumps in and around London were .... not only in close proximity to the churchyards, but actually in them. The water from St. Clement's Well and St. Giles' Well came through the burial grounds." Other sites are also listed, and an interesting indication of a limited understanding of public health issues but thankfully including the dangers of cholera and its spread associated with cemeteries. There was a community water pump "in St. George's in the East, to which his parishioners used to resort for drinking water until the Rev. Harry Jones, during a cholera scare, hung a large placard on it, *'Dead Men's Broth'....*" Holmes (1896).

Nevertheless, the Researcher is only aware of four documented studies of groundwater and/or soil sampling in relation to cemeteries in the modern context. The extent of the work done is quite variable and two of these were university degree projects that received considerable input from the Researcher. Similarly the Researcher reviewed various aspects of the other studies, including a significant contribution to the major desktop study undertaken for the Environment Agency (Environment Agency, 1999).

This latter study produced a significant document which considers the likelihood of pollution arising from cemeteries. It reviews a significant amount of the known information also discussed above, however, the nature of that study required a broad-based evaluation; hence much of the data and references, for example, Schraps (1972) in Bouwer (1978), van Haaren (1951), van Honing et al. (1988) Pacheco et al.

(1991) have apparently not been considered in an unbiased manner. The study has a significant benefit in that it was able to correlate other information from industry personnel – personal communications about conditions in cemeteries, embalming materials and practices and occasional water tests. It appears that those latter kinds of tests (viz. Nash and Anglican Region) (Environment Agency, 1999) are likely to have detected in-cemetery decomposition products as ammonia-N and increased COD; one in-grave groundwater sample from a London burial ground in 1992 detected formaldehyde (methanal).

The study also considers local burial and planning legislation and policies of local water authorities with respect to protection of water supplies. The report highlights the fact that, the Code of Good Agricultural Practice for the Protection of Water by the Ministry of Agriculture, Fisheries and Food (MAFF), together with Guidelines form the Environment Agency's Policy and Practice for the Protection of Groundwater (Environment Agency, 1999) are now widely being used as a standard for cemetery establishment and interments.

The MAFF Code, which is not prescriptive in law, states that the disposal of animal carcasses should comply with the following:

- "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 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 carcase;
- when first dug, the bottom of the hole must be free of standing water." (MAFF, 1998)

Whilst the Guidelines, which devolve from a classification of aquifers and their protection based on vadose zone seepage travel times, recommend that cemeteries not be located in Zone I areas, that is, where travel time is less than 50 days. Young (from the company WRc plc, and on the basis of his work for Environment Agency, 2001) has further developed location parameters for cemeteries on a risk management basis. The concepts embodied therein were first applied to a site by Lelliott (2001), in a student study at the University of Reading.

Two other, widely cited reports in the context of aquifer protection:- Southern Water Aquifer Protection Policy, 1985 and Guidelines on the Provision and Protection of Water Supplies for Community Survival, 1985; have been diligently sought by the Researcher. Each document supposedly includes provision for siting of cemeteries and might have been useful for understanding their likely environmental effects; however, the documents appear to not exist and it is possible that the ideas, if formulated, were incorporated in other works such as the Environment Agency's Guidelines – see later.

Of the contemporary studies of potential groundwater contamination in the UK; two of these – Lelliott, as above, and Harden (2000) were student projects. Lelliott's work was relatively intense and focused on a cemetery located on high river terrace alluvial deposits. Unfortunately his inorganic data wasn't complete and his bacteriological data is not usable because insufficient protocols for sampling were in place. However, Lelliott (2001) managed to once again detect decomposition products – including ammonia –N, total organic N, TOC, and elevated chloride and EC within the cemetery. The data was relatively variable and the movement of decomposition products off-site was not convincingly demonstrated.

Harden's (2000) work primarily focussed on soil differences in a Welsh cemetery compared to above-site and neighbouring soils. There were some sampling difficulties in this study with the outcome that most samples were too shallow. A final analysis of his data has not been seen, however, it appears to have been inconclusive in respect of any pollutant effect of the cemetery.

Another study was carried out under the supervision of Trick (2000) of the British Geological Survey. In a short timeframe two opportunities to examine cemeteries occurred. In the first, a cemetery was resumed in Nottingham and samples of perched groundwater from about 2 m below grave level were taken. The testing of these waters apparently showed increased TOC and ammonia but also industrial contamination as phthalates and chlorinated hydrocarbons so that the results are inconclusive with respect to decomposition products.

Trick's second study was in connection with a series on graves in a lawn cemetery in Wolverhampton dating from the 1950s, wherein several rows of graves suddenly sunk. A number of piezometers were established onsite in connection with the subsequent geotechnical study. The Researcher inspected this site with Trick in October 2000 and reviewed the groundwater test data. There appeared to be some irregularities in sampling methodology and considerable variation in the results. Unusual bacterial results including of *Staphylococcus aureus* were obtained and viruses were also sought. The study's results appear to have been complicated by pollution from former industrial waste disposal upgradient of the site.

A review of relevant legal case records for the UK and territories, Northern Ireland and Ireland (via BAILII, 2001, and other sources) did not yield any results of interest in this context.

Grave Re-use and Disused Cemeteries

As cities' space and services demands grow, or as service corridors are expanded or upgraded cemeteries are frequently relocated. Usually the services of an archaeologist, forensic scientist or anthropologist are engaged for this task. It is often very expensive, and is certainly today an exacting task. Historians and archaeologists are keen to use records of relatively recent past society (as revealed in their cemeteries) to understand the present; for example dietary studies, socio-economic and general health indicators. In the UK there have been many archaeological excavations of cemeteries, but also relocations of cemeteries which are only 300 years or less in age.

Three such recent studies were:

- the Spitalfields Project in London, for which the data has been published by Janaway (1993), and was useful for studies of adipocere – see Chapter Two, as well as indications on the survival of the smallpox virus (Spinney, 1995), when over a 1000 exhumations of interments from 1729 – 1852 in the crypt of the Christ Church were made;

- ❖ Centre for Life, Newcastle upon Tyne, where certain data is readily available – see below;
- ❖ and St. Luke's Church, London, from which data is not yet known to be available – see below.

Another detailed study of cemetery records for Tynemouth General Cemetery, 1833 – 1853 (Gould and Chappel, 2000) has shown that victims of cholera were buried more deeply than those deceased of other causes, in an effort to prevent the disease spread. This practice, if conducted in the wrong hydrogeological settings, may well have encouraged spread of the disease.

The International Centre for Life and Dance City, Newcastle upon Tyne, was an important project from the perspective of risk management of a contaminated site being redeveloped (Smith and Allen, 1998). In this case an old infirmary, with cemetery of related interments, and contaminated former bus garage, disused factory land, barren ground and carpark were re-developed. The interred remains were cautiously recovered with attention to the possibility of disturbing pathogenic organisms in soil or groundwater (Jessett, personal communication, and reports – Mott MacDonald, 2001). Unfortunately there is little test data of relevance to the needs of this Study, and its main scientific interest was from industrial archaeological and medical perspectives.

The site was carefully cleared of formal burials and collected remains examined by osteologists from the University of Sheffield. A limited number of soils and groundwater samples were taken throughout the site. The soils showed considerable metal contamination of a fairly diverse nature, but not directly linkable to the cemetery. In November 1996, soils in the chest cavities of 8 skeletons were sampled for lipid analysis in connection with the identification of tuberculosis – however, the results are unknown. Several soil samples from the cemetery were tested for the anthrax bacillus, but it was not present. (Mott MacDonald, 1996).

The graveyard and crypt of St Luke's Church, London were excavated in 2000. The researcher had the opportunity to visit this work in progress in October, 2000. Many lead coffins, stacked 4 or 5 high, were being recovered at the time, and where ground interments or remains from damaged coffins were recovered they were examined for osteological features and funereal artefacts. The interments dated from approximately 1750 – 1850; much adipocere was found in the wet and leaky crypt coffins, but very little in the churchyard burials; some coffins still retained small amounts of flesh (Mitchell, pers. comm., 2000). Specific soil tests were not undertaken here.

The issue of disused burial grounds – their legal status and re-use has received considerable attention. It has been recognised that the maintenance of these, essentially community, spaces, is a costly exercise, and there is now a growing disquiet about their appearance (Boon, 1974, Harrison, 1984, Ward, 1999). However, the status of many of these sites had also been considered much earlier by Holmes (1896) who also carefully listed the prior existence of cemeteries in London and their redevelopment. A comprehensive study of the issues in a modern context was completed by Dunk and Rugg (1994).

A complementary issue is that of grave re-use for recent interments. Initially this was antagonistic to the majority of British society, however, this is also changing with the pressure on burial space (Davies and Shaw, 1995, Ward, 1999). The report by Davies and Shaw (1995) comprised a comprehensive survey of current attitudes to the idea of grave re-use and beliefs held in respect of this. Most of the work known, however, has had an inevitable 'social' context, and environmental aspects have not been fully understood or introduced into the considerations. In a response to Ward's (1999) newspaper article, a correspondent wrote: "At the old Jewish cemetery in Prague you can find up to seven layers of burials on one spot. We should be encouraging this practice in disused cemeteries,..." (Goldstein, 1999).

At Carlisle Cemetery, the practice of "Woodland Burial" was introduced as a method of creating an ecologically sustainable, low maintenance cemetery landscape (West, pers. comm. 2000). These sorts of sites which seek to use nil or readily bio-degradable coffins, interred amongst treed and planted settings, impose a very low load of decomposition products on the environment. Bodies interred in this kind of situation are not embalmed; gravesites have no markers or monumental work.

The concepts represented by this kind of interment are now widely practised throughout the UK in specialised cemeteries. They are also gaining popularity in the USA (United States of America) (Campbell, 2000). The findings of this Study support the generalised concept of grave re-use as ecologically sustainable – see later chapters and also Knight and Dent (1998).

UNITED STATES OF AMERICA (USA)

In the USA a number of different published studies and notes are available that refer to several issues relevant to the role of cemeteries in the environment. The most fruitful has been the assemblage of case law reports; these reports have value in terms of the conceptualization of likely contamination problems. Only one limited study by Sponberg and Becks (2000) has presented new data, and this was on cemetery soils' metals. However, several discussions allude to the actual and potential threat of arsenic and metals contamination of groundwaters as a result of older embalming practices. Whilst other work refers to the assessment of 'risk' cemeteries and the role of cemeteries as open spaces in the community.

Review of Law Reports

American case law has provided a rich source for consideration of the complex issues regarding the existence of cemetery decomposition products and their likely migration from one property to another. An in-depth search of case law citations for the USA has been made, principally using the electronic database Lexis-Nexis (1999 and 2001) and other aids like Purver (1971); the data are assembled in Table M1 (Appendix M) for the period 1860 to present.

The similarities of many general interment and cemetery practices (except embalming), the variety of landscapes and hydrogeological contexts, between the USA and Australia and many other societies, makes the analysis of these court cases very useful. Many of the arguments and considerations, and hence the findings and evaluations, would be applicable in various parts of the World.

The arguments made have principally fallen into three categories; firstly, that the presence of a cemetery is a general nuisance; secondly, that because there is a cemetery there will be downgradient movement of decay products so as to affect neighbouring groundwater wells/springs or streams; and, thirdly, that cemetery management practices for stormwater have sometimes been injurious to neighbours, or that cemeteries have been affected by neighbours' poor control of stormwater.

Certain issues about nuisance caused by cemeteries and whether *the existence or potential existence* of a cemetery will have an effect on an adjoining landholder have been raised in argument several times. The courts have consistently held that society has the right and obligation to bury the dead in lands dedicated to the purpose, and hence these lands are a necessary feature in any town or society and thus can't be a nuisance. On the issues of decomposition product movements, however, the courts have relied heavily on expert testimony and usually dismissed actions where mere assertions as to potential problems have been made (see e.g. Harper et al. V. City Of Nashville et al., 1911, Table M1); but the case outcomes have been very varied. In the earlier cases "insufficient evidence" of a likely threat or nuisance was often cited as a cause for dismissing actions. Over time, many 'expert' arguments have been mounted and significantly many of these have been with regard to the hydrogeological setting; many have been contentious and supported by conflicting 'facts'.

The language of argument about natural phenomena e.g. the occurrence of underground streams of water, the presence of contagion and decomposition products, description of strata and permeability provide an interesting documentation of the prevailing ignorance of the times in these matters. The use of expert witnesses shows a similar evolution. In most of the earliest cases the experts cited are medical practitioners, some who seem to have attempted well-meaning, but incorrect, field evaluations of the vadose zone.

No cases appear to have benefited from a sufficiently comprehensive geoscientific investigation; however, the courts have demonstrated a considerable ability to weigh arguments about natural processes with little formal understanding or evidence about them; sometimes, eminent experts on each side (see e.g. McDaniel v. Forrest Park Cemetery Company, 1923, Table M.1) have equally disagreed.

After more than a hundred and forty years of argument the issues seem relatively settled in legal terms. For instance, what would now be required for resisting the establishment of a cemetery close to any drinking water source (or to mount an argument about pollution effects) would be a proper geoscientific evaluation of subsurface conditions and groundwater paths plus a consideration of the likelihood of decomposition products being able to be transported to the drinking water. Research such as the present can help to solve these debates.

One case, involves the burial of a cattle carcass (Long v. Louisville & Nashville R. R. Co., 1908) 70 ft (21 m) uphill of a well which was subsequently contaminated. Another (Kingsbury v. Flowers, 1880) records a landholder's efforts to protect his well, situated downslope from a cemetery, from surface water contamination; as such it represents an early case of well-head protection.

Other matters litigated concern runoff or seepage pollution potential of streams, such streams providing stock or domestic water supplies or being part of a reservoir catchment. In these cases the courts have been unconvinced that a potential problem exists; mostly the cemeteries are quite far from the stream or drainage or seepage probably goes another direction. The evaluation of surface drainage characteristics has often been shown to be very poor.

Issues of flooding of cemetery land by mis- or re-directed runoff have been considered on their merits and usually involved a simple resolution of matters of pre-existing drainage lines, blockages and re-directions of drainage. Such cases do, however, serve to highlight one of the less satisfactory aspects of cemetery location. Namely that they often occupy lower and/or swampy and/or poorly drained land, and that they may alter the natural drainage aspects.

Were There Ill-effects? An Analysis of USA Court Cases (Table M.1)

Almost every case argued about the potential of ground- or surface- water contamination was dismissed. During some cases, details of soil types and locations between wells and interments or cemetery boundaries were given, but these often conflict in elementary detail. From the reports it is not usually possible to get a precise slope distance or appreciation of the hydraulic gradient or even a good understanding of the vadose zone; however, two wells – different settings - reported at about 100 ft (30.5 m) from interments were in one case clean and unaffected, and in the other, quantifiably affected (a legal non-equity issue which really did away with the need for technical arguments).

Other interment or boundary to well/stream distances reported at:- 100 ft (30.5 m) at 85 ft (25.9 m) depth; 150 ft (45.7 m) at 40 ft (12.2 m) depth; 182 ft (55.5 m) 36 years adjoining cemetery; 200 ft (61.0 m); 200- 300 ft (61.0 – 91.4 m) at 20 ft (6.1 m); 570 ft (173.7 m) with 20° slope; wells more than 200 ft (61.0 m) depth at 250 ft (76.2 m), 600 ft (182.9 m), 1500 ft (457.2 m) respectively; have all had no reportable contamination effect. In one case (Wahl v. Methodist Episcopal Cemetery Association of Williamstown, 1900, Table M1) the groundwater was said to improve – possibly due to the tendered lawn areas (a finding consistent with this research for WOR and in The Netherlands).

In a 1953 case (McCaw et al. v Harrison et al., 1953, Table M1), a Professor of Bacteriology and others, categorically alleged that 50 ft (15.2 m) is a sufficient sanitary, separation distance for drinking wells, in shallow soils overlying cavernous limestone. In this case the weight of evidence was insufficient to reach a conclusion against the development. The lateral distance to the well concerned was 500 ft (152.4 m).

In two cases (E. A. Reid et al. v. Memphis Memorial Park., 1927, and Kenneth Carter et al. v. A. H. Chotiner et al., 1930, Table M1) buffer zones around the cemetery at 25 ft (7.6 m) and 40 ft (12.2 m) respectively, have been considered or enforced. The soil conditions were not reported, but in the latter case it was considered that the buffer would help in a situation where the experts conflicted in their assessments.

In several cases the alleged likelihood of pollution was tempered by the courts because of other pollutant sources already located on the land in question, including, cesspools, privies and barnyards. There seems to have been a willingness to place the risks and uncertainties in context.

Embalming Problems and Soil Issues

Embalming practices, today using proprietary products based on formaldehyde (methanal) solutions, are commonplace in the USA and Canada. As a consequence the employees of organisations providing mortician services have been regularly targeted for consideration of relevant health aspects in this occupation from various perspectives such as disease transmission or risks from formaldehyde (methanal) exposure (see for instance; Nwanyanwu et al., 1989, Korczynski, 1994). In addition, since the early 1990s concerns have arisen in various places about the possible leaching of formaldehyde (methanal) from cemeteries into groundwaters.

Like most aspects of cemetery operations and processes the leaching of formaldehyde (methanal) has not been well studied, and there is little public information – but 'everyone is talking about it'! Cook (1999) produced a short magazine article which sets out the main concerns and reports that the matter has supposedly been widely considered by various regulating bodies. The only known study, however, is that of Soo Chan et al. (1992) for some Ontario (Canada) cemeteries. Their results indicated no significant problem but they did appear to find the substance within cemetery groundwaters, but with a major proviso- namely that their blank samples had unexplainable levels of formaldehyde (methanal) greater than that found naturally: all of which gives little confidence in the use of their results.

This issue, with comment on the sampling and testing of formaldehyde (methanal), was also addressed by Wendling (1991) who concluded that proper siting of cemeteries and geoscientific evaluation was probably of much greater importance than testing for formaldehyde (methanal).

Of greater concern in the USA is the possibility of arsenic and lead leaching from embalmed bodies. It was common practice from the American Civil War times to embalm bodies with substantial amounts of arsenic salts. This issue has been quite thoroughly researched by Konefes (both professionally and as an interest, pers. comm., 2001) and is well summarized in Konefes and McGee (1996) These authors also cite the use of mercury in some embalming preparations and this has also been noted by Iverson (1994), but there is no detailed information recorded. Up to 6 or 12 or 15 pounds (6 kg) of arsenic was used per body (the amounts are inconsistently reported) and its form, other than it was in embalming fluid, is also unreported.

In an earlier paper Williams and Konefes (1992) reported limited sampling of remnant drinking water wells located in a variety of cemeteries in Iowa. These hand pumped wells typically abstracted from shallow unconsolidated, phreatic aquifers; the wells were located within, but in some cases may have been upgradient of, or not adjacent to, burial areas. These researchers were after evidence of arsenic contamination related to Civil War burials; 14 wells were sampled (Groundwater Newsletter, 1992). Details of the sampling techniques, the wells, or the background levels have not been reported, but 2 samples contained As in concentrations of 30 ppb. This information has been variously reported and restated in other newsletters and papers, for example Gaea (1992) and Konefes and McGee (1996).

The practice of embalming with arsenic compounds was apparently stopped in 1910. Another study (Hayden and Rayne, 1996) was apparently commenced at Hamilton College Cemetery, Clinton, New York state, in respect of arsenic, lead, zinc and mercury associated with a cemetery containing 68 bodies interred before 1910. However, the Researcher is not aware of any results reported from this study. In their study of soils from a cemetery and adjacent to interments dating from the mid to late 1880s, Sponberg and Becks (2000) found significantly elevated arsenic levels at depths > 1.4 m. They also found elevated concentrations on-site compared to off-site for the metals zinc, copper, iron, lead, and cobalt: all except the latter are probably relatable to casket construction.

Cemeteries in the Community

Some other interesting publications from the USA identify the role of cemeteries in other contexts. These contexts are likely to be applicable Worldwide and all are related to the correct geoscientific assessment of sites and/or understanding the relationships of landuse to the hydrological cycle.

In the USA the amount of fertilizers added to the vast lawn areas of cemeteries has received criticism (Kone, 1974, Farnsworth, 1974); similarly these sites have been delineated for the potential they offer for consumption of composted wastes and domestic fertilizers (Dakes and Cheremisinoff, 1977, Lang and Jager, 1990).

In New Orleans a hydrogeological problem of a different kind – namely the very high watertable (about 2 ft (0.6 m), as well as the city being below sea level) (Bloom, 1998) has caused a unique development of reusable "oven vaults". Despite many efforts at below-ground burial the original Spanish and French settlers apparently resolved the problem by ornate above-ground methods.

The last matters in this thread concern the detection and relocation of cemeteries. From time to time, reports of historical or engineering interest about these aspects are published, for example see reports in ENR (1987, 1990). From another forensic and/or archaeological perspective the development of ground penetrating radar techniques has been well used in detection of interments, for example see Unterberger (1992), Mellett (1992) and others.

An important aspect has hitherto been absent from most of these investigations, however, see previous comments on UK exhumations. That is, the sampling and testing of soils and any captured (for example, in-coffin) groundwaters within the graves, for the presence of bacteria and viruses with a view to better understanding the longevity of such organisms and particles. An enhanced compilation of the detailed state of decomposition remains, soil type and hydrogeological setting, would advance the understanding of the interaction of cemeteries and the environment.

*

CHAPTER FOUR

THE INVESTIGATION

Contents

OUTLINE OF PROGRAM

A series of key tenets of the Study were related to the locations at which the investigations were conducted. These locations to be as representative as possible of:

* the Australian population in respect of the availability of cemeteries relative to population density so that there was a good likelihood of the ethnic diversity of the population being represented amongst those that chose a burial option;
* the cemetery industry and any variations in practices and management;
* a range of hydrogeological situations for operational cemeteries, and if possible including variations in soil and climate.

In addition, opportunities to consider various ethnic/cultural groups, identifiable via particular sections in cemeteries, for any likely effects due to interment practices, were also sought. At least this was a "wish-list" of how things ought to be done. The final outcomes were tempered by the costs of continuously expanding the Study's horizons, the availability of Contributing Research Partners to provide funding, and the time availability of the Researcher.

Cemeteries in a majority of the country's capital cities were likely to substantially meet the needs. As noted in Chapter One, about 63% of the country's population is located in our major urban (Capital City) areas. It was not possible to study cemeteries in the Brisbane/Gold Coast or Darwin areas. This had the effect of disenfranchising the sought-after representation for about 9% (ABS, 2000) of the population. Whatismore, the effect of not having sites to consider in these areas also meant that tropical and more sub-tropical climatic areas were not available.

Nevertheless, the Study has focused on a significant proportion of the population likely to be interred, together with their variations in cultural and religious practices during burial. The cemeteries studied and their representation of recent census statistics for distribution of the Australian population are shown in 4.1.

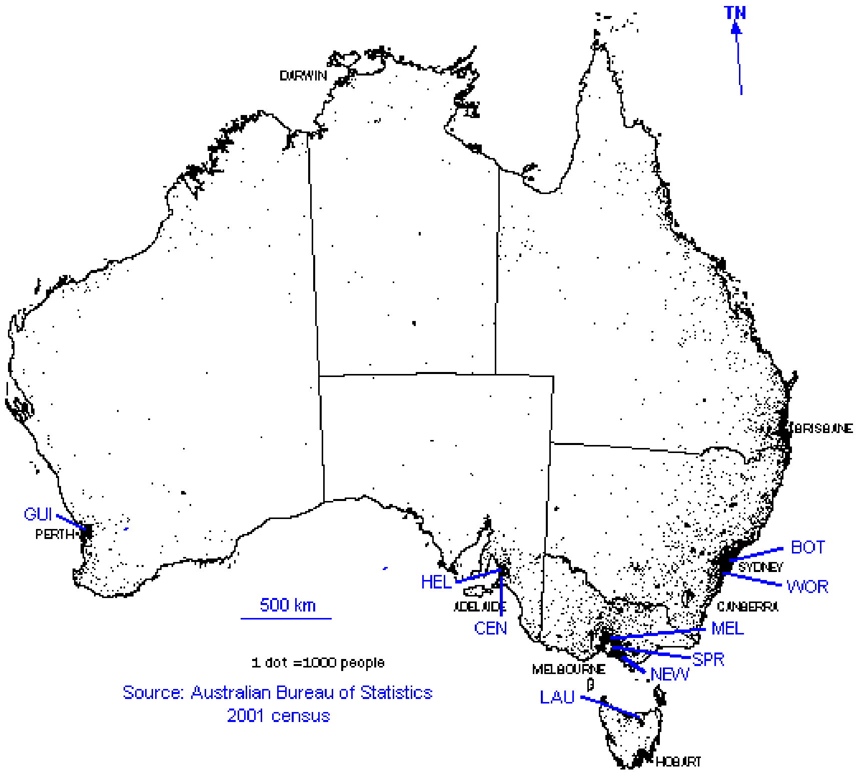


Figure 4.1 Location of Cemetery Sites Relative to Australian Population

Climatic considerations are the least explored in the whole Study. Of the sites investigated; none lay closer to the Equator than the 31.7°S (GUI) or further south than 41.5°S (LAU). However, this means that the results can be considered to be widely applicable to all temperate, and similar dry summer areas (Aust. Bureau Meteorology, 2000), of the World where the population has substantial influence from Anglo-Celtic heritage and/or has interment practices roughly in keeping with those of the United Kingdom (see Dunk and Rugg, 1994 and Environment Agency, 2000).

From the outset, five key conditions served to direct all considerations for the field and evaluation aspects of the Study. Specific site aspects are discussed later. Firstly, any infrastructure established e.g. piezometers, had to be done entirely within the cemetery boundaries. There were no agreements to locate such devices in local government property beyond the cemeteries' boundaries; this would have led to delays, additional permit requirements and the involvement of non-related parties.

Secondly, any infrastructure establishment was done on a permanent basis: the infrastructure is a capital investment for the sites and is also available for future study if required.

Thirdly, a full audit trail had to be available for any equipment or services purchased: in effect the cemeteries' monies or Victorian Government Grant are public monies. This was done by using the UTS financial systems established through its unit the National Centre for Groundwater Management. Consequentially to this was the need for all works to comply with state laws e.g. the licensing of investigation wells in Victoria and South Australia, as well as the furnishing of data in South Australia and Western Australia.

Fourthly the completion of the work had to be guaranteed, from all parties' points of view. This was attained by having formal research contracts between the Contributing Research Partners and UTS. The completion and supply of this thesis is the final condition of these contracts. At some stages of the contract with the Victorian Department of Human Services special progress reports and/or a seminar was required.

Fifthly, the intellectual integrity of the Study and the availability of the data and considerations had to be guaranteed. This was also done by way of the formal contracts with UTS and by the support of ACCA, the publication of results by Dent and Knight (see Chapter 1) and the promulgation of the Study's outcomes at conferences and professional societies (discussed elsewhere). The final non-contract stage in this process is expected to be the publication of several refereed papers in the international hydrogeological literature.

OVERVIEW OF SITES

At the commencement of the Study each potential cemetery site was visited and as much readily accessible published geological and hydrogeological data about the area was gathered. A consideration of this data and discussions with relevant cemetery staff led to an early evaluation of the sub-surface conditions of the sites being made available for the Study: this was followed by an initial assessment of methodologies required for greater investigation and sample collection.

In effect, the establishment of each site became its own site-specific investigation but this was tempered with its need to conform to the Study's overall strategies and financial parameters. Generally speaking, this meant that there was only limited opportunity to make initial subsurface investigations prior to establishing sample collection points. Financial constraints were key because the total money available for the Study was quite fixed and had to be spread over a very large range of tasks and requirements: consequently, decisions on sample point location and method were ‘final’. The physical factors that necessitated that approach were: the diverse hydrogeological environments of the cemetery sites, the need to sample in the vadose zone, in widely placed sites, for a wide range of analytes as was eventually sought (see later) and which required relatively large volumes of sample water.

The cooperative nature of the Cemeteries' Staff was an important factor in these early stages and did permit excavation of exploratory pits and up to 48 hour monitoring of water seepage in them at LAU and WOR; and boring of open seepage-well sized (600 mm diameter) holes at MEL (Melbourne General Cemetery), SPR and NEW. Extra sampling points were also able to be established at BOT, SPR and CEN while part-way into the Study.

A small site diagram setting out well locations is included in the following, however, full details of the individual sites - maps, geology, bore or pit logs, soil sample locations, as well as site photographs, are found in individual Appendices B to J.

Some limited modeling of decomposition product movement within the cemeteries is made later (see Chapters Four and Five). To assist with this and in order to better document the sites, the local rainfall was also considered. Comprehensive rainfall and evaporation records were obtained from the Australian Bureau of Meteorology for relevant recording stations: this data for the time of the Study is summarized in the Appendices B to J, for each site. Each site’s climate (Modified Köppen Classification) (BOM, 2001) is recorded below together with an overview of the rainfall data.

The GUI and parts of the BOT sites are founded within phreatic aquifers that respond relatively quickly to rainfall and drought events. HEL, which is also phreatic, seems to exhibit lag effects. For all these sites, as well as for SPR and NEW that are founded within semi-confined and/or phreatic aquifers which were not monitored as extensively as the others, well water level data is also presented in the Appendices B to J.

Eastern Suburbs Memorial Park (Botany Cemetery) (BOT)

This site comprises an area of about 24 ha is located approximately 11 km southeast of Sydney's Central Business District in the suburb of Phillip Bay. It occupies a geographically constricted setting being enclosed by industrial and landfill developments on most of two sides, the valley of ‘Yarra” Creek (not an official name, see Dent, 1995) along its southern boundary, small parks including one on the Botany Bay foreshore which hosts recycled materials above landfill, and an area formerly occupied by Bunnerong Power Station but now mostly attached to the cemetery. Major roads define two boundaries (Figure 4.2).

This site has undergone some notable changes and influences. It is in the first place a combination of the Bunnerong or New Botany Cemetery and the original Botany Cemetery (Zelinka, 1991). It has been extended at least once, has had the crematorium lands added and is now incorporating adjacent former power station land. The first interment took place in the original Botany Cemetery in August 1893. The former Bunnerong Cemetery portion is notable because it contains the re-interred remains of 21000 of Australia’s earliest settlers (Zelinka, 1991) and is now almost fully re-developed by standard interments: thus likely representing the first example of grave re-use in this country. The re-use practice described here, however, does not accord with the practices officially sanctioned in South Australia and are further discussed in Chapter Eight.

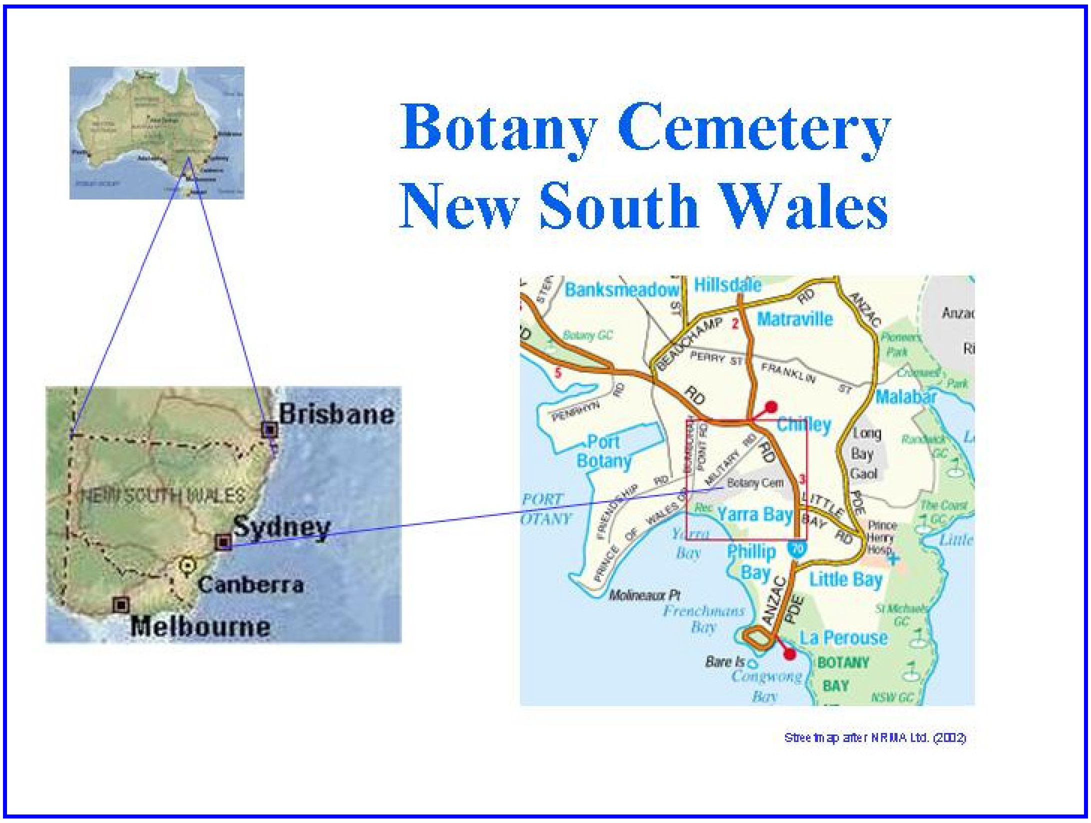


Figure 4.2 Generalised Site Diagram for BOT

Geologically, most of the central portion of the site lies on the northern edge of a small, Holocene and Pleistocene age, unconsolidated aquifer of aeolian sand dune deposits over reworked beach and fluviatile deposits which occupy a former small embayment on the eastern edge of Botany Bay. This hydrogeological unit has been called the "Yarra Aquifer" and was originally delineated and described by Dent (1995); see also Gallard (1998). The aquifer, which is about 80 ha in size, is partially drained by a perennial stream ('Yarra' Creek) which is fed by spring waters rising in the surrounding ridges of Hawkesbury Sandstone, a Triassic age unit. A centrally located streamline within the cemetery, generally flowing from north to south, joins the main stream just outside the cemetery boundary.

The remainder of the site mostly lies in aeolian dunes above weathered sandstone with minor siltstone lenses. A representative K = 0.8 m/day has been proposed by Dent (1995). The sandstone rises slightly above the cemetery to the ridges which entirely enclose the Yarra Aquifer.

Prior to the present Study this site was extensively studied by Dent (1995) in connection with the evaluation of a groundwater resource for the cemetery. During that work it was determined that the site was affected by two industrial leachate plumes containing BTEX (benzene/toluene/xylene) compounds and/or salts, and chlorinated hydrocarbons. Following this work, it became clear that the issue of cemetery decomposition products generally needed further investigation; see Knight and Dent (1995). The Trustees of the Eastern Suburbs Memorial Park were at the forefront in fostering this Research.

The present Study focused on a small area of relatively recent interments underlain by a definable watertable and flowlines heading towards and along the central streamline. These were accessed by a series of standard monitoring wells; and new background wells were established within the site. Eleven standard monitoring wells were employed for groundwater sampling (Appendix Figure B.2). During the study it became clear that the background well (B1) was yielding samples with some bacterial contamination. Consequently two other background wells (B11 and B12) were established and proved to be better suited to the purpose, but were only properly sampled once each.

All wells were established as new, however, B5, B6, B8 and B9 happened to be in the same locations, respectively, as boreholes HAH 26, 29, 4 and 7 used by the Researcher in the previous study (Dent, 1995).

Details of this site and specific hydrogeological data are located in Appendix B, whilst an overview of the sampling points and number of water samples taken is given in the next section. The site's climate is classified as 'Temperate – no dry season (warm summer)' ; average rainfall from 68 years of records at Sydney Airport is 1103.4 mm/a.

Woronora General Cemetery (WOR)

This site is located in the southern Sydney suburb of Sutherland and comprises approximately 51 ha. It is enclosed by residential development on two sides and by parks and reserves for the remainder (Figure 4.3). The land behind hosts near pristine sandstone plateau landscape leading to a cliffline well above the Georges River. The ground comprises residual sandy clays and minor clayey sands, often lateritised, overlying a quartz sandstone (Hawkesbury Sandstone) with substantial siltstone lenses; one of these was mined for brick clay and subsequently backfilled with overburden (Boyd, 1995). The first interment occurred on 1 April, 1895.

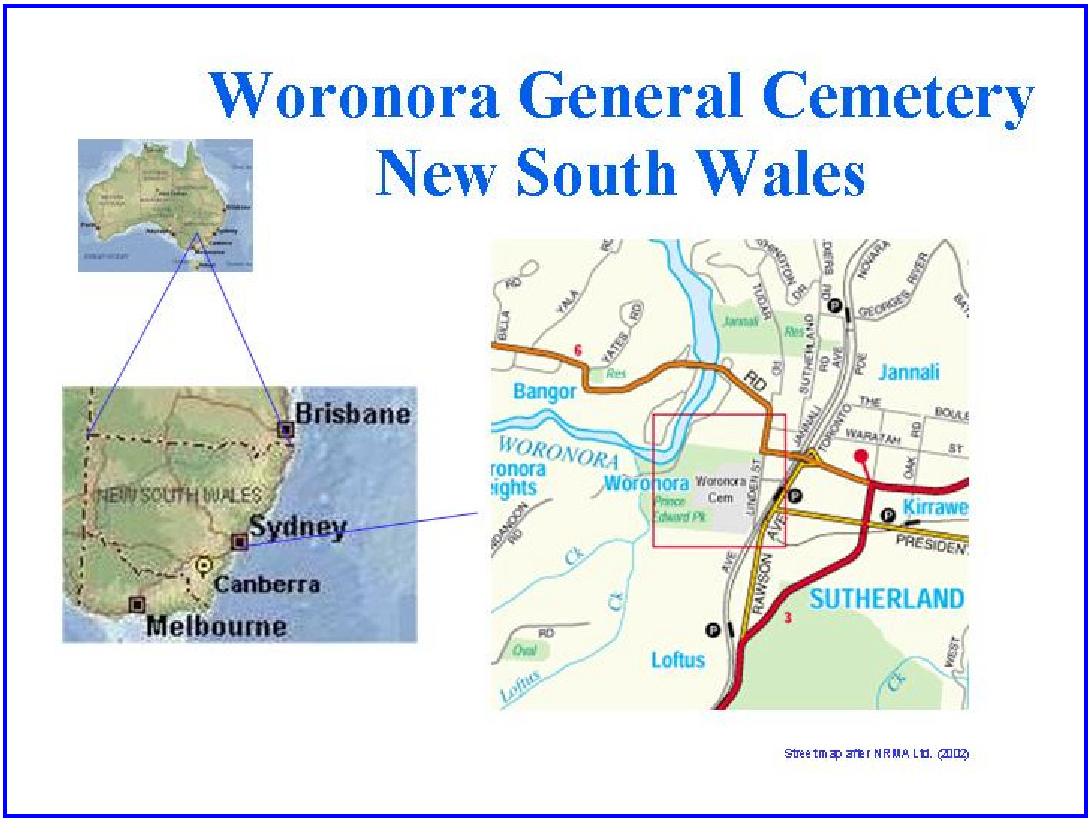


Figure 4.3 Generalised Site Diagram for WOR

The bedrock hosts a variable, but active, spring system with perched watertables readily apparent. From its earliest times, subsoil drains filled with broken rock and tile were constructed and extended throughout much of the cemetery (Boyd, 1995, Smith, 1997, pers. comm.). These drains are generally led off the site; they are significant interruptions to the normal hydrogeology of the site but have been essential to make it workable and dry underfoot in most places at most times.

The influence of such drains is considered in Chapter Seven, whilst details of this site and specific hydrogeological data are located in Appendix C; an overview of the sampling points and number of water samples taken is given in the next section. The study of the site's vadose zone was accomplished using seepage wells (Appendix Figure C.2) close to the perimeter and within internal parts where the near-surface spring system could be tapped. One subsoil drain was also sampled and an experiment to observe downgradient migration of decomposition products was attempted.

The site's climate is classified as 'Temperate – no dry season (warm summer)'; average rainfall from 37 years of records at Lucas Heights is 1061.0 mm/a.

Melbourne General Cemetery (MEL)

This site is located on the uphill, immediate edge of the Central Business District of Melbourne in a suburb called Carlton North. It comprises a total of about 42 ha and is fully developed. Except for interments into existing family plots and into the new mausoleum, there have been no new gravesites allocated since 1980 (Spark, 1997, pers. comm.). The site is surrounded by residential and educational development on 3 sides and parkland for the remainder. Busy streets define the cemetery boundaries Figure 4.4).

The first interment occurred on 28 May 1853, when the cemetery took over the principal burial role from the original Melbourne Cemetery which was located nearby.

The majority of the site is comprised of fractured siltstone (Dargile Formation) of Upper Silurian age (Geol. Surv. Vic., 1974). This formation is described as being comprised of siltstone, sandstone, and minor shaley siltstone. At the site the formation was covered with brown coloured, residual clayey and sandy clay soils to a maximum 2.8 m, but more usually 1.2 – 1.4 m deep. Mostly the soils and bedrock were moderately to highly impermeable, but there was clear evidence of springlines and shallow groundwater pathways, as for example erosion in roadways. A number of ephemeral seepage lines were intersected in the seepage wells established in order to obtain groundwater samples.

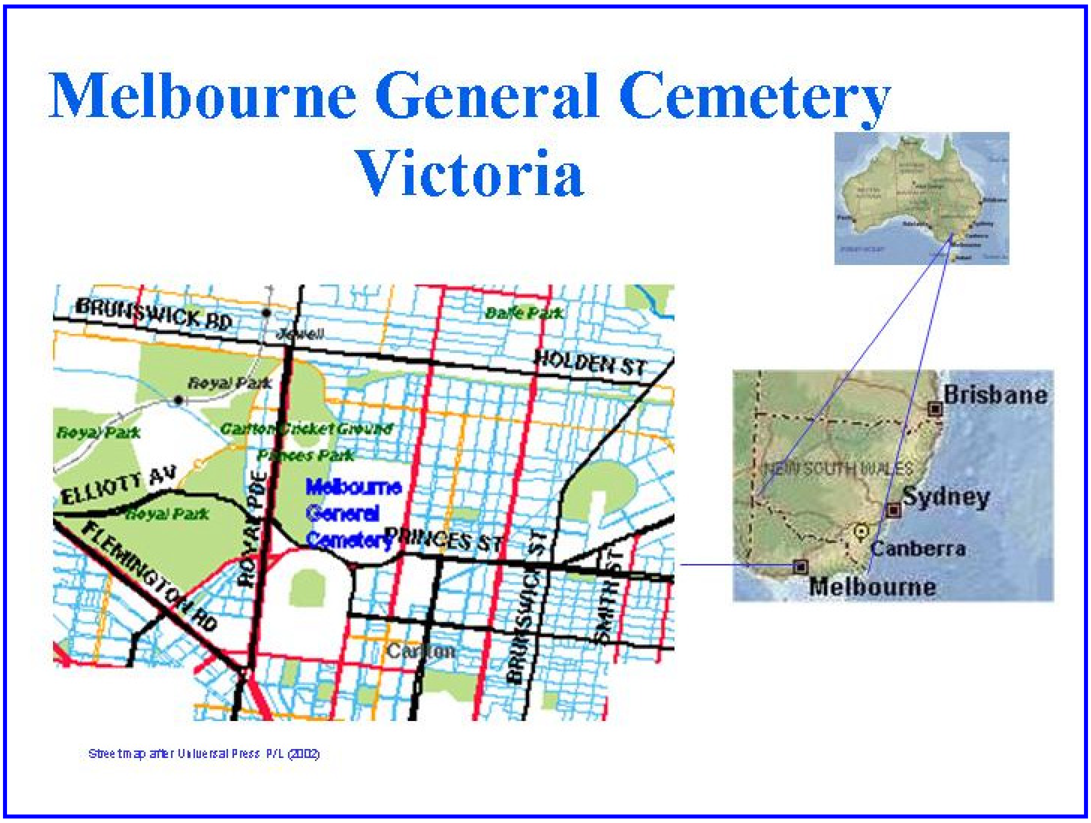


Figure 4.4 Generalised Site Diagram for MEL

The northwestern third of the site, which is generally the more elevated area, is overlain by Pliocene age sand deposits (Red Bluff Sand) of variable composition (Geol. Surv. Vic., 1974). Cemetery staff (Scheele, 1997, pers. comm.) reported that this material is frequently very hard to excavate causing difficulties for interments and that it also runs groundwater. This latter aspect was not observed by the Researcher but is presumed to result from highly localised infiltration.

The northeastern corner of the site contains much fill – mostly thought to be overburden from previous interments (Scheele, 1997, pers. comm.). Much of this fill was placed over an unknown number of earlier interments and the filled area was subsequently re-used for shallower interments. The historical details of such management and practice are now lost, but this occurrence is likely to represent an unofficial re-use of grave space; and one of the few examples of this process by employing pure landfill methods. The hydrogeological conditions in this part of the site are quite disrupted and were not further considered in this Study. One seepage well (M6) is located immediately adjacent to and upgradient of this filled area; the location of sampling wells is shown in Appendix Figure D.2.

Details of this site and specific hydrogeological data are located in Appendix D whilst an overview of the sampling points and number of water samples taken is given in the next section. The site's climate is classified as 'Temperate – no dry season (warm summer)'; average rainfall from 142 years of records at Melbourne Regional Office of BOM is 657.9 mm/a.

The Necropolis - Springvale Cemetery (SPR)

The Necropolis, is located at Springvale a southeastern suburb of Melbourne, Victoria. It occupies a gently sloping area of about 160 ha and is roughly pentagonal in shape. It is bounded on two sides by busy roads, by an intermittent stream which the cemetery Trust has dammed on its west, residential, light industrial and other cemetery lands (two separate Jewish cemeteries) for the remainder (Figure 4.5). The stream defines its lowest points and the general direction of site drainage whilst the uppermost portion is in the northeastern corner where a small open reservoir has also been constructed.

The topography of the site is an important feature to be appreciated because it does not reflect the underlying groundwater conditions. The site is comprised of densely unconsolidated to partially consolidated, firm clays to 10-12 m overly sandy silts, silty sands (Brighton Group) containing a phreatic (probably) to partially phreatic aquifer at 14-28 m Immediately adjacent to the stream the incline of the slope steepens noticeably, so that at the cemetery boundary on the stream banks the depth to the water table is only about 4.8 m. The watertable has a very shallow gradient under the whole site, whilst the land surface has fallen about 26 m.

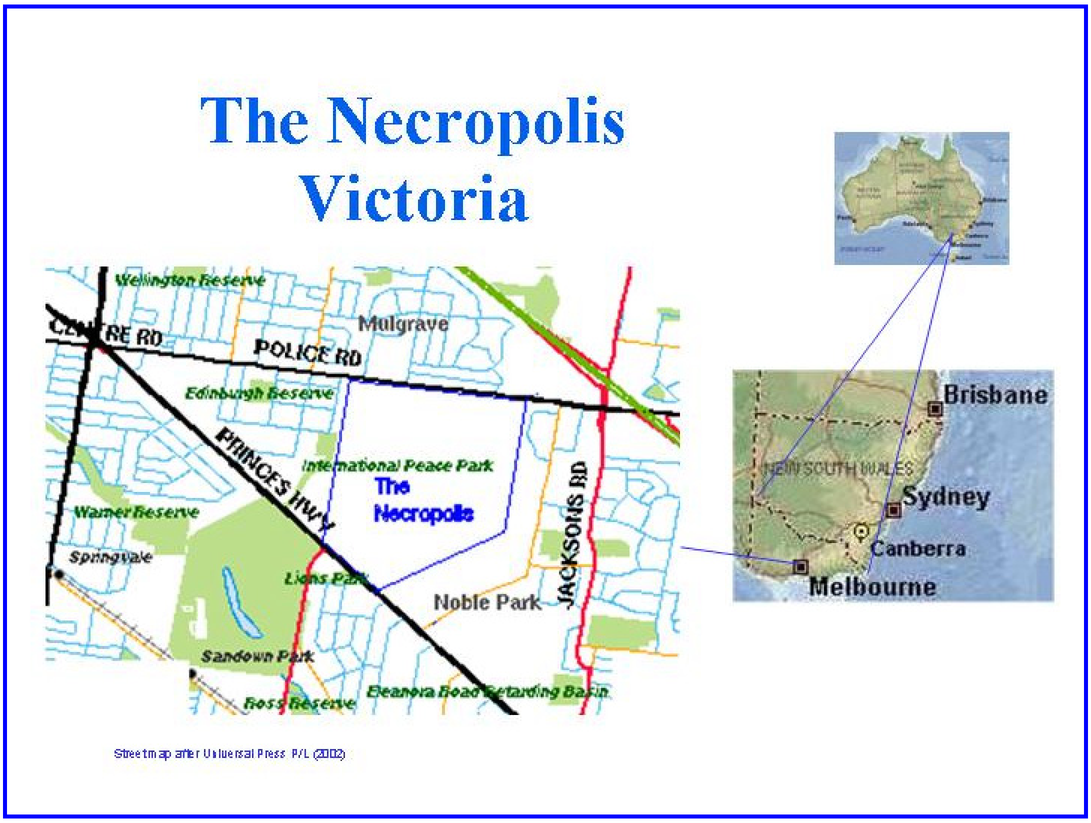


Figure 4.5 Generalised Site Diagram for SPR

It is likely that parts of the aquifer are partially confined and that ephemeral perched water tables are present – particularly after rain. The seepage wells used to assess the upper vadose zone (the seepage wells are at 2.5-5.5 m depth) certainly worked as satisfactory sinks and were able to be sampled on most occasions (see tables in a later section). Well locations are depicted in Appendix Figure E.2.

The first interment at the site occurred in 1902 and since that time a large number of interment styles and ash scattering areas have been developed. However, all interments are coffinated (Spark, 1997, pers. comm.). A very large portion of the funerals at this site result in cremation, a practice here since 1905; consequently a large crematorium is present with substantial ash pits. These pits are located in the vicinity of the stream (western boundary). An effort was to be made to assess their impact, however, that proved to be impossible within the constraints of this Study. This is an aspect of the general topic that needs further investigation.

Details of this site and specific hydrogeological data are located in Appendix E whilst an overview of the sampling points and number of water samples taken is given in the next section. The site's climate is classified as 'Temperate – no dry season (warm summer)'; average rainfall from 40 years of records at Moorabbin Airport is 730.1 mm/a.

Bunurong Memorial Park (NEW)

This site is very new, the first interment occurred in February 1996 and at the conclusion of the Study in October 1998 there had been 501 interments in the whole site. About half of an approximately 120 ha area is currently developed for the cemetery and crematorium at Bangholme a suburb on the southeastern edge of the Greater Melbourne metropolitan area (Figure 4.6).

Figure 4.6 Generalised Site Diagram for NEW

This site represents an excellent opportunity for long-term monitoring with data virtually available from inception. Upon the site's establishment some peripheral monitoring wells were established. These proved to be suitable for this Study as background wells; whilst an additional two standard wells and two seepage trenches (in the non-Muslim area) were installed downgradient of the earliest interments.

Despite diligent enquiries and contacts it proved impossible to obtain original details of these monitoring wells. However, the driller who had installed them was fortuitously engaged for the present Study at SPR and as much information as possible was obtained from him. It is certain that the wells were installed to a good standard with a 3 m PVC screen that mostly (if not always) straddles the watertable: accordingly these wells were deemed suitable for the sampling required in this Study and more details are presented in Appendix F. Well locations are depicted in Appendix Figure F.2.

In early 1997 a special area was developed to accommodate non-coffinated Muslim interments. However, the rate of usage of this area was too slow for this Study and the use of seepage trenches NT3 and NT4, which were specifically emplaced in order to examine these burials, was of very limited value.

The site has the disadvantage of being comprised entirely of imported sandy clay, clay and clayey sand fill which has been mounded onto the existing poorly drained floodplain. The primary site is low lying and essentially flat; present relief is due to the emplaced 2.0 – 3.0 m fill layer. From observations of graves it appears that the original land was generally poorly prepared for the filling task: some topsoil and vegetation appears not to have been stripped, drainage at the fill/natural boundary has not been intercepted and some fill may not have been correctly keyed in. Some of the original fill (in the area of the first interments and the administration area) was deemed to be unsuitable and/or contaminated for the task and was subsequently removed (Gilbertson, 1997, pers. comm.).

The natural site is comprised of a phreatic aquifer hosted in Quaternary, unconsolidated, undifferentiated paludal sediments (Leonard, 1992). The nature of the sediments is sandy at the site but also contains silts, clayey sands, silty sands, pea gravels, gravelly sands, some clays, and probably peat. Parts of the site behave like a semi-confined aquifer wherein groundwater levels rose quickly when breached in investigative borings; most of the site is now also substantially influenced by the low hydraulic conductivity fill mound. The natural surface is poorly drained for overland flow and the district is host to large drainage works leading to the Patterson River and Port Philip Bay.

Details of this site and specific hydrogeological data are located in Appendix F whilst an overview of the sampling points and number of water samples taken is given in the next section. The site's climate is classified as 'Temperate – no dry season (warm summer)'; average rainfall from 40 years of records at Moorabbin Airport is 730.1 mm/a, as for SPR since the climate station is about equally spaced from each site.

Carr Villa Memorial Park (LAU)

This site is located in Kings Meadows a southern suburb of Launceston (Figure 4.6). The dedicated cemetery area is approximately 64.5 ha and the first interment was in 1905; part of the general site now includes an excised portion – Carr Villa Flora Reserve. Prior to this, and on occasions until about the 1970s, the site had a mixed land usage including being extensively logged for charcoal production, shallowly mined for gravels and a site for nightsoil disposal. The topography is gently undulating and the site hosts two broad gullies that rise in its eastern upper portion and flow northwards; they host ephemeral streams but have readily detected sub-surface flows, albeit along restricted flowlines at the thalweg.

The central of the two gullies has been partially filled at its upper end and now comprises lawn burial areas and hosts a significant drainage pond. These lawns are regularly irrigated which contributes to a groundwater flow system heading along the thalweg and beneath the pond.

The pond feature is quite important; it was the only such feature routinely sampled during the Study. It receives overland flow and direct rainfall as its only sources of replenishment and chemically has been shown to be some of the purest water in all of that sampled. Bacteriologically it suffers from being an open source which is influenced by dust, wildlife and neighbourhood dog bathing.

Figure 4.7 Generalised Site Diagram for LAU

The whole of the site is comprised of Tertiary sediments – sandstone, clays, ferruginous clays and sandy gravels, of unknown extent and which vary from unconsolidated to partially consolidated. Sometimes a normal soil profile is present (podsols developed under scherophyll woodland), sometimes considerable laterisation is present and elsewhere only skeletal to nil soils appear. The clays show considerable variation in mottling and texture and at times are sufficiently fractured or hosting coarse facies to permit groundwater flow; or they are tight and relatively impermeable. Seepage well L1 was the only sampling point in the whole Study that remained dry throughout the entire investigation.

Iron-rich groundwaters are common but irregularly encountered at the site and in the nearby district. The northeastern corner of the site in the vicinity of sampling points L5 – L8 is the site location most influenced by this phenomenon, and also a location where springlines occur.

Considerable difficulty was encountered in obtaining a suitable background sampling point. After seepage well L1 consistently failed to produce groundwater, a separate attempt was made to establish a background well in the eastern gully area at the same time as additional investigations were made of the groundwater flow system beyond the pond. In the last eleven months of the Study after the establishment of the additional seepage wells, no background samples were obtained. Well locations are depicted in Appendix Figure G.2.

Details of this site and specific hydrogeological data are located in Appendix G whilst an overview of the sampling points and number of water samples taken is given in the next section. The site's climate is classified as 'Temperate – no dry season (mild summer)'; average rainfall from 65 years of records at Launceston Airport is 684.4 mm/a.

Centennial Park Cemetery (CEN)

The Centennial Park Cemetery lies in the basal part of the Adelaide Hills and comprises approximately 40 ha; the first interment was in 1936 (Figure 4.8). The site lies mostly in deep, transported and possibly some residual, alkaline clay soils – mostly known as the Hindmarsh Clay, and which are typical of the lower slopes (Upper Outwash Plain, Aitchinson, et al. 1954) of the Adelaide Hills. It is difficult to precisely identify the geological units present and their true relationships because of the combined depositional and residual nature of the site's soils. These soils also contain shoe-string gravels and sands (Sheard, 1996 pers. comm.), of unknown extent but with possible connections well into the Adelaide Hills at the rear, and above, the site. The soils characteristically absorb surface water and internally drain at a moderate to slow rate (Taylor, et al., 1974).

The soils comprise a variable mixture of heavy and stiff, mottled clays of grey and red-brown hues, gravelly clays, light brown sandy clay, and sandy clayey silt. These can be moist or dry and host caliche nodules to 30 mm diameter or frequent $CaCO_3$ granules. At depths from 0.3 – 1.5 m rounded quartzite cobbles to 200 mm diameter are common but variably located, sometimes these are in bands. The heavy clay soils doubtlessly have a very low hydraulic conductivity and from the evidence of extremely limited sub-surface seepage to the seepage wells, probably are little fractured.

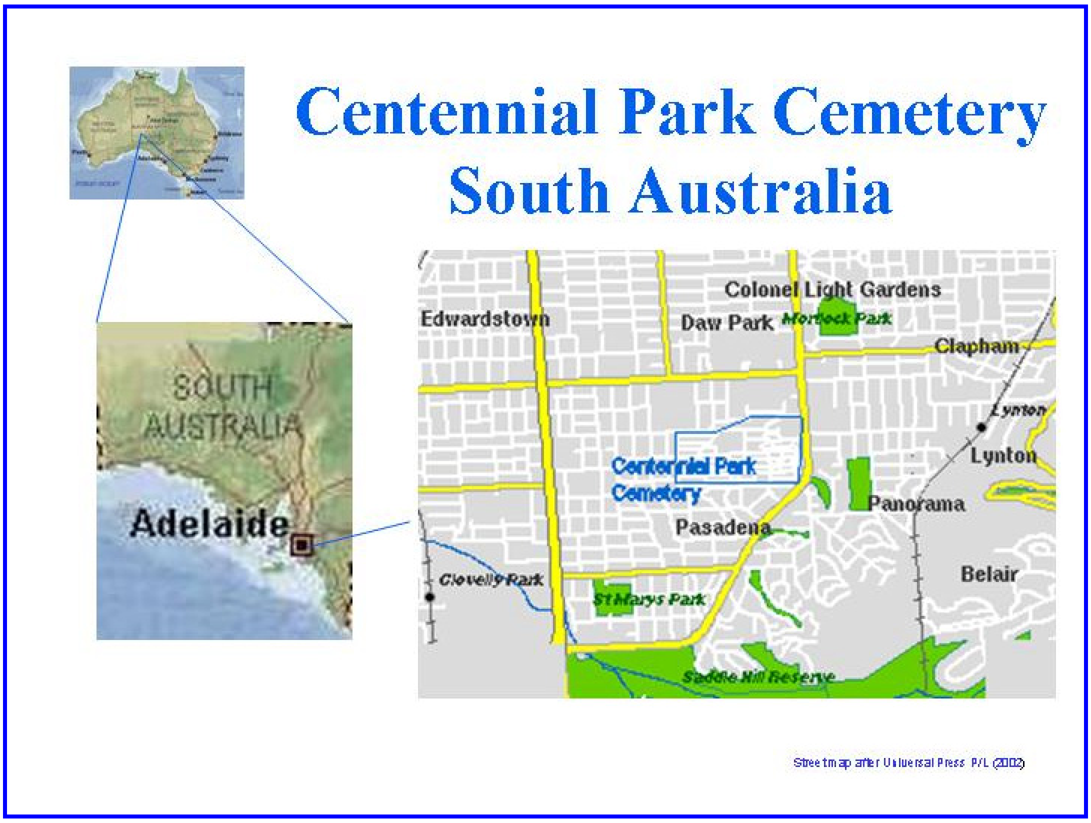


Figure 4.8 Generalised Site Diagram for CEN

The pathways of the shoe-string channel fills are completely unknown; but these were encountered in the central and northwestern parts of the site in wells C1, C2, C3 and C5 (Appendix Figure H.2). In C2, C3 and C5 the groundwater was confined or semi-confined and rose to a new piezometric surface when encountered. The well at C5, the closest to the northwestern corner, of all the wells here, was established in a significant depth of fill. This fill, estimated to be up to 2 m deep, was built up during the years of cemetery operations by the haphazard dumping of overburden from grave and other excavations.

In the uppermost part of the soil profile to depths of up to 2m, there are extensive networks of subsoil drains which doubtlessly influence groundwater flow in the unsaturated zone. Extensive lawn irrigation also effects the sub-surface water distribution at any time. Subsoil drains are mostly aligned along the Central Drive and in the upper northeastern and lower southwestern areas. The western boundary comprises a road above a piped watercourse (pipe of 1.2 m diam., Platten, 1996, pers. comm.) with a small garden buffer zone.

A substantial subsoil drain, believed to be up to 4 m deep (Platten, 1996, pers. comm.) lies immediately above the site beneath Goodwood Road – the generalized eastern boundary. This drain has the effect of substantially intercepting upgradient drainage beneath the site. One background well (C6) established near this boundary was consistently dry during the Study. Two investigative bores put down in the same vicinity in the initial search for establishing a background well failed to show any freely moving groundwater. A consequence of these works is that the shoestring gravels first intersected at upgradient positions within the site are very likely to reflect regional off-site groundwater flowlines to a large extent, and may be used as a representative 'background' water.

The CEN Trust has been extremely concerned about water supply and drainage issues at the site since 1941 at least (S.A. Dept. Mines, 1941). Since the 1980s it has commissioned several ground and surface water studies of relevance and been party to Government investigations of Adelaide's water supply – (Gerges, 1981) when a production bore was established near the present crematorium (see Appendix H).

Details of this site and specific hydrogeological data are located in Appendix H whilst an overview of the sampling points and number of water samples taken is given in the next section. The site's climate is classified as 'Grassland– warm (persistently dry)'; average rainfall from 72 years of records at Adelaide's Waite Institute which occupies a similar foothills location as the site, is 618.6 mm/a.

Cheltenham Cemetery (HEL)

The Cheltenham Cemetery comprises an area of about 14.6 ha; the first interment occurred on 27th July, 1886. The site has been increased three times since commencement by adding immediately adjacent land and closing contained roads (Figure 4.9). It is one of the oldest, still active cemeteries in Adelaide. This cemetery is the ‘birthplace’ of official grave re-use in Australia. By a fortuitous combination of the right-of-burial legislation in the state of South Australia, and the geography of the Adelaide urban area, many cemeteries are widely invoking the management practices of grave re-tenure and re-use: this is discussed in detail in later chapters, and the influence of re-use on groundwater composition is considered in Chapter Five.

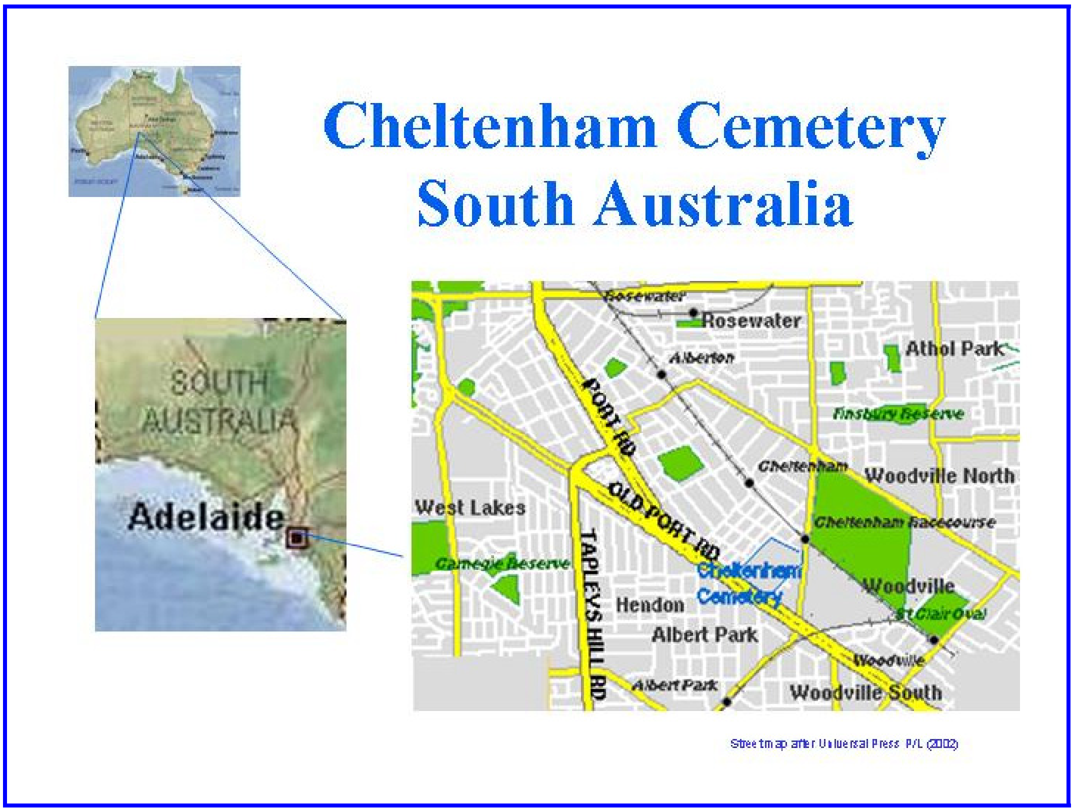


Figure 4.9 Generalised Site Diagram for HEL

The site is hosted by an aquifer of the Adelaide Plain called the Pooraka Formation, with a phreatic surface between 4 – 4.7 m below ground surface. The surface geology of the Adelaide area is complicated by a series of outwash alluvial fans from the Adelaide Hills overlying residual and transported materials. This site occurs within the River Torrens Fan of the Lower Outwash Plain (Aitchinson et al., 1954). The soils comprise light and dark brown and yellow brown silty and sandy clays, silty clayey sands, and minor silty sand lenses. The latter probably representing channel fills. The soils are reported to be relatively low in lime content but possibly affected by fluctuating saline groundwater (Taylor et al., 1974).

Most hydrogeological investigations in this District have focused on deeper, confined aquifers underlying the Adelaide Plain, and there is little readily available data on near-surface groundwaters. These groundwaters are variously reported as perched and/or with variable depths 1.5 – 6 m, saline, low yielding and occasionally used for market gardens and stock supplies (see e.g. Taylor et al., 1974, Gerges, 1987), locally restricted and variable and subject to level variation with rainfall and seasonally (Miles, 1952). An isolated measurement of hydraulic conductivity on soil similar to those at Cheltenham Cemetery has yielded hydraulic conductivity, $K = 10^{-4}$ m/day (Gerges, 1996, pers. comm.).

Hydraulic gradients of the Cheltenham Cemetery are extremely low (0.0007 to 0.004). Since monitoring commenced in September 1996 they have shown some reversals in direction with a number of stagnant areas likely to have developed. The standard wells near the cemetery boundary, but still within cemetery grounds, have experienced groundwater flows from offsite as well as from within the cemetery. During this Study the watertable in this cemetery has lowered by about 0.3 - 0.5 m in 9 months. The September 1996 watertable was about 0.2 – 0.6 m below average invert levels of individual graves. Well locations are depicted in Appendix Figure I.2.

The phenomenon of lowered watertable was originally interpreted as a direct reflection of drought conditions (Knight and Dent, 1998); however, a closer scrutiny of the long-term combined rainfall and evaporation data for the site (Appendix I) suggest that this relationship is probably not as immediate as first thought. It is more likely that lag effects in infiltration have been observed.

Details of this site and specific hydrogeological data are located in Appendix I whilst an overview of the sampling points and number of water samples taken is given in the next section. The site's climate is 'Grassland– warm (persistently dry)'; average rainfall from 42 years of records at Adelaide Airport is 450.4 mm/a.

Guildford Cemetery (GUI)

The Guildford Cemetery, Perth, WA is sited on Holocene shallow marine, clayey and silty sands and fine sands (Bassendean Sand formation). This site consists of an area of about 24 ha of which only about 9.5 ha is actively in use. The cemetery reserve contains a large amount of relatively undisturbed native vegetation as well as significant introduced vegetation in the developed part relating to the district's earliest pioneer settlements and usage. The first interment was about 1892 (records of the Metropolitan Cemeteries Board, 2001). For these reasons the site is placed on the Western Australian Register of Heritage Places and lately has come under the influence of the Perth BushPlan (MacLean, 2001) which will have the effect of severely limiting further development (MacLean, 2001, pers. comm.).

The site is roughly bisected by a major road (Kalamunda Road) which has had significant levels of large vehicle movements on it for a long time (Figure 4.10). The results obtained for the site (see Chapter Five) reflect this occurrence. The site has provided other significant aspects for the Study; notably the undisturbed background area for a site on a phreatic aquifer, and an area of relatively recent interments of shallowly buried (1.4 m average), single occupied, non-coffinated bodies but wrapped in shrouds according to traditional Muslim practice. Well locations are depicted in Appendix Figure J.2.

The site's unconsolidated sediments comprise a phreatic aquifer with the watertable at 1.8 - 4.5 m. Previous studies of the site have been undertaken in order to assess the relatively shallow watertable and its impact on possible burial areas (Soil & Rock Engineering P/L, 1986) . This information was made available for this Study and assisted in the location of sampling wells; however, this Study's results are at some variance to the previous work. In addition, since the 1986 study an expressway (Gt. Eastern Highway Bypass) has been developed along the site's northern boundary and is likely to have had some influence on groundwater flow in the site. At the time of the initial site inspection in winter 1996, a high watertable was evident as large groundwater fed ponds and an amount of swampy ground within the unused portion of the cemetery reserve. This phenomenon was also reported in the 1986 study, but the pond features were never seen again during this Study.

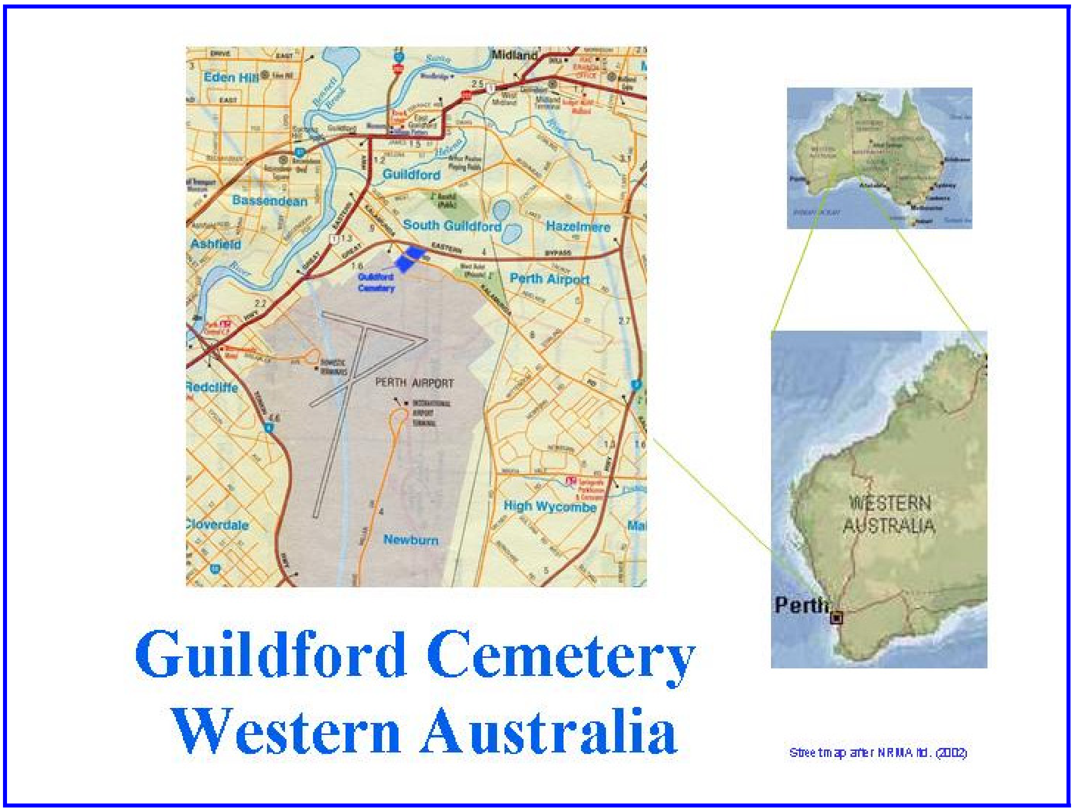


Figure 4.10 Generalised Site Diagram for GUI

Details of this site and specific hydrogeological data are located in Appendix J whilst an overview of the sampling points and number of water samples taken is given in the next section. The site's climate is 'SubTropical – distinctly dry summer'; average rainfall from 53 years of records at Perth Airport is 797.8 mm/a.

SAMPLING POINTS

Four types of sampling points were used to access the full range of vadose zone seepage or phreatic aquifer watertables. This included the development of novel collectors for a number of sites. The sampling points are referred to throughout this thesis by the terms listed below. Complete details and borelogs for individual sites are located in Appendices B – J, and analyses of the sands used in the filter packs are to be found in Appendix K. Each sampling point is designated by type in Table 4.1.

This table also includes a summary of the number of sampling events of each location and other data which is discussed below.

Wells. These are piezometers of standard design. They were drilled using truck or trailer mounted hollow flight augers, typically 200 mm in diameter. Graded sand (filter pack) encompasses, and is completed above, the screened interval. A mortar plug up to 300 mm thick was then emplaced and the remainder of the bore backfilled with site materials. However, in the cases of G1 and G2 a bentonite seal was established above the filter pack. This practice was abandoned and replaced by a cheaper, and easier to install, sand-cement mortar seal (see additional discussion below).

Seepage Wells. These are boreholes approximately 400 - 500 mm in diameter and up to about 5 m deep. They were drilled with short-length solid flight augers, frequently boom mounted. The base of the bore was covered with graded sand (filter pack) to about 200 mm depth and then the standard piezometer tube held centrally until about 100 – 200 mm above the screened interval was completely backfilled with the sand. A mortar layer about 100mm thick was then carefully poured onto the filter pack and the bore completely backfilled with site materials. Further analysis of this method is given below.

Seepage Trenches. These are trenches 450 mm wide and up to 6.0 m long and 3 m deep cut with a backhoe. This style of sampling point was used to intersect a diffuse drainage or spring area in the case of LAU, and to intersect the fill/natural boundary in the case of NEW. These were sites where particular seepage conditions were thought to be worthy of sampling. The base of the trench was gently graded to a small sump about 300 mm in depth located at one end. About 200 mm of graded sand (filter pack) was laid on the trench base then slotted piezometer tubing was centrally emplaced on this for the whole length connecting to a riser pump with sump tail piece. The trench was then backfilled to a further 300 – 400 mm with the sand. A layer of tough PVC plastic sheet was laid above the filter pack and around the riser pipe. A layer of low slump (relatively dry) readymixed concrete 100 – 150 mm thick was then emplaced and the remainder of the trench backfilled with site materials. Further analysis of this method is given below.

Ponds. Initially it was thought that a number of artificial lakes or ponds at the sites would be sampled. Early-on however, it was determined that a satisfactory study of such storages would involve too many resources for the Study and was in many cases was not relevant to the groundwater system. This was either because they also trapped off-site runoff, recycled site drainage and irrigation waters, were augmented by mains water or were decorative surface features. Only one pond - at LAU, which was thought to probably be connected to groundwater flowlines, was sampled routinely. Subsequent analysis suggests that this pond is in fact only maintained by on-site irrigant and rainfall runoff.

The basic completion layout for each sampling point was a 50mm i.d., Class 18, PVC tube, capped at the base or end, with basal slotted screen length of 1.0 – 6.0 m, and led to the surface directly or from a sampling sump 0.3 m deep. At all sites except CEN and HEL these piezometers were finished above the surface with an approximate 0.7 m capped collar which was then encased by a capped, locked, metal housing. The piezometer covers had a flanged footing which was then embedded in a pad of concrete about 0.8 m x 0.8m x 0.15m which provided a surface seal. The screens comprised slotted tubing with 3 equal-sized slots per circumference and opening widths of 0.4 mm. All tube lengths were screwed together; no glue was used in any new installation. However, it was noted that PVC glue had been used above the screens for existing piezometers N1 – N5 used for sampling at NEW.

At CEN and HEL the sampling points were completed just below surface level. Here the piezometer tubes were capped and covered by a tough plastic irrigation valve box, which was in turn embedded in the concrete surface sealing pad. The box was free-draining into the site soils. At every sampling event of these installations it was verified that any surface runoff had not penetrated the well. This system was only employed in Adelaide and was used in order to be visually less intrusive.

All the piezometer tubing was supplied by Iplex Plastics Pty. Ltd. in Brisbane and shipped direct to each site. The tube and screens were washed in dilute hydrochloric acid at the factory, packed and well sealed inside plastic bags. The tube always arrived on site in good condition and it was carefully stored prior to use. During sampling point construction the tube was handled minimally and cleanly in order to prevent site artefacts entering the prepared well. Local, graded filter sands were used for the filter packs.

A rare opportunity was afforded to check the efficacy of the well sealing procedures when well N8 had to be reconstructed. During installation of the filter pack two aquifer systems were inadvertently linked – the site's underlying aquifer and the perched watertable system at the fill/natural interface. When the mistake was realized, before any sampling event, the upper 3m was excavated and the filter pack lowered, a new seal created and the piezometer reconstructed. The near-surface fill soil at this location is very wet, yet the original filter sand from the position of the original seal to the perched watertable was completely dry.

VADOSE ZONE TECHNIQUES

The sampling of groundwater in the vadose zone is not as easy as saturated zone sampling because of the total amount of water present and the variability of its presence with changes in percolation rates and evaporative effects. The usual techniques available consist of sampling vadose zone solids and then extracting pore fluids or using some kind of lysimeter or porous suction sampler because of the negative matric head. Neither of these techniques lend themselves to sampling the same location time and time again or to returning large volumes of fluid. Alternatives are the construction of standard type wells in the deeper part of the vadose zone with the hope of trapping perched water tables. All these methods are reviewed by Wilson, 1990 who also points out that unsaturated zone flows are usually ephemeral.

The requirements of this Study meant that significant volumes of sample water were required from the same location on a number of occasions. An effort was therefore made to trap the unsaturated zone flows. Some of these result from ephemeral perched watertables, and/or spring or diffuse flow emergent areas, and others are merely resultants of percolation of rainfall or irrigant waters applied by the cemeteries. The amounts and timing of flows vary considerably. The principle guiding emplacement of the seepage wells and trenches, however, was that they should gather significant flows that have a high likelihood of interacting with interred remains; i.e. that there is a likelihood of significant length pathways (flowlines) to the well or that they intersect some obvious hydrogeological feature. As with any well installation it was important to prevent any seepage from the surface direct to the filter sand interval. In these cases though the surface area of the seepage well or trench was large; for this reason a great deal of effort was spent in emplacing a seal above the filter sand and completing the surface piezometer casing pad.

It was reasoned that a large storage volume would function as a sink and preferentially accumulate sufficient groundwater in the short term to permit the requisite sampling. The considerations showed that the method would be better suited for finer grained soils and it would be expected that once accumulated the well would then work as a reservoir and its local head would then drive some water from it. This latter effect would be exacerbated by discontinuities in soils or bedrock. In one instance at WOR (W9) the sampling point was linked to a rubble sub-soil drainage system. This location was dry on 1 occasion.

The wells installed worked very efficiently. Of the 34 seepage wells and 5 seepage trenches emplaced for this Study, only 4 wells in LAU (L1, L11, L12, L14) and 1 in CEN (C6) and 1 trench (NT3) failed to produce any stored sample. A number of the wells had stored water but this was lost between some sampling events; this effect was most obvious at WOR and MEL. In both these cases losses through bedrock discontinuities are the likely cause.

The efficacy of these sampling systems is recorded in Table 4.1. The losses of stored water either noted by dryness or reduced/fluctuating water levels provides a good testimony to the renewal and relative freshness of each sample. On a few occasions the seepage well was virtually emptied during the sampling process. On three occasions some seepage trenches at NEW and LAU were completely dewatered when late stage sampling showed some variation suspected to be an artefact of the concrete seal.

Conversely, seepage wells W5, W7 and L2 frequently made water during the sampling process. Well W7 intersected a semi-permanent spring system, W5 is close to a sub-soil drain and L2 seems to be maintained by semi-permanent irrigation waters and possibly an ephemeral spring system.

SURVEYING

Surveying control of the sampling points was, for the most part, not established during the Study. Only at GUI were the precise locations and relative levels of the ground surface at the wells determined. At SPR, CEN and for part of WOR accurate site maps were available so that the surface levels for wells in those cemeteries are quite good. The information obtained is shown in the site maps and well logs in Appendices B – J.

For BOT, MEL, LAU (part), and HEL the relative levels were determined by the Researcher and approximately fixed to known benchmarks or well established survey marks. There were minor exceptions to this, and at BUN, where topographic, construction or other plans were used to establish positions and estimate surface relative levels. This is expected to have no significant impact on the analyses within the Study or any representations in cross-sections or plans.

QUANTITY SURVEYING

Quantity Surveying is the term adopted here for the recording of grave numbers and date information relative to the sampling points. For analytical reasons related to the movement of decomposition products within the cemeteries (see later Chapters), it was determined that a quantification of interred remains within the likely zone of sampling from the sampling points, should be made. The results for individual sites are reported in the Appendices B – J.

Table 4.1 Sampling Events – Statistics

BOT															TOTALS
Sampling Location	B1	B2	B3	B4	B5	B6	B7	B8	B9	B11	B12				11
Location Type (1)	w	w	w	w	w	w	w	w	w	w	w				w11
No. full samples analysed (2)	5	1	6	5	5	3	6	6	6	2	1				46
No. partial analyses (3)	1	1							1		1				4
No. disinfection samples (4)															13
No. rinsate check samples (5)															5
No. other samples (6)	drainage basin x 1 partial, pond x 1 partial														2
No. dry wells (7)		3 /5									1/2				4
No. rejected analyses (8)	1		3			1			1						6 (13.0%)
WOR															TOTALS
Sampling Location	W1	W2	W3	W4	W5	W6	W7	W8	W9						9
Location Type (1)	s	s	s	s	s	s	s	s	d						s8 d1
No. full samples analysed (2)	6	6	4	5	5	6	6	5	4						47
No. partial analyses (3)						1									1
No. disinfection samples (4)															8
No. rinsate check samples (5)															6
No. other samples (6)	pond x 1 partial														1
No. dry wells (7)				2/7				1/6	1/5						4

No. rejected analyses (8)	1	2	1	1					1						6 (12.8%)
MEL															TOTALS
Sampling Location	M2	M3	M4	M5	M6	M7									6
Location Type (1)	s	s	s	s	s	s									s6
No. full samples analysed (2)	7	1		1	2										11
No. partial analyses (3)		1				1									2
No. disinfection samples (4)															3
No. rinsate check samples (5)															5
No. other samples (6)															0
No. dry wells (7)		1/7		6/7	1/7	6/7									14
No. rejected analyses (8)															4 (36.4%)
SPR															TOTALS
Sampling Location	S1	S2	S3	S4	S5	S8	S9	S10	S12						9
Location Type (1)	s	s	s	s	s	w	w	w	w						w4 s5
No. full samples analysed (2)	3	4	3	5	4	6	4	3	4						36
No. partial analyses (3)						1									1
No. disinfection samples (4)															9
No. rinsate check samples (5)															5
No. other samples (6)	pond x 1 partial														1
No. dry wells (7)	1/5	1/5		1/6											3

No. rejected analyses (8)	2	1			2	1		1(9)							6 (16.7%)
NEW															TOTALS
Sampling Location	N1	N2	N3	N7	N8	NT1	NT2	NT3	NT4						9
Location Type (1)	w	w	w	w	w	t	t	t	t						w5 t4
No. full samples analysed (2)	5	5	2	5	5	5	4		3						34
No. partial analyses (3)						1	1		1						3
No. disinfection samples (4)															12
No. rinsate check samples (5)															3
No. other samples (6)	front dam x 1 full + x 1 partial, back dam x 1 partial														2
No. dry wells (7)								3/3							3
No. rejected analyses (8)						1	2		2						5 (14.7%)
LAU															TOTALS
Sampling Location	L1	L2	L3	L4	L5	L6	L7	L11	L12	L13	L14	L15	L16	LP	16
Location Type (1)	s	s	s	s	s	s	s	s	s	s	s	s	s	p	s13 p1
No. full samples analysed (2)		6	6	6	4	3	5			2		1	1	6	40
No. partial analyses (3)		2	1		1	2	1							1	8
No. disinfection samples (4)															18
No. rinsate check samples (5)															7
No. other samples (6)	2 x miscellaneous														2
No. dry wells (7)	6/6							3/3	3/3		3/3	1/3	2/3		18

No. rejected analyses (8) (10)				2	1					1			1	3	8 (20%)
CEN															TOTALS
Sampling Location	C1	C2	C3	C4	C5	C6	C7	C8							8
Location Type (1)	w	w	w	w	w	s	s	s							w5 s3
No. full samples analysed (2)	3	3	3	5	5		2	3							24
No. partial analyses (3)		1	2	1	1		1								6
No. disinfection samples (4)															7
No. rinsate check samples (5)															6
No. other samples (6)															0
No. dry wells (7)						3/3									3
No. rejected analyses (8)		1	1(9)		1										3 (12.5%)
HEL															TOTALS
Sampling Location	H1	H2	H3	H4	H5	H6	H7								7
Location Type (1)	w	w	w	w	w	w	w								w7
No. full samples analysed (2)	5	3	6	2	5	5	5								31
No. partial analyses (3)		1													1
No. disinfection samples (4)															5
No. rinsate check samples (5)															5
No. other samples (6)															0
No. dry wells (7)							1/6								1

No. rejected analyses (8)		1		2	1		4								8 (25.8%)

GUI															TOTALS
Sampling Location	G1	G2	G3	G4	G5	G6	G7	G8							8
Location Type (1)	w	w	w	w	w	w	w	w							w8 (11)
No. full samples analysed (2)	5	2	2	4	6	5	6	6							36
No. partial analyses (3)	1	1		1	1		1	1							6
No. disinfection samples (4)															6
No. rinsate check samples (5)															7
No. other samples (6)															0
No. dry wells (7)		3/7	2/7			1/7									6
No. rejected analyses (8)	1		1		4	1	1	1							9 (25.0%)

GRAND TOTALS AND SUMMARY										TOTALS
Cemetery site	BOT	WOR	MEL	SPR	NEW	LAU	CEN	HEL	GUI	9
Tot no. sampling locations	11	9	6	9	9	16	8	7	8	83
Tot no. full samples	46	47	11	36	34	40	24	31	36	305 (2)
Tot no. partial samples	4	1	2	1	3	8	6	1	6	32 (3)
Tot no. disinfection samples	13	8	3	9	12	18	7	5	6	81 (4)
Tot no. rinsate check samples	5	6	5	5	3	7	6	5	7	49 (5)
Tot no. rejected analyses	6 (13.0%)	6 (12.8%)	4 (36.4%)	6 (16.7%)	5 (14.7%)	8 (20.0%)	3 (12.5%)	8 (25.8%)	9 (25.0%)	55 (8) (18.0%)

Notes to Table 4.1

(1) type of sampling point; w = standard piezometer (well), s = seepage well, t = seepage trench, d = subsoil drain, p = pond

(2) these samples have a complete inorganic chemistry and complements of HACH tested nutrients and bacterial analyses

(3) these samples have certain key analyte groupings or individual analytes missing

(4) these samples were taken at various stages and analysed for key microbial analytes used to infer cleanliness of sampling equipment; only samples where the clean quality of the sampling equipment prior to sampling could be assured, are allowed

(5) these samples represent field blanks of rinsing waters used in disinfection; they were mostly analysed for inorganic chemistry by ICP and taken at the beginning of the day's fieldwork

(6) other samples are site specific and do not constitute part of a regular sampling sequence; they are not reported in Appendix L

(7) sampling points that were dry at the time they were intended to be sampled or when measured during a sampling round; a field indicator for vadose zone percolation to seepage wells and trenches

(8) inorganic chemical analyses rejected on the basis of ionic balance or relationship of electrical conductivity to TDS (calc.) or other reasons

(9) one sample partially rejected (microbiology) because disinfection check showed uncertainty in equipment cleanliness

(10) 7.5 total bacterial analyses(29 data points) of the first sampling event's bacterial testing at LAU was rejected because of unexplainable contamination in many disinfection check samples

(11) at GUI, sampling points G1 & G2 and G3 & G4 were clustered; two depths at each location

What was not initially certain was whether an analysis had much validity at all, particularly since only three of the sites lie immediately above unconsolidated, phreatic aquifers. The remaining sites exhibit a considerable range of hydrogeological environments which may only develop a small chance of complying with the assumptions of the quantity survey models. Furthermore, those parts of sites like SPR and possibly NEW and CEN in part, where deeper aquifers are considered, should not be interpreted by this process. So quantity survey data is not given for all sampling points.

There seemed to be no standard methodology for this determination which had to account for: the likely decomposition products related to flowlines, all the considerations with respect to interments (see Chapter Two), and variable vadose zone conditions. The situation has only a few parallels to systematic grid sampling in order to detect a circular "hot spot" in a contaminated site.

The methodology adopted was in three parts; one for wells in aquifers and one for each of seepage wells and seepage trenches.

For wells. BOT, HEL and GUI were considered on the basis that there was a potential circular zone of influence around the sampling point (well) and a teardrop-shaped zone upgradient, and immediately along the flowlines. The situation is depicted in Figure 4.1. Since the sites varied in their soils, being more silty at HEL and very sandy at BOT, adjustments were made to the geometry of the projected zone of influence for those sites. At BOT there was some overlap between the zones identified for B5 and B6, and B6 and B7.

For seepage wells. At WOR, MEL, SPR, LAU and CEN a generalized pattern was adopted wherein the zone of influence was designated as equal to a circle of radius three times the sampling point depth.

At WOR some significant adjustments were made to this because of topographic influences, the presence of springlines or perched water tables, the subsoil drains and the distances of wetter areas from obvious interments. Consequently some zones of influence were extended to 50 m radius, and some were distorted uphill.

At CEN the topography also dictated that the seepage wells were at a significantly lower topographic level than the surrounding interments' area; hence some adjustment to the zone of influence was made here.

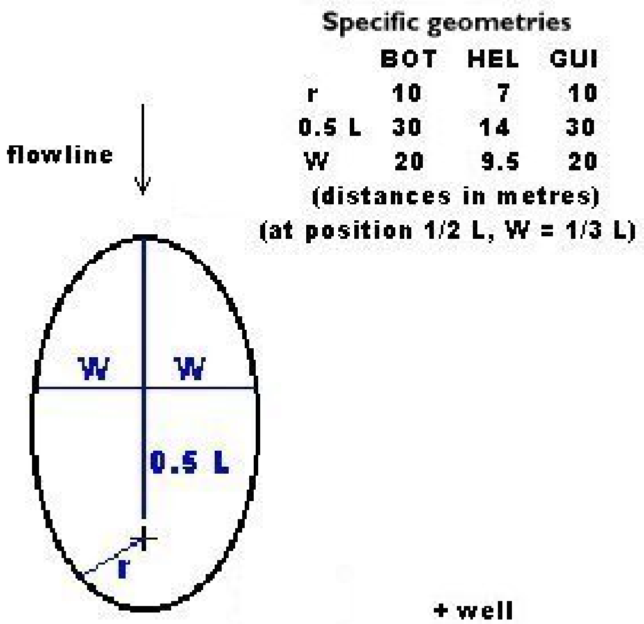


Figure 4.11 Geometry of well "zone of influence"

For seepage trenches. These sampling points had the specific role in LAU of trapping diffuse, spring-dominated discharge, and in NEW of trapping the perched watertable and above at the fill/prepared natural surface interface. Consequently their zone of influence for possible source generators is quite large and also hard to identify.

At LAU the seepage trenches were considered to lie in the centre of the base of an elongated triangle (where base length equals 3 x trench length) with maximum height to apex equal to 6 x trench length. For L7 this zone area had to be adjusted because of the trench's relationship to the topography and its position at the cemetery boundary.

At NEW only two seepage trenches – NT1 and NT2, were closely related to interments in the Le Page Lawn and for this location all interments were considered; however they were very recent, having all occurred within the period February 96 – October 98 (end of sampling). For NT4 the results reflect only a very general influence of the cemetery's interments.

STATISTICAL DESIGN

The sub-surface program in this Study was essentially construed in order to extensively characterize the inorganic and microbiological nature of cemetery groundwaters. The overarching philosophy was that, within the constraints of costs and for a variety of hydrogeological settings, the groundwaters within active cemeteries (for the most part) would be studied and their nature compared to background groundwaters of the same site. As it turned out, the choice of suitable background groundwaters and sampling was much more difficult than initially expected. Also the idea of regularly sampling from every sampling point at each sampling event could not be attained because of field operational difficulties, changes in watertables, dryness of seepage wells, and cost. Some of these latter aspects were anticipated, but until the Study had commenced and wells were established, the extent of the difficulties could not be fully assessed.

The general arrangement of sampling points comprised one to provide background groundwater within the cemetery boundary, and then points at downgradient boundaries if these can be identified, or within the cemetery. The within-cemetery locations were sometimes chosen where there was some likelihood of intercepting percolating groundwater. The exact layout of the sampling points is shown for each site in Appendices B – J. This arrangement is generally consistent with the concepts of stratified random sampling, however, it suffers from a reduced number of background wells; see later discussion.

It is important to note that the Study has an entirely different character to one which only obtains and tests samples from a known hydrogeological setting with correctly sited monitoring wells. Only in BOT and to some extent in CEN and GUI was *a priori* knowledge available on a significant scale. Even though exploratory pitting was carried out at WOR and LAU, this should only be regarded as a first step in the first stage of site characterization. Such a situation is common in geoscientific fieldwork, and is widely recognised as normal in the hydrogeological evaluation of landfills or contaminated sites. The matter is well discussed in the literature and recorded in many official protocols and guidance documents; for example see: Keith, 1991, ANZECC, 1992, Christensen et al., 1992, U.S. EPA, 1992 and Jewell et al., 1993.

Of particular concern is the spatial positioning of the sampling points and hence any statistical analyses of samples acquired from them. For a highly constrained situation sampling points on a brownfield site (e.g. a cemetery) would initially be established according to some grid system or other stochastic statistical pattern. A number of orderly methods are available within the field of spatial statistics and are well canvassed in applicable literature; for example see: Getis and Boots, 1978, Ripley, 1981, or Rock, 1988.

For this Study, in at least 1/3 rd of the sites and possibly 2/3 rd depending on interpretation, the locations of the sampling points were deliberately chosen. Some, like G3 – G6 were deliberately positioned to take account of flowlines. Sites like W5 – W9 and L1 – L4 were located following a preliminary pitting exercise within each cemetery, and W1 – W3 are an in-line experiment. The sites at BOT were contrived to take account of the known area of recent interments. As a consequence of such decisions each sampling point is not randomly located. Despite the fact that random samples are taken from the sampling points, it is therefore not reasonable to use parametric methods for analysis. In the highly contrived situation, these methods would be quite suitable. This is an area of current debate in the environmental sciences (Morrison, 2001, pers. comm.).

The best conclusion possible is that the patterns adopted represent some kind of random, stratified sampling, possibly with assignment (Getis and Boots, 1978). The strata for these purposes are; *background* (and/or upgradient), *in-cemetery*, (downgradient), and *boundary*. One difficulty in using analyses of this distribution is that sampling strata require a N = 2 minimum number of values. This was not generally achieved for the background sampling points used at each site, see below. Overall, the most satisfactory effort in the sampling design therefore is to eliminate bias in choosing sites and then continue this by properly controlled sampling techniques; and this is done by a systematic approach (Chai, 1996).

These concerns, at the highest possible level described above, are not widely treated or considered in hydrogeological literature: their resolution here has been by empirical rather than formal means, representing the best possible solution in the circumstances. The ANZECC Guidelines (1992) and NSW EPA Guidelines for Contaminated Sites (1995) which build upon these, mention the concept of "judgemental sampling" as being an applicable consideration for the situation; whilst Keith (1991) and Jewell et al. (1993) discuss this and other methodologies. The situation has parallels in ecological studies where individually random samples from the chosen points are simply treated with standard multivariate analytical methods (Bowman, Morrison, Murray, 2001, pers. comm.). The key effort goes into obtaining *representative samples* of the population that is being assessed. In this context, probabilistic analyses have less value (Brown, 1998) and in fact assume a lesser importance than the need to obtain a representative sample (Gibbons and Coleman, 2001, Morrison, 2001). As a consequence of these concepts, later analyses in this Study were completed using non-parametric methods in preference, and probabilistic interpretations were avoided, where it is possible that non-stochastic factors may have operated.

Background

In an ideal sampling program 3 or 4 background wells, at least matching the spatial variation of the monitoring wells would be desirable (Gibbons, 1994, Brown, 1998, Gibbons and Coleman, 2001). The constraints of cost (and time), and the organizational and operational difficulties of this Study, however, rendered that idealized goal unattainable.

The first significant problem was finding on-site locations that could effectively be used as background sampling points. In the typical cemetery the distribution of interments bears little relationship to the groundwater system nor frequently to the topography. Many cemeteries have either developed hap-hazardly or in strictly segmented denominational (or otherwise defined) areas. In some sites like BOT where a central water feature generally defines an area of high watertable, or in GUI where a previous groundwater survey has helped direct cemetery development, there is some minor variation to this.

At BOT, the first background well was eventually abandoned due to persistent bacterial and nitrate readings which were interpreted as contamination. However, two additional background wells were completed but were only sampled towards the end of the Study. The GUI site is the most disappointing because the background represents a minimally disturbed, near pristine bushland. There were however, at the background site, two clustered wells at different depths and this provides some value.

Other sites like CEN are strongly influenced by installed sub-soil drains both on- and ex-site. No background was found here, but an internal well will be satisfactory for some comparative studies. At LAU, three searches/explorations were made for background wells, and when finally established, they proved to be dry. At MEL, the site is so developed – interments lie at all cemetery boundaries, that a background well was virtually impossible to locate; the only viable location, which was drilled, was quickly into dry bedrock. The situation with respect to interment density is the same at HEL, however, by judicious consideration and deliberate installation of wells in order, two and possibly three wells happen to be at upgradient – boundary - locations.

There are more similarities to these situations at WOR. A considerable effort – by preliminary pitting, was made to locate a suitable background area. The considerations here were governed by the topography, the presence of spring systems and past developments including a brick-pit and boundary roads. Only one background seepage well was installed. However, for this site, some comparative studies are possible within the cemetery as spring water can be compared with downgradient seepage water. This is also the only site where a deliberate experiment aimed at examining seepage attenuation was constructed.

At SPR, flow directions in the underlying aquifer were anticipated, but only one well was successfully located upgradient due to cost and the extremely difficult drilling conditions. Another possible well only made it to the capillary zone because it was prematurely terminated due to practical and cost considerations. A seepage well far removed from interments is likely to provide some comparative value.

At NEW, two wells which were originally installed at the time of the site's construction, were regularly sampled. These are now known to be representative of the background. An additional near-boundary well far inside the site probably also provides a point of comparison.

On balance, the sites with the weakest statistical viability for the background stratum of a stratified sampling process are WOR, SPR, and GUI with only one well each. Whilst MEL, LAU and CEN have none. In the data considerations of later Chapters these difficulties are taken into account and only appropriate statistical analytical techniques are used. But given the general nature of this preliminary characterization work, the WOR, SPR and GUI data have had to be used as valid statistical representatives in limited ways.

The situations described above are not unique to Australia and the current Study. When the Researcher was in Brazil he observed the same sampling design difficulties for the researchers there and discussed the matter in some detail. In fact, one major criticism of Pacheco's early work (Pacheco et al., 1991) is that he failed to address the issue of background in his paper. In meetings he was asked about this aspect (Pacheco, 2000, pers. comm.) but was unable to satisfactorily provide evidence for on- or ex-site background considerations. At best, in the Vila Nova Cachoeirinha Cemetery in São Paulo, Pacheco used a topographically elevated, internal well as a background; compare WOR and CEN. Additional recent work by Matos (2001, and 2000, pers. comm.), in the same cemetery as Pacheco had used, had the same problems.

Analytes

The sampling regime was designed to return a very large range of analytes in order to comprehensively characterize the cemetery waters. These routinely included 7 field, 30 inorganic, and 4 or 5 bacterial types. Others, like TDS, inorganic N, and usually HCO_3 were calculated from other determinands. The key analytes were considered in several groupings which allowed for separation of the groundwaters' gross characteristics and then special relationships to the sampling environment; e.g. the metal profile that may develop from interred coffins and funereal artefacts, or medico-environmentally related elements like Sr and Se. These are listed in 4.2.

A great deal of consideration was given to the choice of bacterial indicators in the samples. The prevailing wisdom for such analytes was obtained from governmental guidelines and key discussion papers, for example: EEC, 1980, ANZECC, 1992a, Who, 1993, and NHMRC, 1994. These matters are discussed in greater detail in subsequent Chapters. The inclusion of any organism was also considered in the light of sample gathering procedures and the cost of sample testing.

Soon after the Study's commencement it was discovered that the bacterium – *Pseudomonas aeruginosa,* might also prove to be a worthwhile indicator, so that it was routinely included; see for discussion:- Ziegert and Stelzer, 1986, de Vicente et al., 1990, Mates, A., 1992, Hollander et al., 1996. The inclusion of this organism was a considerable departure from the usual quality assessments, despite its pathogenic nature.

Thermotolerant indicator organisms have usually been assessed by collectively examining for Faecal coliforms. During the Study a technique referred to as the Colilert ® Method became routinely available for this and other testing. But this method focused on the precise identification of the thermotolerant bacterium – *Escherichia coli* (E. coli). Of the thermotolerant bacteria, *E. coli* is now regarded as a better water quality indicator, whilst faecal coliforms are in fact a small sub-set of these (Hanko, Walters, and others, 1997 - 1999, pers. comm., Gleeson and Gray, 1997). During the Study the laboratory in South Australia ceased to test for Faecal coliforms, and Colilert ® became the preferred method in the Melbourne laboratory.

Towards the end of the sampling events, new research concerning the use of chloride/bromide ratios for water source evaluation, was published (Davis et al., 1998). It was considered that this work may be applicable in the characterization of cemetery waters, however, until now no relevant data (bromide measurements) were available. Consequently, some bromide measurements were undertaken on later samples where they could be easily done by the commercial laboratories.

SAMPLING TECHNIQUES - GROUNDWATER

Abstraction

All water samples were collected by the Researcher. All samples except those from wells –S9, S10 and S12, were collected using an all-plastic, submersible 12V DC 'Amazon' brand pump driven by a portable, on-surface, wetcell battery with plastic coated wires clipped to the delivery tube; these were joined with the factory-fitted wires about 1.5 m above the pump. A clear PVC tube 13 mm i.d. was clamped onto the pump spigot and led for 13 m to the surface without joints.

Table 4.2 Water Sample Analytes

Principle 'Major' and 'Minor' Cations and Anions Na, K, Ca, Mg, NH_4 HCO_3, Cl, NO_2, NO_3, SO_4, PO_4
Significant Environmental Ions Fe, Mn, Sr, Zn, B, As, Al, Se
Other Heavy or Trace Metals Cu, Ni, Cd, Hg, Cr, Pb
Biological Indicators BOD, total N, total P, TOC
Microbiological Indicators Total coliforms, Faecal coliforms, *E. coli*, *Enterococcus faecalis* (faecal streptococci), *Pseudomonas aeruginosa,* occasionally:- Yersinia spp., Salmonella spp., Clostridia perfringens
Others Si, Br, total inorganic N, TDS, occasionally:- CO_3, F
Field Parameters pH, EC, Eh, temperature, dissolved O_2, alkalinity, dissolved CO_2

These pumps proved capable of delivering a full-flow sample from a vertical depth of about 11 m. In the case of well C 5 which is 12.2 m deep, the sampling technique involved filling the delivery tube with water then lifting the pump and pouring the water from the tube; purging was done to the same standards as for other wells. Each cemetery was equipped with a dedicated pump and this was alternated between samplings with one carried to the site each time. The flow rate was determined by back-pressure exerted by an in-line control cock near the discharge end.

In the case of the wells at SPR different techniques were used because of their depth and flow characteristics. S10 was sampled using a peristaltic 'Waterra' brand hand pump with plastic foot valve; this well proved unsuitable for sampling with the larger submersible pump available. S9 was, on some occasions, when the water level was low, also sampled with this equipment whence it invariably produced a very silty sample that was allowed to still in the flow-cell apparatus. S12 was always sampled using a submersible, fully factory assembled, 'Grundfos' brand pump driven from a portable 240 volt generator.

Considerable difficulty was experienced with sampling at GUI in wells G3 and G4. These wells became significantly silted during installation and then development. They remained improperly usable at times because of fluctuating water table, but were eventually made fully functioning by repeated cleaning using a specially developed, stainless steel, sludge bailer which had to be used when the small submersible pump proved incapable of the necessary de-sludging.

On every occasion, an effort was made to obtain as representative a sample as possible. The emergent water was lead into a plastic flow-cell wherein probes for measurement of key parameters were suspended. A low-flow protocol was adopted from the outset to be used for all sampling where water was directly abstracted from a phreatic aquifer - a working range of 0.2 - 0.7 L/min was used. However, the maintenance of such rates is extremely difficult with the equipment used and the volumes of potential samples consequent to the submerged screen length. The Grundfos pump also always produces a considerably higher rate of flow, otherwise it can’t operate.

In addition, a standard purging of at least three well volumes was first employed before monitoring of sample parameters commenced. Although with low-flow sampling this older technique is not required, it was considered that this method would assist in dislodging any biofilm in the well screen and more fully rinse any sampling apparatus; thus assisting in the quality of bacterial sampling. The samples were taken when the EC, pH and temp were stable. The flow cell hosted a spout that allowed free discharge to the surface at a distance of at least 1 m away from the well.

The abstracted waters were considered to be lowly hazardous in terms of potential contamination to others who might be near to them. Consequently no special precautions were taken for discharge or runoff or rinsing or waste within the cemetery boundaries. Except that no such surface activities were ever carried out closer that 1 m to the wellhead.

The issue of low-flow sampling was given considerable attention before the Study commenced. The US EPA (Environmental Protection Agency) and many others (U.S. EPA, 1991 and 1992, Connelly, 1995, White, 1995, Puls and Barcelona, 1996) consider that the low-flow technique provides the greatest quality in samples with least stress to the aquifer. The methodology also is useful if there is any likelihood that the well is partly deficient in filter pack or construction so that non-turbid samples are obtained. During the considerations of this issue it was noted that low-flow sampling is quite ill-defined as to rate: it seems to be very site dependent, but certainly isn't "fast rate" or "normal" sampling.

Where electric pumps were not used, at least four volumes of well water were removed prior to taking the sample. The sample was only taken after the pH, EC and temp parameters became stable.

In the cases of the seepage wells and trenches the concept of low-flow pumping was not applicable. These were large storage devices wherein the screened interval was always very well surrounded by filter sand of known properties. Except for M2, which turned out to be improperly constructed, all such sampling points returned non-turbid samples all the time. The water was abstracted by the submersible pumps that were located in the sumps of the seepage trenches, or at about half to two-thirds depth in the water column of the seepage wells.

The seepage wells and trenches were purged quite rapidly, and then routinely sampled at a rate of about 1 L/min. This pumping rate was commenced before monitoring for the stability of the EC, pH and temp parameters. On two occasions - one each at W4 and L6, this methodology mined all the available water with the consequence of reducing the amount available for testing. On another occasion at L6 the abstracted water clearly changed its character towards the end of the sampling process - probably representing some that had been trapped in contact with the concrete covering, and sampling was discontinued. This seepage trench was completely purged on a later occasion.

On balance, over 97% of the samples were considered to be unaffected by any abstraction artefact, and to be of satisfactory, representative quality. Unacceptable samples are either not included in the sample database (Appendix L), noted therein or only included for any part deemed to meet all necessary quality and/or representation criteria.

Sample Containers

All samples other than those that were turbid or obtained by bailer, were discharged directly from the pump hose into the container. Preservatives, if required, were always added prior to filling.

Working with a number of different commercial laboratories for the sample testing (see below) dictated that their usual requirements for sample containers would prevail. There was some difference in the number and style of containers required at each site. Generally, samples for nutrients and anions were collected in new 250 or 500 mL polypropylene bottles, except in LAU where samples for the later sampling events were collected in similar, 1 L recycled bottles. Samples for cation analyses, except mercury, at these laboratories were filtered (see below) and usually collected in new acid-washed polypropylene bottles containing nitric acid preservative.

Samples for mercury testing were collected separately except for BOT, WOR and GUI whose sample was drawn from the total volume available for cations. Otherwise, these samples were placed into new acid-washed polypropylene bottles containing nitric acid preservative for CEN and HEL; and into acid-washed, recycled glass bottles, without preservative for MEL, SPR and NEW. In the latter case the laboratory preferred to add its own preservative upon sample receipt. Usually all these samples had air gaps.

Bacterial test samples were usually collected into sterilized and sealed, 1 L glass bottles except for a few occasions at GUI where similar plastic bottles were used. These samples were all supplied with no air gap.

BOD test samples were collected into recycled, 500 mL glass bottles with a small air gap. Samples for TOC testing were usually collected in 125 mL dark glass bottles, but occasionally these were substituted by pre-rinsed polypropylene bottles. These samples had no air gap.

Two, new 125 mL PET (polyethylene terephthalate), rinsed bottles were used to collect unfiltered samples for bench testing using the Hach Colorimeter (see below). Occasionally a 250 mL polypropylene bottle would be substituted. If necessary, because the discolouration of these samples made the proposed testing impossible, these samples were also conveyed to the relevant laboratory.

Filtered samples were drawn from the flow-cell, at the conclusion of abstraction, using new, rinsed 50 mL syringes and forced through 0.45 μm cellulose acetate media, of area 1734 mm^2, in a well-rinsed (occasionally acid-washed) portable, polypropylene, filter holder. 125 mL of filtered sample were collected into new, acid-washed PET bottles with no air gap, for later analysis using ICP at the UTS laboratories. Filter media were frequently changed if the flowrate noticeably dropped and were renewed for each sample. The initial flow of the sample was spent, allowing for the filter media to be totally saturated before the sample's collection.

Prior to the Study considerable attention was given to the use of filtering protocols for cation samples. The USA EPA and others have released several discussion papers about this methodology (Gibbons and Sara, 1995, Pohlmann et al., 1995, Puls and Barcelona, 1989, Reece, 1995, Horowitz et al., 1996); it is still a controversial issue with opponents claiming that the filtration removes colloids and that this may have an affect on the analysis because of adsorbed ions. Extremely large amounts of sample testing - in all countries and hydrogeological domains, have been done with filtered samples which is the "norm" rather than otherwise.

Certainly the use of low-flow sampling generally returns a visually clear sample most of the time, and best practice techniques actively discourage wholesale filtering of samples. However, samples are not always free of suspended clays and definitely not of bacteria. Filtering provides a consistency in samples and their preparation and for some foreseeable time is likely to provide the only satisfactory mechanism of comparing current and historic data. One of the most thorough studies, but which still has a number of uncertainties, was by Horowitz et al. (1996) who considered that for trace levels of base metals – but particularly Al, Cu, Fe, Ni, Zn, and possibly Co, Cr, Mo, Pb – filtration may lead to an underestimation of the real values. The data for Cu is considered by this Researcher to be quite inconclusive; however, due consideration has been given to the findings in later discussions.

A further consideration arises and which appears to have been substantially overlooked in the literature; viz. all ICP equipment pre-filters samples in-line before they enter the injection nozzles so as to prevent clogging by clays or colloids! Thus, whilst ever such routine analytical techniques as ICP are used, then the field filtering of samples is possibly non -consequential.

Blank samples (referred to as rinsate check samples) were taken in the field to ensure the integrity of the rinsing, transport and preservation methods. The usual sample comprised commercially obtained, purified water extracted from field wash bottles by syringes and run through the field filtering equipment into a 125mL PET bottle. This was then preserved, stored and shipped together with any other samples. Very infrequently, similar, but unfiltered samples, were submitted to the commercial test laboratories for some anion or bacterial analyses.

Sample preservation, when required, was done using analytical grade, concentrated nitric acid. The acid was always transported to site and added into the bottle before the sample using a new, disposable, plastic pipette. Sufficient preservative was added to induce a pH of about 2. When the samples were subsequently tested at UTS, the data from testing blanks of the preservative were routinely subtracted form the final results before reporting.

Immediately after collection all samples were transferred to an insulated chest containing melting ice and kept shaded until they were later transported to laboratories still within the chest. This protocol, however, was not possible for the samples to be returned to UTS. Prior to their final transport they were transferred to thermal bags and kept as cool as possible. During flights they were kept with the Researcher in the passenger cabin. At UTS the samples were transferred to a refrigerator at 4°C where they were kept for up to 3 months until analysed.

Measurement of Field Parameters

Each sample was tested in the field for gross parameters by sensors suspended in a flowcell. Separate handheld meters by TPS Pty. Ltd. were used as follows: Model MC-80 for pH and redox which were automatically temperature corrected; Model MC-64 for EC and temperature; and Model MC –82 for dissolved oxygen. All measurements are reported in Appendix L as raw field values; the EC measurements are not temperature corrected to standard 25°C. The sensors were carefully cleaned between each sample by rinsing with distilled water. The instruments were routinely calibrated with in-date standard solutions according to the manufacturer's recommendations and specifically before each sampling event. In addition, as a precaution, the factory pre-set measurement of redox was also checked using Zobell Solution, and corrections applied where necessary.

The measurements for dissolved oxygen (Appendix L) are incomplete. The meter used occasionally stopped functioning as the reference solution in the sensor probe became contaminated. It was not possible to repair this during the sampling process. The measurements of alkalinity and carbon dioxide were sometimes not taken in the field because the samples were too coloured and the tests required being able to interpret clear/pink or green/violet colour changes which were masked. In these cases, a suitable sample was shipped with others to commercial laboratories where the alkalinity was determined by standard methods.

Immediately after securing the samples in bottles the remaining water in the flowcell was tested for alkalinity and dissolved carbon dioxide. This was done by a titration process using a portable Hach Digital Titrator Model 16990 and according to Hach standard methods.

GROUNDWATER SAMPLE AND TESTING QUALITY

One of the potential problems recognised at the outset of the Study was for great quality variation in the groundwater samples due to the diversity of sampling environments, the considerable amount of handling and transport of the samples and the range of testing laboratories involved in the testing cycles. Details of the laboratories used for testing are given in Appendix A. Portions of all samples were analysed by multiple laboratories; two instances of the considerable amount of transport and handling required are outlined in the following.

Samples from GUI were tested for bacterial characteristics by Microserve but other non-metal analytes by ACAL; it was a 25 minute drive between each laboratory. The ICP analysis of the same samples was performed in Sydney - a 3300 km flight away from the sample point; whilst the testing for Hg was done by ACAL after the samples were shipped from Perth to their laboratories in Melbourne (a flight of 2700 km); Br was analysed at another of their laboratories also in Sydney. A similar regimen applied for samples from LAU (on the island state of Tasmania). Initially bacterial and non-metal analytes were all tested at the Agricultural and Environmental Chemistry Laboratory of the Department of Primary Industry and Fisheries in Launceston, and ICP analyses were done in Sydney (a flight of 920 km). After sample event # 2 the function of the government laboratories was changed and reduced, so that they were only available for bacterial tests. Key nutrient related testing was then done at the nearby Ti-Tree Bend Laboratory of Launceston Council (a 15 minute drive from the first laboratory) but other analytes e.g. Cl, Br, and Hg were done by Water Ecoscience in Melbourne (a 480km flight).

Within the considerable economic constraints of the costs of sample testing imposed on the Study, a range of quality control checks was incorporated into the sampling regimen in order to ensure their integrity. Of particular concern was the integrity of the samples analysed for bacterial content, and the reliability of the ICP testing for major and minor cations. It was reasoned that the bacterial test data had to be beyond scepticism and that this could only be ensured by extensive check samples of the disinfection process before the collection of each sample (this is discussed elsewhere in this chapter).

The testing for BOD, total contents of P, N and Organic Carbon could only be done by commercial/government laboratories. Except for a few duplicate and field blank samples it was decided to rely on the integrity of the laboratories' QC programs in respect of these analytes.

At the Study's commencement it was thought that a quality control program of selected metal analyses - B, Cd, Na - might be run between the commercial laboratories and the subsequent ICP testing at UTS. Although this was commenced for some early samples it was abandoned early-on because of cost pressures and the integrity of the ICP testing regimen: this is discussed below. The few results obtained in this program have not been reported.

ICP analyses of all samples were done at the UTS laboratories using a Perkin Elmer (PESCIES) ELAN 5100, ICP-MS machine with an AS90 Auto Sampler. This was the most significant testing in terms of establishing the samples' inorganic chemistry. All samples for this testing were prepared by the Researcher; duplicate aliquots of samples were frequently included and later checked for match of results. Blanks of ultra-filtered (Ominpore) water were run as a check on apparatus or handling contamination. Any error in the pure water or duplicate aliquot analyses would have led to repeating the testing. In over 700 ICP tests this happened only twice for two different sample runs. On each occasion a systematic error was traced to incorrect use of the Gilson pipette for sample preparation. On another occasion, the incorrect sample numbers were entered into the ICP spectrometer's controlling computer so that major ion analyses were carried out on samples prepared for minor metals analysis. The samples were re-tested.

The only other source of groundwater test quality data problems was the analyses of inorganic N, and ortho-P. The samples in this regard, with the exception of a few reported on some laboratory test certificates were completed by the Researcher - usually within 12 hours, sometimes within 20 hours, of sample collection, using a portable Hach colorimeter. Whenever possible, and for over 96 % of samples, appropriate standards for NO3-N, NH4-N and PO4 relevant to the general level of analyte sought, were tested during the analysis of each batch of samples. Generally a batch in this context represented a day's sampling (up to 7 samples). Blank and rinsate samples were not tested by this means; once again the integrity of relevant testing for N and P by the other laboratories was used as a means of establishing data reliability. Where the results were at all doubtful they have been rejected and excluded from the results' database – Appendix L. This is further discussed in the next section.

In the analysis of inorganic N and P analytes for all samples the results from the Hach testing were compared to the values obtained by the laboratories for Total N and Total P. Inorganic N continues to be consumed in samples after sampling at least until specimens are frozen for later analysis as per Australian Standards or by other test methods used by the laboratories (Appendix A). The consumption of P probably also continues by algae and some bacteria. This is the reason that such samples should ideally be tested within 24hours of sampling; even if the samples are correctly stored at low temperature prior to analysis.

In the majority of instances, the results from the Hach analyses were equal to or greater than those from the commercial laboratories. At all times the Hach results were considered superior, as they arose from quickly tested samples and covered the full range of nutrient analytes required, and are consequently reported in the dataset (Appendix L). A number of samples from GUI, HEL and some from BUN and BOT were a strong straw yellow to green-yellow colour at the time of sampling (see discussion elsewhere in this chapter). In these cases the existent colour meant that the Hach colorimeter could not be used for testing; hence the reported results for inorganic forms of N and P were measured by other laboratories. Accordingly, the relevant laboratories' QC programs were relied upon in these cases.

Overall the quality of the water testing data is very high. However, as would be expected in a large scale study, some data is of lower quality than other and some contains errors which either rendered it unacceptable or subject to conditional acceptance. There are two instances of this in the Study's results, one has been preserved, one has been eliminated (Appendix L).

For the first series of samples at LAU (event #1, LAU/1) unexpected faecal streptococci (*Enterococcus faecalis*) contamination was detected in the majority of samples with variable, but non-patterned contamination also in the check samples. A discussion with the laboratory personnel (Waters, 1997, pers. comm.) eliminated the idea of any laboratory contamination in the analysis, so the bacterial results were rejected except in the instances where the quality control sampling indicated that the samples were acceptable.

For groundwater samples generally in the sampling events #5 and #7 there were systematic errors in the ICP analysis of the major cations (Na plus Ca or K). These errors were eventually traced to improper preparation of standards and the results were corrected accordingly. ICP standards were prepared by progressive weight accumulation of pipetted amounts of commercial, concentrated cation solutions.

Finally, all the chemical test data assembled in Appendix L was tested for numerical consistency. A set of criteria were developed for analytical accuracy in the light of the various sampling protocols and applied to each analysis. Table 4.1 contains a summary of the number of total analyses that were subsequently rejected; that is 18% of 305 full analyses. In addition there were 32 partial analyses; and, even if overall an analysis is rejected, it frequently still held useable data for microbiological and metal analytes. Further explanation is found in the introduction of Appendix L.

The ionic balance was calculated with a general tolerance of +/- 12.5% although this was uncommonly applied. A value of +/- 5% is more generally acceptable (Freeze and Cherry, 1978). However, larger variations are tolerable when the TDS is low, say less than 250 mg/L, or if the total of ion milliequivalents is less than +/- 5.00 meq, or when there are known interferences e.g. organic acids indicated by the yellow colour yet all analyte values seem reasonable (Freeze and Cherry, 1979, Hem, 1989). Here, for samples with 275 <= TDS >= 975 mg/L the higher tolerance was considered.

A TDS value greater than 1000 mg/L is another cause for concern; in such cases a tolerance of +/- 10% is more acceptable, since the dominant concentration of an ion is not adequately evaluated by ionic balance (Hem, 1989). Moreover, there may be other effective constituents at this level of TDS; the effect of Si for example, was never included.

Another matter evaluated was the balance between EC and TDS in terms of the formula:

$$KA = S$$

where K is the specific conductance (EC), S is the dissolved solids (calculated TDS here) and A is a constant of proportionality. A is generally in the range 0.55 – 0.75 but can be outside this – to 0.96 in the presence of high SO_4 (Hem, 1989). Here, a range of

0.57 – 0.74 was used to indicate that an analysis was likely to be acceptable. The total data spread for the Study was examined by means of this relationship in Figure 4.12; here the mean value of A was found to be 0.62. The highly salty waters found in CEN (wells C4, C5, C8) are clearly represented as a distinct subset in the upper part of the scatterplot.

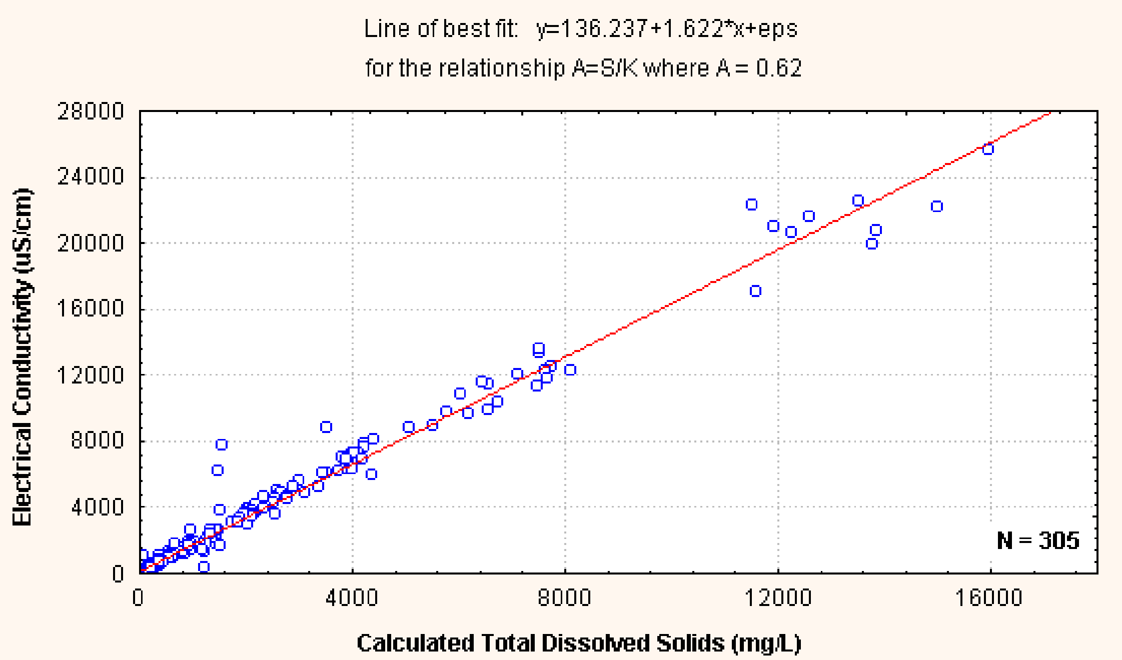


Figure 4.12 Scatterplot of EC Vs TDS for all data

TESTING FOR ANIONS AND AMMONIUM

At the commencement of the fieldwork it was assumed that major anion analyses would be carried out using ion chromatography equipment in the UTS laboratories; and in-field bicarbonate alkalinity would be obtained using a Hach DR700 Colorimeter. A great deal of effort was expended in attempting to obtain nitrite, nitrate, sulfate, and chloride analyses by this method together with a review of bicarbonate; with careful attention to running standards over a wide range because the likely water compositions were unknown.

Unfortunately the hoped-for methodologies were never satisfactorily developed. Coinciding with the commencement of the testing, the Department of Chemistry experienced a loss of key technical staff, the HPLC (High Performance Liquid Chromatography) equipment and software consistently malfunctioned, expensive replacement ion exchange columns for the HPLC were not available to the Researcher, and satisfactory training and support was not available: all attempts to test indicated that the duplication of standard and specimen results was very limited with considerable drift apparent in the results. These matters, considered with the general difficulty of analysing considerably complex solutions like groundwaters, led to the abandonment of this testing approach.

Consequently the earliest samples from HEL/1, CEN/2 and GUI/2 were incompletely tested (Appendix L). Results with high degrees of uncertainty are not reported. A review of test methodologies led to the decision that key anions would henceforth be tested in commercial labs already contracted for testing like TOC and BOD. This had an additional advantage of ensuring that tests for bicarbonate and inorganic nitrogen forms were conducted in better time frames than using the UTS laboratory with a higher degree of reliability.

Testing for bicarbonate alkalinity is best done in the field at the time of sampling, however this is not always possible. The tests using the Hach equipment are adversely affected by any yellow or brown discolouration in the water, and numerous samples because of this occurrence, were tested as soon as possible in commercial laboratories. The same discolouration affects testing for inorganic nitrogen in any oxide or ammoniated form so that where necessary such tests were also done commercially.

All testing for alkalinity, dissolved carbon dioxide, nitrite, nitrate, ammonium, and orthophosphate was, where possible if the sample was not strongly discoloured yellow or brown/green or was turbid, carried out strictly in accordance with the Hach test methods for their digital titrator (Model 16900) and DR700 Colorimeter. Only fresh reagents supplied for the Hach equipment were used and tests for nitrate, ammonium, and orthophosphate were supplemented whenever possible with testing of appropriate, within-date, Hach standard solutions. There was no standard for nitrite.

The test methods were:

* Alkalinity - Method 8203 - range: 10 - 4000mg/L
* Dissolved Carbon Dioxide - Method 8205 - range: 10 - 1000mg/L
* Nitrite - Method 8040, LR - range: 0 - 0.350 mg/L as N
* Nitrate - Method 8039, HR - range: 0 - 30.0 mg/L as N
* Ammonia - Method 8038 - range; 0 - 3.00 mg/L as N
* Phosphorus (Reactive) - Orthophosphate - Method 8114 - range: 0 - 45.0 mg/L $PO4^{3-}$
(Hach Company, 1993 and 1996).

Samples for Colorimeter testing were collected separately in the field in new, unwashed, 250mL polythene bottles; the samples were not filtered or preserved but were stored on ice until allowed to come to room temperature for testing. Testing usually commenced within 11 hours of collection but occasionally within 20 hours where field operational requirements meant that they had to be transported to another location (plane transfer). Any transported samples remained cooled by ice and were transported within the pressurised aircraft cabin.

The samples were batch tested in Hach glass test vials that had been washed in warm soapy water and rinsed with purified water. Usually appropriate standards were run with each batch of samples tested by Colorimeter and the samples' results were then corrected according to the results obtained for the standards. The nitrate test is very sensitive to temperature, shaking methodology and chloride content. The orthophosphate test is also sensitive to temperature.

The Hach test methods are variously influenced by other ions in solution according to the following list (Hach Company, 1993):

* nitrite - Method 8040 - substantial Cu2+ and Fe2+ presence leads to a lower result than actual, whilst NO3- > 100 mg/L reduces to
  nitrite thus increasing the result.
* nitrate - Method 8039 - substantial Fe3+ increases the reported result, whilst Cl- > 100mg/L decreases the result.
* orthophosphate - Method 8114 - is effected if either S2- or Fe2+ are > 100 mg/L.
* ammonia - Method 8038 - should not be effected by high Cl- or Ca2+ > 250mg/L.

The analysis of all sample data took these possible influences into account and where necessary appropriate adjustments were made to the results database (Appendix L). S^{2-} ions were mostly less than 100 mg/L except in CEN and one result in MEL. NO_3^- ions, however, were sometimes in excess of 100 mg/L and where this occurred the nitrite value was reduced by 5%. Cu^{2+} concentrations were generally low, whilst Fe^{2+} concentrations were never in excess of 100 mg/L and were generally low except in LAU and some samples of BOT, WOR, SPR and NEW. Where the concentrations of Fe^{2+} and Fe^{3+} ions were at higher levels they were frequently associated with the yellowing/oxidation of samples at the time of collection (see Chapter Four and Appendix L); for such samples, the analyte measurements that could possibly have been affected by the discolouration were obtained from commercial laboratories. Further QC testing for any effects due to increasing Cl ion concentrations in samples of ammonia standards was carried out; no consequences were noted.

On a few occasions (less than 4% of all samples) it was impossible to run standards with the test batches. Based on an analysis of all other results it can be concluded that on these occasions the results were most likely understated by up to 5% for nitrate, and by less than 1% for ammonia and orthophosphate. Accordingly such results are not corrected in the sample database (Appendix L).

SAMPLING AND TESTING FOR BACTERIA

When the study commenced a great deal of time was spent considering the scant information that could be found about bacterial sampling/ sterilization/disinfection. The issues were discussed with colleagues and several microbiologists from the laboratories later chosen for analyses. This led to the development of a unique protocol for the work. In the literature, work by Cullimore (1992) was the most seminal, and basically accords with the methodologies adopted.

There are many published accounts of groundwater samples taken for bacterial or viral analyses, however, the majority either say little about their collection methodologies, or are dealing with freely flowing water supply wells, or are considering deep origin waters. Most talk about collecting into “sterile” containers from free-flowing streams; some talk about “sterilizing” (sic) taps or discharge tubes. None discuss sampling needs similar to this Study either in total number of samples, diversity of sites, range of critical analytes, or containment of cost. Forms of the term “sterilize” are freely used when the situation clearly is not sterile. The term “disinfect” is much more appropriate (Parker, 1978).

Occasionally cited works in this context include:- Dunlap et al. (1977), Stetzenbach et al. (1986), Pedersen and Ekendahl (1990). The first refers to itself as ‘early’ in the development of appropriate technology/methodology, whilst the latter two are concerned with sampling free-running flows from depth. Wilson et al. (1983) and Chapelle (1992) concentrate on aseptic sampling of sediment/rock cores, in the latter example this being the preferred (almost exclusive) technique. The only know work that refers to treated sampling tubes and pumps (and also happens to be 70% ethanol solution) is for shallow sampling in Northern Germany (Hirsch and Rades-Rohkohl, 1983).

The Researcher’s experience is that, sampling for bacterial indicators from monitoring bores is not simple, easy, quick or cheap. On the last matter it is often more expensive to test for the appropriate range of indicator organisms compared to say a routine, gross inorganic chemistry. The protocol developed also needed to apply in a standard field situation where the sampler is not dressed up as for a contaminated site. The methodologies also had to be very portable, quickly re-supplied and as easy to operate as possible.

The question of biofilms on the bore wall and whether they harbour the bacteria of was also considered; see also Pedersen and Ekendahl (1990) and Chapelle (1992). This is once again an area lacking in suitable groundwater context studies. However, it’s probably likely that some of the bacteria of interest will happily exist in surface indentations of these biofilms or will be caught by their structure during flow. Many will not, since the environment is organically barren or anaerobic in parts or otherwise not conducive. It is likely that significant resident colonies will be dislodged during sample purging operations as flowing water breaks up films particularly in the vicinity of the screen. For this reason a suitable well purging is required. On the other hand, this won’t always happen; but simple disinfection won’t fix the problem either because not all biofilms and their colonies will be attacked; vigorous cleaning and strong disinfection are then probably required.

Accordingly it was concluded that if the bacteria of interest are in any biofilm they are only there because they are resident in the groundwater in the first place – this is also the knowledge being sought. If the subsequent sampling technique is consistent with the current practice of purging and obtaining clear water with stabilised parameters, then this is likely to be the best that can be done. The result can't return a false positive or negative because the bacteria of interest are either there or not. The level of presence may, in some circumstances, be exacerbated. The collection and comparison of successive samples could be done. When this was done for this Study, no significant differences were found.

The necessary protocol then, needs to ensure the proper disinfection of pumps and sample delivery equipment. The field procedure used consisted of disinfecting the pump before its use then after each sample. Disinfection was obtained as follows:

Following sampling, flushing the pump and line with about 9L of potable water;
filling the pump and line with a solution of 75% methylated spirit in distilled water [note a];
leave the pump impeller submerged and the line filled with solution for at least 5 minutes;
rinse with 2L of distilled/de-ionised water (dedicated containers);
carefully encapsulate the pump [note b] and also the discharge end of the line with a clean (new) plastic bag. Re-coil/store the pump while wiping down the outside with a clean (new) rag soaked in methylated spirit solution; store in a clean (new) plastic bag and label sequence number [note c].

Notes:- (a) Methylated spirit is at least 95% ethanol; 70% ethanol solutions are widely considered to be good disinfectants for the bacteria of interest. Originally 100% methylated spirit was used but further research showed that a watery baseload, greater in volume than that remaining in the pump and line was required. Dedicated containers are needed for the solutions.
(b) It is important to ensure that the pump and discharge ends do not contact grasses and dirt; these frequently harbour contaminating bacteria on the surface.
(c) Wherever possible two pumps were used in rotation – one was rested between samples; the sequence number was recorded so that mistakes or possible problems could

be chased down.

Table 4.3 summarises the frequencies of bacterial sampling; in total there were 1454 tests across all analytes and sites from the 7 sampling events. This testing was supported by a rigorous disinfection quality control program (see earlier discussions) of 81 tests which were routinely tested for Total coliforms and Faecal streptococci (Table 4.1).

Another significant aspect of sampling point establishment concerned the avoidance of deliberate subsurface contamination by near-surface micro-organisms. In field settings it would be difficult to prove that this didn't occur, so the approach was taken that some minimisation of risk was best. This was achieved by very carefully washing-down hollow flight augers, hand augers and backhoe buckets (in respect of seepage trenches) between each boring or excavation, using pressurised mains water. Care was taken to ensure that topsoil was not flicked back into any hole below the ultimate level of the filter pack. In all cases except for the seepage trenches, the filter pack sands were delivered in large plastic bags which maintained their 'cleanliness' until used. Bulk sand was required for the seepage trenches, and apart from washing-down the mechanical scoops used for transporting it, little else could be done to ensure its cleanliness.

Chapelle (1992) also discusses these matters and particularly raises the issue of using drilling fluids and possible contamination pathways from this practice. It was necessary to use a small quantity of drilling polymer-enhanced fluid in establishing well S12; the partially consolidated sediments proved highly resistant to this drilling style at the considerable depth necessary (Appendix E). About two weeks after establishment this well was sampled for the first time. On this occasion a very long well development and flushing process was employed. In excess of 1200 L was flushed before the first sample and then a further 400 L before a repeated sample. The bacterial test data (Appendix L) indicate that *Pseudomonas aeruginosa* was found in the three earliest samples from this well. This occurrence is quite out of character with other testing of this aquifer and could logically represent an artefact of the drilling process. These results therefore need to be treated very cautiously.

Table 4.3 Sampling Frequencies for Bacteria

	Bacteria description	Number of tests taken per cemetery									
Cemetery:-	(3)	BOT	WOR	MEL	SPR	NEW	LAU	CEN	HEL	GUI	TOTAL
Total Coliforms	Fn, G-, bacillus	48	49	12	37	37	42	30	30	39	324
Faecal Coliforms (1)	Fn, T, G-, bacillus	40	40	0	0	0	35	14	8	39	176
Faecal streptococci (2)	Fa or N, G+, cocci	48	48	11	37	37	42	29	30	39	321
E.Coli (1)	Fn, T, G-, bacillus	26	31	12	37	37	42	16	22	23	246
Pseudomonas aeruginosa	A or Fn, G-, rods	39	48	11	36	37	42	22	27	30	292
Clostridium perfringens/spp.	ON, G+, rods	0	0	7	15	21	14	0	0	2	59
Yersinia spp.	Fn, G-, bacillus	0	0	0	0	0	16	0	0	2	18
Salmonella spp.	Fn, G-, bacillus	0	0	0	0	0	16	0	0	2	18
TOTAL		201	216	53	162	169	249	111	117	176	1454

(1) Faecal coliforms are thermotolerant; they produce acid and gas from lactose at 44 °C in 24hr (Singleton, 1999).
(2) "Faecal streptococci" refers to *Enterococcus faecalis* and related organisms; originally referred to as "*Streptococcus faecalis"* but transferred to alternate genus about 1984 (Singleton, 1999).
(3) A = aerobe; N = anaerobe; O = obligate, meaning 'strict' in requirements as to the presence or absence of oxygen; F = facultative – 'facultative anaerobes' (Fn) normally grow in oxygen but can grow in anaerobic conditions, 'facultative aerobes' (Fa) normally grow in the absence of oxygen but can grow in aerobic conditions; G+ gram positive; G- gram negative; T = thermotolerant
could logically represent an artefact of the drilling process. These results therefore need to be treated very cautiously.

SOIL SAMPLING AND QUALITY ISSUES

Soil samples were taken throughout the profiles of the various cemeteries as piezometers or seepage wells were established. The primary objective behind the sampling was to cover a significant range of the soil profiles available with concentration on the portions below the average grave invert level. The lowermost soils and unconsolidated regolith are of course the natural receptor and matrix for percolating groundwater and decomposition products.

There was no standardised quality control program for the soil sampling or the subsequent sample preparation. In this Study the primary intent was on soil characterisation, including chemistry and mineralogy; the samples were stored for later preparation and analysis. Pore waters and the field moisture content were not examined.

The samples were bulk, depth-controlled, grab type either from the spoil removed by drill-rig auger flights or backhoes or directly scraped off the flights; or, were extracted from the lower half of the contents of a shell auger when well holes were hand dug at BOT. All samples were gathered by the Researcher; each was immediately sealed in a pre-labeled polythene bag and stored in a basement until required for testing.

The soil samples mostly represent the unsaturated zone and have shown themselves to be subject to drying out to different extents. The moisture content measured at the time of sample preparation thus in some cases was a reasonable presentation of the as-sampled condition, but for others clearly it was a drier form.

Most chemical soil testing methods, and certainly those described below, are developed for air-dried soils. However, it was not possible to make these preparations for this Study so that all soil samples were oven dried at 110° C. Discussions were held with technical advisers of the Australian Association of Soil Scientists (Yates, 1999, pers. comm.) to ascertain whether this methodology would affect the results; the collective wisdom was that it 'would not'. Prior to being placed in the oven on clean aluminium foil trays, representative sub-samples were removed from the field bag, weighed and generally described. Each was also described by its Munsell colour (Munsell Color, 1994). This data (Appendix K) is considered later in respect of correlations of soil and groundwater characteristics, and aspects of cemetery planning and management.

The samples were oven dried and comminuted to particles by bashing, rolling and shaking so that primary clasts were not broken. Subsamples were then prepared using a stainless steel splitter box and sieved on a nest of half-phi-sized sieves made of brass or aluminium. This methodology was chosen because it gives a better approximation of in-situ soil peds and agglomerations in unsaturated soils and sediments compared to the particle size distribution which may result for fines by wet sieving or hydrometer determination. In particular, not all silt or clay sized particles are liberated as discrete particles - natural agglomerations, for example those cemented by iron oxides and carbonates are retained (Northcote, 1979, Kutilek & Nielsen, 1994). The difficulty of the technique, however, is that accurate gradings and classifications are not possible for samples with a high degree of fines (silt and clay). Wet sieving and Atterberg Limits determination were not carried out.

The primary purpose of the grading analysis was for subsequent determinations of hydraulic conductivity and general considerations of percentage of "fines" i.e. particles < 0.06 mm (4.0 ø = 0.075 mm actually used) for use with the Unified Soil Classification (USCS) (Bureau of Reclamation, 1960). Consequently where the soil material was highly silty or clayey, as evident from the field description, the grading was not deemed relevant and is not reported (Appendix K). A classification of each soil was thus made according to USCS field principles, supplemented by grading analysis and considerations of mineralogy and CEC. There are difficulties linking the hydraulic conductivity to the USCS however it is otherwise a useful classification (see Chapter Seven and Fogg et al., 1998, for further discussion). The samples were not subsequently tested for base metals so that it is considered that any contamination due to handling and preparation procedures was non-consequential.

The second sample split was further prepared for chemical and Cation Exchange Capacity (CEC) analyses, and X-ray Diffraction (XRD) studies of mineralogy. The split sample was initially sieved at 2.00 mm and then split again. The whole of one part was placed in pre-labeled polythene bags for later chemical testing, whilst a substantial portion of the second split was placed in a small ball mill with ceramic balls and ground to a fine powder suitable for XRD analysis; this prepared powder was stored in a pre-labeled polythene bag until required. Soil test results are summarised in Appendix K.

During the preparation of samples for chemical testing the grinding and storage equipment was meticulously cleaned between samples. This prevented cross-contamination. The chemical, CEC and exchangeable cation testing and solution preparation itself was all carried out by the Researcher; the procedures used were concluded with a final cleaning step, thus ensuring that each sample was tested using clean apparatus. The chemical testing of leachate developed for CEC analysis using ICP, was also controlled in the testing phase. During this testing it was unnecessary to reject any results.

The final quality assurance program related to the filter pack (sand) materials used in all groundwater sampling points. A sample of each material so used, including a few progressive samples where successive materials' deliveries to cemeteries were involved, were tested in the same manner as the cemeteries' soils. An exception was at GUI where the sample was inadvertently contaminated, and thus rejected. The idea here was to isolate any potential effect - should it be even possible - on the groundwater test results. There are no detectable effects or unusual artefacts in the results or sampling that can be attributed to this source. These test results are presented in Appendix K.

SOIL TESTING

XRD was carried out on powder specimens representative of the whole-of-soil fraction less than 2.00 mm. The powder was packed into a rimmed steel mount and fed from an automatic sample loader onto the stage of a Siemens D5000 X-ray Diffractometer within the Microstructural Analysis Unit of UTS. The diffraction was particularly examined for the range 2θ 2 - 40 degrees. This range suits the overall detection of clay, feldspar and end-product minerals of the weathering process.

The diffraction patterns were read using a computerised database - DIFFRACplus Basic V5 Evaluation Program (EVA ver., 5.0.1.8) (SOCABIM, 1996-1999) software, wherein the samples' patterns were compared to those in an extensive library of patterns. The interpretation of patterns and decisions regarding mineralogical composition and quantification were all made by the Researcher. The results of the soil testing are

Table 4.4 Summary of Soil Sample Numbers

Site	Sample numbers (and numbers of samples)			Totals
	Vadose zone	Saturated zone	Filter sands	
BOT	B1/1, B1/2, B2/1, B2/2, B3/1, B6/1, B7/1, B7/2, B7/3, B9/1, B9/2 (11)	B2/3, B6/2, B8/1 (3)	Bsand#1 (1) (a)	15
WOR	W1/1*, W1/2*, W1/3*, W2/1*, W2/2*, W4/1, W4/2, W4/3, W5/1*, W5/2*, W6/1, W6/2, W6/3, W7/1*, W7/2*, W7/3* W9/1* (17)	W6/4 (1)	nil (a)	18
MEL	M1/1, M1/2, M2/1, M2/2, M2/3, M3/1, M3/2, M5/1, M5/2 (9)	nil	Msand#1 (1) (b)	10
SPR	S1/1, S1/2, S1/3, S1/4, S1/5, S1/6, S2/1, S2/2, S2/3,S2/4, S2/5, S3/1, S3/2, S3/3, S3/4, S4/1, S4/2, S4/3, S5/1, S5/2, S5/3, S9/1, S10/1, S10/2, S10/3, S11/1,S12/1, S12/2, S12/3, S12/4 (30) (c)	S8/1, S9/2, S10/4, S12/5 (4)	Ssand#1 (1) (b)	35
NEW	N1/1, N1/2, N1/3, N1/4, N1/5, N2/1, N2/2, N2/3, N3/1, N3/2, N7/1, NT1/1, NT1/2, NT1/3, NT1/4, NT3/1, NT3/2, NT3/3, NT4/1, NT4/2 (20) (d)	N3/3, N7/2 N8/1 (3) (d)	Nsand#1, Nsand#2 (2)	25
LAU	L1/1, L1/2, L1/3, L1/4, L1/5, L1/6, L2/1, L2/2, L3/1, L3/2, L3/3, L3/4, L3/5, L4/1, L4/2, L4/3, L5/1, L5/2, L5/3, L6/1, L7/1, L7/2, L11/1, L12/1, L12/2, L13/1, L14/1, L14/2, L16/1, L16/2, L16/3 (31)	nil	Lsand#1, Lsand#2, Lsand#3 (3)	34

CEN	C1/1, C1/2, C2/1, C2/2, C2/3, C3/1, C3/2, C4/1, C4/2, C5/1, C5/2,C5/3, C6/1, C6/2, C6/3, C8/1, Ca/1, Cb/1, Cb/2, Cb/3, (20) (e)	C7/1, C8/2 (2)	Csand#1 Csand#2 (2) (f)	24
HEL	H1/1, H1/2, H2/1, H2/2, H4/1, H5/1, H7/1 (7)	H1/3, H1/4, H2/3, H3/1, H3/2, H4/2 (6)	nil (f)	13
GUI	G1/1, G1/2, G1/3, G1/4, G3/1, G5/1, G6/1 (7)	G1/5, G1/6, G2/1, G3/2, G3/3, G6/2, G6/3,G7/1, G7/2, G8/1, G8/2, (11)	nil	18
Totals	152	30	10	192

Notes for Table 4.4
* samples at WOR taken from exploratory pit
(a) sample Bsand#1 applies for BOT and WOR; general numbers used for filter sands
(b) sample Msand#1 applies for MEL and SPR
(c) borehole S11 was subsequently abandoned
(d) NT samples at NEW from seepage trenches, others except N7 and N8 from exploratory boreholes
(e) Ca and Cb were exploratory boreholes; subsequently abandoned
(f) sample Csand#1 applies for CEN and HEL

discussed in Chapter Five and further considered in Chapter Seven. Typical XRD patterns are presented in Appendix K. The fraction of soil designated for chemical evaluation was tested for pH and Electrical Conductivity (EC) with small variations to standard methods necessary to accommodate readily available laboratory apparatus at UTS. The methods - 3A1 (for EC) and 4A1 (for pH) (Rayment and Higginson, 1992) used were based on a 1:5 soil/water suspension by weight and using reagent grade filtered water (EC < 18 (S/cm) at the required pH and at prevailing laboratory temperatures. 20.0 g of soil were tested and the measurements made using the previously described TPS meters; probes were cleaned between sample measurements. CEC and exchangeable cation results were developed by using a back-to-back combination of methods 15B1 (Exchangeable bases and cation exchange capacity ...1M ammonium chloride pH 7.0, no pretreatment for soluble salts), 15B2 (as before but including pretreatment for soluble salts) and 15I3 (Cation exchange capacity - automated determination of ammonium and chloride ions) (Rayment and Higginson, 1992). A variation was made in the final testing of chloride ions in that they were measured electo-voltaically with a CMT10 Chloride Titrator using 20 µL doses and appropriate NaCl standards (Radiometer, 1982) this gave results immediately in meq/L. This methodology was satisfactory and generally returned repeatable results but was made more difficult by the necessity to constantly vary the amount of test sample and by the age of the apparatus.

The ammonium concentration in the extracts of treated soils was determined using a Skalar Segmental Flow Analyser and Skalar Methods (Ammonia, 1 - 50 ppb in water) (Skalar Analytical BV, 1989) in the UTS laboratories. These analyses depend on quite complicated carrier and reactive solutions and suffered because of the concentration of the ammonium ions and the age of the apparatus. It was necessary to re-run many samples with a wide range of standards in order to achieve meaningful results.

CEC results are reported in meq/100g on an oven-dry basis and can be found in Appendix K. The methods used, whilst applicable for the apparatus available, also have the distinction of being able to be linked to previous determinations as reported in others' tabulations of soil results (Rayment and Higginson, 1992). However, CEC and exchangeable base results are known to be widely variable and only moderately comparable when developed with different methodologies and even between like samples (Tucker, 1983, Isbell, 1996). Accordingly, a calculation was made of the likely error in the CECs determined due to systematic and analytical procedures. This was found to be about 6% plus unknown minor losses due to rinsing. The total processes for the ICP analyses for exchangeable cations had an error of less than 9%. Nevertheless, some CEC values when calculated were unacceptably negative and were thus discarded.

Exchangeable cations were determined from the soil extracts using ICP analysis: this departs from the original procedure in Methods 15B1 and 15B2 which used Atomic Absorption Spectrometry. ICP was readily available and also permitted the additional determination of Al and Sr; the latter being considered of possible importance in decomposition product migration and the former possibly being able to be correlated with soil clay mineralogy.

AQUIFER PROPERTIES – SLUG TESTS AND EVALUATION OF K

Wherever possible the sites' aquifer properties have been evaluated by slug tests. This method was chosen as the preferred one because of the portability of the equipment needs and the fact that almost all wells only partially penetrated any aquifer to a very limited extent – averaging 1 – 2 m. A significant exception was wells S10 and S12. The data accumulated are compared to possible values of K (hydraulic conductivity) developed from grading analyses of soil samples (Appendix K) and are reported for individual sites in the relevant Appendices B – J along with other hydrogeological data.

The slug tests involved the withdrawal of a well water slug using a disinfected plastic bailer with a maximum volume of 1020 mL. This caused a maximum depression in the watertable of 0.520 m for the wells available. Recovery was then measured with a bore-dipper at initial intervals of 1/3 or ½ minute increasing to 10 minutes for longer tests. The tests have been interpreted according to the methods of Bouwer and Rice (1976) and Bouwer (1989), Cooper et al. (1967) for those cases where the aquifer condition may be considered to be partially confined, or Hvorslev's method for partially penetrating wells in confined aquifers (Hyder et al., 1994) if the other methods were inappropriate. (Table 4.5).

In the cases of analyses by the Bouwer and Rice method the interpretation has been corrected for sand pack recharge which has been shown to have a specific influence on the validity of the final K value (Binkhorst and Robbins, 1998). In addition the suitability of the technique was assessed in respect of potential errors with respect to anisotropy and aspect ratios (Hyder et al, 1994) and only applied where the evaluation was appropriate. The Hvorslev interpretations are much more general but are widely regarded as acceptable where other techniques are not available. The Cooper et al. (1967) technique, for example, was found to be inappropriate in some cases because of a lack of early-time recovery data.

There is some controversy in the use of such tests in small diameter wells and generally.

In respect of the first matter, it is considered that the amount of water in the withdrawal volume - up to 90% of the screened volume in some cases, and usually 25 – 40%, is a very reasonable amount given the design of the wells. The results clearly demonstrate the involvement of the aquifer matrix in the test and the rapid drainage of the well filter pack. In the second matter, the Bouwer and Rice method is one of the very few available that specifically accounts for partially penetrating wells and screens that straddle the watertable; other types available are of a double-packer design (Widdowson et al., 1990) and in some limited circumstances it is possible to use Cooper-type evaluations (Hyder and Butler, 1995), although this may not be strictly correct.

The technique has been shown to be very suitable in the field provided that any skin effect due to well installation can be ignored by knowledge that a low-permeability skin is not influencing the results, and, that the filter pack definitely has an hydraulic conductivity greater than the formation (Bouwer, 1989, Wylie and Wood, 1990, Hyder and Butler, 1995). For the present Study these conditions were met. The slug testing was performed as one of the last pieces of fieldwork in the Study. Each well which was so tested (Table 4.5), had previously been developed at the time of installation and then sampled between 2 and 6 times prior to the test. It is considered that skin effects are not of concern. The data are reported for individual sites in the relevant Appendices B – J.

Despite the best efforts at seeking and evaluating K by an appropriate technique, some of the data obtained defied evaluation. This was principally because the waterlevel recovery in the wells was too rapid; although in the cases of S9, N7, C1 and C2 there were insufficient early datapoints to enable calculation. The field conditions required use of pressure transducers for waterlevel measurements, however, these had not been available for the Study.

The gradings of soil samples obtained during well installation were also used to develop representative values for K. The data are recorded in Appendix K and are also reported for individual sites in the relevant Appendices B – J. The development of k (intrinsic permeability) from grain size analysis is another common method of establishing aquifer properties in the absence of other methodologies, and these are also reported here. In several recent studies, for example Millham and Howes (1995), the same techniques as present have been used in tandem in evaluating a coastal aquifer.

Table 4.5 Summary of Slug Testing

Well Tested	Date of Test	Respective no. of times well sampled before slug testing	Analytical Method (discussed in text) (tests marked * were unable to be evaluated by any method)
B5*, B9*	26/11/98	5 , 6	Bouwer and Rice
S8	28/10/98	6	Bouwer and Rice
S9*, S10*, S12*	28/10/98	4, 3, 4	Cooper et al.
N1, N2	30/10/98	5, 5	Bouwer and Rice
N7*, N8	30/10/98	5, 5	Cooper et al. and Hvorslev
C1, C3, C4	26/7/98	3, 5, 6	Cooper et al. and Hvorslev
C2*	2/10/98	4	Cooper et al.
H1 – H7	6/11/98	5, 4, 6, 2, 5, 5, 5	Bouwer and Rice
G3, G5*, G8	24/7/98	2, 6, 6	Bouwer and Rice
G1	29/9/98	6	Bouwer and Rice

However, the evaluation of K by this means for the unsaturated zone is fraught with difficulties. In the matter of cemeteries, the majority of the groundwater considerations are initially focused on this zone because this is where infiltration occurs, where groundwater flow first occurs, decomposition products (electrolytes) are made available and mounding takes place. Strictly speaking K should be evaluated in terms of the volumetric water content at any point of concern; Kutilek and Nielsen (1994) provide a comprehensive discussion of this. But what is also important is the electrolyte content of the unsaturated flow waters (Bresler, 1981) since the soil has an ability to restrict flow by accumulation of salts.

The Anion Exchange Capacity (AEC) of the soil may be another parameter which should be considered in further assessment of unsaturated zone soils. For instance, it has been shown relatively recently that subsoils with a high AEC can positively retard nitrate mobilization (Bellini et al., 1996). This seems to be a phenomenon that would be more relevant in unamended, highly weathered materials – perhaps in more tropical climatic areas or in parts of Australia shown to have had variable weathering conditions in the Recent Period. The apparently reduced presence of nitrate and chloride in some clay-rich, unsaturated zones of cemeteries (see Chapter Five) may be explainable in terms of increased AEC. More in-situ work is needed to verify any such effect.

In view of these considerations, it was decided that an additional evaluation of the sites' unsaturated zones and aquifers should be done by methods related to the particle size distribution. The aquifer materials have an intrinsic permeability (k) developed using the relationships of Krumbein and Monk (1942):

$$k = 760(GM_d)^2 e^{-1.31\sigma}$$

where: $\mathbf{GM_d}$ is the geometric mean grain diameter (mm) and $\boldsymbol{\sigma}$ is the standard deviation in phi units [$-\log_2$ (diam. in mm)].

Furthermore, for sediments in the saturated zone, K is developed from the widely reported relationship recognised by Hubbert namely that:

$$K = \frac{k\rho g}{\mu}$$

where: **k** is the intrinsic permeability, $\boldsymbol{\rho}$ is the groundwater density, **g** is the coefficient of gravity and $\boldsymbol{\mu}$ is the dynamic viscosity for the temperature of the groundwater measured (Freeze and Cherry, 1979).

These methods depend upon empirical relationships developed from experiments using reconstituted glacial outwash sands, for the size ranges 0.0625 – 2.00 mm. Consequently they are not totally applicable for soils or sediments where fine particles (<0.06 mm) predominate, and strictly speaking they only apply to unconsolidated materials in the saturated zone. The information provided by this kind of analysis, however, is useful for characterising the sites' hydraulic responses. Thus, for deeper soils at BOT, SPR, NEW, HEL and GUI where the degree of compaction is relatively high, and transient saturated conditions (such as the capillary fringe or mounding) are likely, then k and an 'apparent K' have also been evaluated.

As noted previously, soils where a significant proportion of the particles are fine, were not fully graded and hence no k or K evaluation is made. This was particularly the case for residual soils at WOR, LAU, and CEN, as well as a few others, and the fill at NEW. Further notes regarding this and the development of the K value are found in Appendix K. The major improvements on this kind of evaluation come from further incorporation of bulk soil characteristics like porosity. Unfortunately, porosity values were not available for this Study.

The development of K values for the vadose zone is more complicated. In this zone the infiltration of water significantly depends on the volumetric water content of the soil. This water content varies with the soil mineralogy, particle size distribution, presence of roots, macropores, the amount of atmospheric gases present (or decomposition gases in the case of cemeteries), dry density, void ratio and other factors (Ross, 1990, Kutílek and Nielsen, 1994, Geering, 1995, Fredlund et al., 1997). Attempts have been made to estimate K from the soil-water characteristics developed from the particle size distribution and an understanding of porosity (see for example Fredlund et al., 1997); however, the processes required are relatively complicated and still inexact.

Typically the K_{sat} (saturated hydraulic conductivity) is obtained from field measurements using permeameters and is reported as an infiltration rate in units of mm/h. This data has implications for runoff, ponding, irrigation, seepage and mounding in respect of cemetery operations and the understanding of cemetery processes, and is further considered in Chapter Seven. The values have not been generally determined for the soils in this Study, however, some limited work was done by Gallard (1996) in respect of BOT and is recorded in Appendix B.

*

CHAPTER FIVE

CEMETERY DECAY PRODUCTS

Contents

STATISTICAL ANALYSIS

This Study has resulted in the largest number of inorganic and bacteriological samples ever obtained from a study of cemetery groundwaters. The data are from 9 sites, all have a unique hydrogeological setting. In excess of 13000 data points of inorganic chemistry, environmental indicators and bacteriology are available for analysis (Appendix L). There are many options for what aspects of this data should be analysed statistically, and hundreds of permutations of different factors and determinands.

The options have been condensed to the sets that allow for development of key understandings about the nature of cemetery decomposition products, and the interactions of these products with the:- within-cemetery, and, external-to-cemetery environments. The analyses have thus been constructed to provide the following outcomes:

1. confirmation of the principal analytes that characterise cemetery groundwaters in terms of inorganic chemistry, Cl/Br ratio, Sr;
2. investigation of the variation of cemetery groundwaters in the vadose zone – inorganic chemistry;
3. investigation of the variation of cemetery groundwaters in the saturated zone – inorganic chemistry;
4. determination of the relationship of decomposition products' presence and attenuation to soil properties of the vadose zone - inorganic chemistry and bacteriology;
5. determination and characterisation of heavy metal and environmentally concerning chemical species in cemetery groundwaters;
6. delineation of any seasonal or other time trends within the data of 1, 2 and 3, prior to other analyses;
7. investigation of the character of groundwater associated with non-coffinated

burials compared with coffinated burials;

8. investigation of the attenuation of decomposition products with downgradient flow - inorganic chemistry and bacteriology;
9. determination and characterisation of any separate effects of decomposition products in the presence of identifiable perched watertables and transient vadose zone flow - inorganic chemistry and bacteriology;
10. examination of the historical impacts of cemeteries reflected in groundwaters;
11. determination of the presence of decomposition products in underlying aquifers due to long-term percolation - inorganic chemistry and bacteriology.

These analytical outcomes have been developed after consideration of the Study's aims, the types of available data, and the statistical limitations discussed in Chapter Four. In a number of the outcome categories it is not possible to use all the data gathered and which might appear to fit the need, for example there may be no measured background values for a cemetery; or, different parts of the data may reflect measurements in the vadose zone and the saturated zone. Consequently the data deemed suitable for the analysis has been chosen.

The choosing of data often leads observers to query whether all relevant aspects have been considered, and whether any data is being excluded because it might produce a result contrary to some pre-conceived position. **There are no pre-conceived positions for this data analysis: the task, hopefully enumerated in terms of analytical outcomes 1 – 7, is to validly determine "what is". The remaining analytical outcomes are intended to reflect a vast range of considerations related to key aspects. Once again this involves no pre-conceived position.** The data chosen is all from Appendix L for groundwaters, and Appendix K for soils. The choice of the data in these Appendices has been carefully explained in Chapter Four, and the following discussions will explain 'when and why' particular data is used.

Pursuant to the discussions in Chapter Four, the statistical techniques used here are mostly non-parametric. In most instances the data do not meet strict requirements for randomness or other measures so that parametric analytical methods would be incorrect. Parametric statistical methods can only be employed for data within any one set, or the variables determined for sampling events at any one well, that is, comparing them internally. Other limitations in the data are the number of measurements (N). Table 5.1 sets out the range of data, categorised by site and aspects of sites, and the statistical methodologies that can be used with them.

Many statistical techniques are designed for N >10, but the Study has not produced such data from a maximum 7 sampling events. This is particularly true for seasonal and time-series considerations (Helsel and Hirsch, 1992), and in this regard the form of the analyses is restricted.

CHARACTERISATION OF CEMETERY GROUNDWATER

Influences on Samples

The most useful data for gross characterisation of cemetery processes from measurements of groundwater and soil analytes is that which can mostly derive from body decomposition, and is independent of funereal artefacts, coffin materials and other influences. The purest form of such data is for the interment of naked, un-embalmed, intact bodies only, which have been interred in relatively undisturbed, untended, unfertilized, natural ground without any other obvious contaminant influence.

This Study, and none other known, did not achieve the state of sampling in a cemetery at the penultimate end of the scale. The closest kind of a relevant study may be one associated with the burial area for pig carcasses. The next purest data with respect to human interments comes from the study of Muslim cemeteries allowing non-coffinated interments. In this Study a special effort was made to consider such aspects at GUI and NEW. However, the part of GUI which is dedicated to Muslim burials is within an otherwise well-maintained, well-established conventional, monumental cemetery. At NEW, only one interment, in a suitably dedicated part of the cemetery, occurred during the time of the Study and that data is not further considered.

Table 5.1 Data Available Categorised for Analytical Treatment

#	Outcome - Statement of Analysis incl. special note on parameters	Site Data to Use	Statistical Methods & References	Relevant Studies
1	characterise cemetery groundwaters all data except lower aquifers at SPR & CEN	all	linear correlation - Spearman's *Rho* non-linear correlation - Kendall's *tau* Principle Component Analysis (PCA) Factor Analysis (FA) i, ii, iii, iv	van Haaren (1951) van der Honing et al. (1988) Pacheco et al. (1991) Beak Consultants (1992) Dent (1995) Lelliott (2001)
2	groundwaters in the vadose zone	all		
3	groundwaters in the saturated zone all data except lower aquifers at SPR or CEN	all		van Haaren (1951) van der Honing et al. (1988) Pacheco et al. (1991)
4	relationships and influences: soil properties and groundwater chemistry, by hydrogeological zones or environmental conditions	all	correlation analysis Wilcoxon Rank Sum	Schraps (1972)
5	heavy metal and environmentally concerning two parts – vadose & saturated zones	all	Wilcoxon Rank Sum	van der Honing et al. (1988) Lelliott (2001)

6	seasonal or other time trends	all	Mann-Kendall Trend SEN Trend Estimator graphical analysis	van Haaren (1951) van der Honing et al. (1988) Lelliott (2001)
7	non-coffinated burials compared with coffinated	GUI	Kruskal-Wallis ANOVA* Wilcoxon Rank Sum graphical analysis	
8	attenuation of products downgradient	BOT, WOR, LAU	Kruskal-Wallis ANOVA* Mann-Kendall Trend SEN Trend Estimator graphical analysis	
9	perched watertables and vadose zone flow	WOR, LAU		Matos (2001)
10	historical impacts of cemeteries	MEL, HEL		Keller (1966)
11	decomposition products in deep aquifers	SPR, CEN +/- NEW		

Notes to Table 5.1

References: i. STATISTICA Manuals (StatSoft, 1995) ii. Helsel & Hirsch (1992) iii. Brown (1998) iv. Rock (1988)

* Gibbons (1994) raises some doubt about the use of the Kruskal-Wallis ANOVA Test for monitoring wells when comparing upgradient – downgradient scenarios (i.e. inter-well comparisons). This is discussed more fully in the Section "Discussion of Results - Outcome 7

Consequently, the interpretation of all cemetery data has to be done with the knowledge that the influence of factors, other than body decomposition, is inseparably imbedded within it. Fortunately, as discussed in Chapter One and Figure 1.1, the amount of interred, non-human waste material is relatively small. Therefore, it is reasoned that, in respect of the main inorganic chemical factors (analytes) relating to human decomposition (see Chapter Two), the bulk of the relevant data reflects the interred remains.

This assumption is also likely, on balance, to hold true for the indicator bacteria organisms considered. However, it is likely that there could be some influence on such data because of bacterial spores or cells being added due to the handling of the remains and/or the coffin and/or funereal artefacts by others; or, by the process of interment at any stage from excavation of the grave to completion of the backfilling. For these reasons, it is considered that the assemblage of relevant bacterial data for one site should be given greater value than any one individual analyte measurement.

There are, in addition, some unquantifiable, but probably small, geochemical factors which influence the soil and groundwater regime. Unlike the generalised filled-cell landfill model to which cemeteries have been compared, there are many, repeated disturbances of the ground brought about by the mere function of the cemetery. This results in variable soil conditions – like inverted and mixed soil horizons, loose backfill, incorporated topsoils, grasses and humic substances – in the grave. Variable oxygenation of soil elements occurs, and variable regional infiltration and percolation rates of the land – to grave invert level – occur. The likely consequences might be; oxidation of soil organic matter, oxidation of some minerals like sulfides, release of nitrogen, hydrogen sulfide or methane, and introduction of plant organic material closer to watertables. In Chapter Two, the model of rapidly depleted oxygen availability in-grave was developed, so that any geochemical responses from soil disturbance may be small, rapid, and generally short-lived.

At the outset, the groundwaters of cemeteries are deemed to generally reflect the regional groundwater system. So that groundwater upgradient of the cemetery is considered the normal/average regional input, and that which is within or downgradient of the cemeteries reflects the operation of the cemetery. But it is important to stress that the cemetery groundwaters reflect *all* cemetery operations, including: the interment processes, the remains themselves, the funereal artefacts and coffins, the construction of monuments, the tending of graves (including cleaning fluids and solvents), the tending of lawns and gardens (including composting, fertilising and pest management), the making and maintenance of roads, visiting of cars, spillage of fuels and oils and fluids, building works, and possibly on-site septic disposal. Some of these influences will be removed via stormwater and irrigation runoff, and localised environmental management practices, some will be intercepted in the first few centimetres of soil, but in some cemeteries and some hydrogeological settings, these matters will have an affect upon the cemetery-influenced groundwater.

For the purposes of statistical analysis it appears unrealistic to eliminate all factors unrelated to decomposition of the remains. A comprehensive approach is required and for this reason the cemetery should be treated as a "black box". All the processes resultant from cemetery operations are comparable between upgradient and downgradient samples. Thus samples from within the cemetery, necessarily reflect the various processes to various degrees. Only where within-cemetery samples have been so derived to reflect specialised or isolated conditions (for example, at BOT, WOR, LAU, GUI) – *that is they can be separately discriminated within the "black box"* - can they be validly used for those purposes.

Provided representative, random samples are obtained, and that the analyte/s considered is/are valid for that sample and analysis, then it is satisfactory to lump them together for the purposes here. Small variations in the value of statistics and analyses are likely to have a limited meaning in this context. Furthermore the totality of logical data sets is of more value than isolated results, with the proviso that, some data/analysis that is highly specific or characteristic is relevant.

Choices of Data Sets

Gross characterisation of the groundwaters is best considered from the perspective of the key analytes deriving from body decomposition. The likely analytes are determined from the considerations of body composition, see Chapter Two and particularly Tables 2.1 to 2.4. These include:

- the suite of nitrogen forms – organic/inorganic, oxides, ammonia/um, total
- the suite of phosphorus forms – orthophosphate, total
- Total Organic Carbon; in the absence of measurements for organic acids and carbohydrates
- anions derivable from body fluids – chloride, sulfate (and forms)
- cations derivable from body fluids and bone – sodium, potassium, calcium, magnesium; as well as strontium and selenium.

The relatively reduced amounts of magnesium available and its mobility in the environment (Hem, 1989, Reimann and Caritat, 1998) probably make this analyte unimportant. The analytes strontium and selenium may also have validity. Seemingly elevated amounts of strontium were noted during ICP analyses; most likely this element could derive from bone and is deemed worthy of consideration. Selenium seems to have a unique association with the human – albeit in very small quantities – it is both necessary and toxic for the human (Moynahan, 1979, Reimann and Caritat, 1998), and is also worth considering.

The use of bacterial analytes is more problematic. Of the 1454 individual measurements made in this Study only 351 or 24% were positive (counting all those below the reporting limit as zero). At this rate, and with the measured counts generally being very low, it probably doesn't make sense to use the results for routine characterisation. Many factors affect the longevity of bacterial life, or the viability of bacterial spores, and depending on the hydrogeological setting they may well be more or less likely to be detected in groundwater systems; this is further discussed in Chapter Six. In the same manner, the values obtained for BOD analyses have been generally very low and inconsistent. BOD is also unlikely to be a useful characterising analyte.

Bacterial samplings may be better considered in the contexts of survival versus environmental conditions, for example the pH of the groundwaters, nature of the soil, proximity to any underlying aquifer. This concept has been previously raised by Knight and Dent (1998). If bacteria arising within the cemetery can be shown to be present at cemetery boundaries, then this becomes a management issue and is relevant to the examination of outcomes 4, 8, 9 and 11 above.

The suite of trace metals and environmental indicators, including: Cr, Mn, Ni, Zn, Cu, As, Mo, Cd, Pb are usable to characterise and examine the possible role of coffin materials and funereal artefacts, and possibly embalming. Although all of these elements occur in the human composition and could be relatively significant, they might also have primary roles in soil and rock geochemistry which needs to be taken into account. Other, more minor metals, are more than likely to be of little general value. Also because of their common occurrence, Fe, Si, Al are not further considered although they were determined and are reported in Appendix L.

Boron and mercury deserve special mention. The Study undertook a diligent search to determine levels of Hg in all samples (see Chapter Four). It was thought that Hg connected with the chemical weathering of dental amalgams may be detectable in significant amounts; this was not the case, but it is further considered in respect of outcomes 4, 5 and 10 above.

Boron has been shown to be somewhat problematic. This element is found in petroleum fuels, plastics, fertilizers and in detergents, all of which occur in or are used in and around cemeteries. Boron's use for water characterisation is limited (see Barrett et al., 1999). The element is also very labile in all sorts of natural environments with concentrations in tenths of milligrams per litre being common in all manner of waters (Bouwer and Chaney, 1974, Hem, 1989, Reimann and Caritat, 1998). Furthermore it is sometimes an unwelcome experimental artifact in ICP analyses (Keegan, pers. comm. 1997). Accordingly it is considered that this element should not be generally analysed in the present context. However, for completeness and as a further check, it has been examined in correlation analyses.

After the sampling for this Study was well established an important paper which highlighted the potential use of chloride/bromide studies in assessing contamination within potable waters was published – Davis et al. (1998). The study of these anions is well established for research work on the origins of brines and subsurface salt waters, and other uses, but the application to characterise waters particularly with low total dissolved solids is new. In another paper – Vengosh and Pankratov (1998) reported successfully applying studies of this ratio to domestic sewage effluents and contaminated and mixed groundwaters. Where possible, measurements of the bromine analyte were obtained commercially for the cemetery groundwaters. The limited data set is considered for water characterisation.

Several determinands remain for consideration: EC, pH, Eh, temperature, dissolved oxygen, dissolved carbon dioxide, bicarbonate, carbonate, fluoride, total dissolved solids and alkalinity. With the exception of EC, pH and alkalinity most of these analytes are not further considered for analysis. Fluoride might have been useful but was not widely determined and total dissolved solids were always derived from calculations (see Chapter Four). Bicarbonate was usually derived from field alkalinity measurements and its principal role is in analytical balance calculations together with carbonate – if determined – see Appendix L.

Alkalinity *per se*, however, has been used in some analyses and for the purposes of completeness, any correlation between pH and/or alkalinity and some other analytes has been considered. However, it was noted during field sampling for this Study and previously (Dent, 1995) that there appeared to be little link or pattern between these measurements and other factors in the context of the shallow phreatic aquifers or vadose zone waters being considered.

Dissolved oxygen and its likely effect on Eh, and its role in pump sampling of limited groundwater flows, has been discussed in Chapter Four. With the constantly changing conditions encountered in the seepage wells, seepage trenches, and fluctuating phreatic aquifers where the watertable was deliberately sampled, it is considered that Eh is of little general value for analytical purposes. Eh did, however, have value in-field in that it indicated that likely anaerobic conditions were encountered, from time to time, thus confirming the general model. It is recorded as a standard field measurement (Appendix L).

Unless noted otherwise, all statistical analyses in the following , if done by computer, have been completed using the software: STATISTICA Ver 5.5 (StatSoft, 2000). The form of the data entered into the computer required some small adjustments. Where the value of the determinand was less than the detection limit the value was left blank: except in the case of BOD and bacterial analytes, where it was recorded as zero. For BOD and bacterial determinands of high value – higher than the dilution level that the test permitted – the values were adjusted up to a definitive 'representative' value. This involved considerable estimation for only 6 values (out of 351).

Outcome 1 – Correlations

Table 5.2 summarises the correlation analyses (shown in Figure 5.1) for the examination of all relevant data, not including the underlying aquifers from SPR and CEN, or the ponds at LAU and WOR. Only accepted analyses or relevant parts of those with partial analyses were considered. Non-parametric, linear and monotonic relationships were sought; the appropriate correlation coefficients were calculated after reviewing the relationship scatterplots. A high degree of correlation was demanded in order to add significance to the results; these were – >0.6 for Kendall's *tau* and >0.8 for Spearman's Rho. The significance of the correlation (p level) is also shown. A value of $p < 0.005$ is regarded as "highly significant" (StatSoft, 1995). For the sake of completeness, all significant correlations are recorded.

From this initial data assemblage there is little useful new insight. The most significant relationships are between inorganic and oxidized forms of N, and, between the major cations and anions, and analytes directly related to them – EC and TDS. There is some minor influence of Sr and Mg. This is surprising for Mg which is 58 times less abundant than Ca in the representative human chemistry (Table 2.1) and is also the least abundant of the major cations, and as noted above would initially be viewed as unlikely to be useful.

Figure 5.1 Correlations of Key Analytes

Table 5.2 Correlations for All Key Inorganic Data

Linear Correlations – Spearman's Rho			
Analytes	**N**	**R**	**p level**
EC and Cl	219	0.938	0.000
EC and Na	219	0.965	0.000
EC and Mg	219	0.887	0.000
EC and TDS	219	0.987	0.000
Na and Cl	219	0.947	0.000
Mg and Cl	219	0.883	0.000
TDS and Cl	219	0.946	0.000
Na and TDS	219	0.977	0.000
Mg and TDS	219	0.902	0.000
Na and Mg	219	0.864	0.000
Ca and Sr	218	0.832	0.000
NO_3-N and Total Inorganic N	207	0.857	0.000
Total NOx and Total N	202	0.801	0.000
Monotonic Correlations – Kendall's *tau*			
Analytes	**N**	**τ**	**p level**
NO_3-N and Total NOx	197	0.786	0.000
Total NOx and Total Inorganic N	199	0.666	0.000
PO_4 and Total P	188	0.725	0.000

As a consequence of the results in Table 5.2, the following analytes are carried forward as possible factors for multivariate analysis: EC, Na, Ca, Mg, Sr, Cl, NO_3-N, Total NOx, Total Inorganic N, Total N, PO_4, and Total P.

The same analysis was done for the main bacterial analytes, BOD, TOC, NH_3-N and pH. The only significant correlation was a predictable one between Faecal Coliforms and *E. coli*, with a p level of 0.000. In any circumstance, caution should be exercised in the consideration of bacterial determinands.

The nature of bacterial colonies is very dependent on the site conditions, the availability of food, the rate of dieoff, and the nature of the bacterial flora interred: **they are far from conservative**. This is further discussed in Chapter Six. The interpretation of bacterial data must be done in conjunction with other site-related information.

It is surprising that there is no ready correlation between any of these determinands and that the anaerobic form of N – ammonia, or TOC: the latter is likely to be an indicator of organic decomposition products not otherwise determined.

Factor and Principal Component Analysis – Outcome 1

Additional multivariate analyses were performed in order to understand any underlying structure in the whole data. These types of analyses have considerable value because they are able to weigh the relative importance of a great many variables together. Most groundwaters have a complicated chemistry, and in the situation where many analytes have been measured, it is anticipated that the analysis will assist the identification of really important relationships. These relationships must exist, and particularly so in stabilized hydrogeochemical environments.

The starting point was the raw data for all continuous variables that measured components of the water samples: thus EC, pH, Eh, and TDS were eliminated; alkalinity was retained since in these samples it almost exclusively represents the component HCO_3 (see Chapter Four). However, the initial evaluations did consider all of these analytes, before it was concluded that more meaningful results were attained without them.

Principal Component Analysis (PCA) seeks to understand the relationships between the data using all of their innate variances, whereas Factor Analysis (FA) seeks to understand similar relationships but where a consideration of the covariance structure of the variables is made (StatSoft, 1995, Brown, 1998). Hence FA is more suitable to use on a correlation matrix where some preliminary analysis has already been completed.

Following the preliminary multivariate analysis of correlation and selection of key analytes, these data were then re-correlated and case-wise (sample-wise) deleted until an acceptable set remained. A suitable non-parametric, "true" correlation matrix was then developed using the Spearman's Rho or Kendall's *tau* correlation coefficients applicable to the new data set. Consequently FA on this correlation matrix is given more power, especially in view of the constraints on the nature of the data already discussed (Chapter Four). The FA was conducted using the method that gave the greatest resolution and a standardised varimax rotation. The number of cases (samples) considered in each analysis varies depending on the completeness of the data for each groundwater sample ('case' in the computer software).

PCA has an additional stricture on it *for this data* because of the same reasoning about its nature. That is, that for PCA to be valid, the Central Limit Theorem permitting use of larger data sets, wherein the values of variables approach the normal distribution, or a simple transform of it (like log-normal), must operate. For sets of data >100, and with the approximately correct distributions as these data display, PCA can be used. To ensure its integrity, the data was standarised according to the relation:

Std. Score = (Raw Score – Mean)/ Std. Deviation

An extensive range of analyses was performed seeking to ascertain both the number and angular relationship of any Factors or Principle Components. The results were then evaluated in terms of communalities to ensure that the best possible clustering and Factor relationship was achieved.

The results attained through both processes are suitably similar (Table 5.3) except for respective different inclusions of SO_4 and Sr. The Factors or Components identified can be used for the groundwaters' characterisation with a further need to clarify the importance of the aforementioned analytes whose inclusion at present still makes sense. The relative strength of the parts is identified by their percentage composition of the whole variance of the data set.

FA is not without critics, for example see condemnations and cautions urged by Matalas and Reiher (1967). It must be remembered that FA does not delineate causes of data variance but is merely a means of visualizing relationships in the data and further it only has usefulness for a limited number of all the Factors possible. In groundwater research, however, it is now being usefully employed where it shows up real differences that can be interpreted in terms of the data set; and it is usually coupled with Correlation Analysis, PCA or Cluster or Correspondence Analyses. Useful examples are by Suk and Lee (1999), Powers et al. (1997), Usunoff and Guzmán-Guzmán (1989), and, Razak and Dazy cited in Brown (1998); the last two examples both provide good illustration of how the graphically presented results further illustrate the analyses.

Table 5.3 Principal Components and Factors – All Data

Principal Components – 143 cases, 17 variables	
Cl + SO_4 + Na + Mg + Ca	32.5%
NO_3-N + Total Inorganic N + Total NOx + Total N	20.8%
PO_4 + Total P	12.9%

Factors – 167 cases, 11 variables	
Cl + Na + Mg *	26.5%
NO_3-N + Total Inorganic N + Total NOx + Total N	29.4%
PO_4 + Total P	17.3%
Ca + Sr	16.8%
* it is possible to collapse Factor 4 and add Sr to Factor 1 with new contribution of 31.2% and the others remaining approximately the same	

Outcomes 2 and 3 – Correlations

Outcomes 2 and 3 comprised analyses for groundwaters in the vadose and saturated zones. These were analysed by the same techniques as previously, however, an adjustment was made to the variables considered. To identify characteristics only dependent on dissolved solute chemistry, all derived variables – EC, Eh, TDS were excluded. There were some small differences compared with the results already obtained for the full data set. The results are summarised in Table 5.4 and show only the key correlates; that is, those of interest for further analysis.

Table 5.4 Correlations for Vadose and Saturated Zones' Inorganic Data

Linear Correlations – Spearman's *Rho*					
Zones	**Vadose**		**Saturated**		
Analytes	**N**	**R**	**N**	**R**	**p level**
Na and Cl	76	0.950	107	0.928	0.000
Mg and Cl	76	0.897	107	0.874	0.000
Na and Mg	76	0.896	107	0.858	0.000
Ca and Sr	75	0.917			0.000
NO_3-N and Total Inorganic N	76	0.803			0.000
NO_3-N and Total NOx	76	0.972	92	0.967	0.000
Total NOx and Total Inorganic N	76	0.778			0.000
Total Inorganic N and Total N	76	0.877			0.000
PO_4 and Total P	76	0.877			0.000
Monotonic Correlations – Kendall's *tau*					
Zones	**Vadose**		**Saturated**		
Analytes	**N**	**τ**	**N**	**τ**	**p level**
Ca and Sr			107	0.759	0.000
NO_3-N and Total Inorganic N			98	0.629	0.000
PO_4 and Total P			87	0.718	0.000
Total Organic Carbon and Organic N			46	0.628	0.000

The results for the vadose zone show that analyte data is much more highly correlated than that of the saturated zone. A result like this probably reflects the reduced influence of regional geochemistry on groundwaters in this zone. The groundwaters in the saturated zone have a much greater capacity for mixing and for cemetery-derived influences to be incorporated into the regional groundwater profile.

Biological Factors – Outcomes 2 and 3

A comprehensive examination of the data on the basis of all microbiological analytes, BOD and their relationships with key environmental analytes as EC, pH, Eh, dissolved oxygen, inorganic and organic forms of N, P, S and TOC was conducted. Initially this was by Correlation Analysis (CA) (non-parametric, using case-wise deletions for missing data) and at different levels after separating the data into groups for 'sandy' versus 'clayey' sites. Soil groupings are discussed in detail later but are based on the USCS descriptor of the soils that generally comprise the soil/sediment profile at the place of sampling (that is, the well).

Lowest level analyses relate to all data on the basis of whether assigned to the vadose (V) or saturated (S) zone. For second level analyses, the data are then retreated on the basis of their primary soil description as 'sandy' or 'clayey'. The highest level analyses devolve the previous groups into background (B) and In-cemetery groupings, for example, vadose background (VB) or In-cemetery saturated (S); a further differentiation is then made with respect to the underlying aquifer at SPR and CEN which may also be background sampled, hence (SUB) or (SU). At the highest level twelve sub-groups are recognised within these combinations.

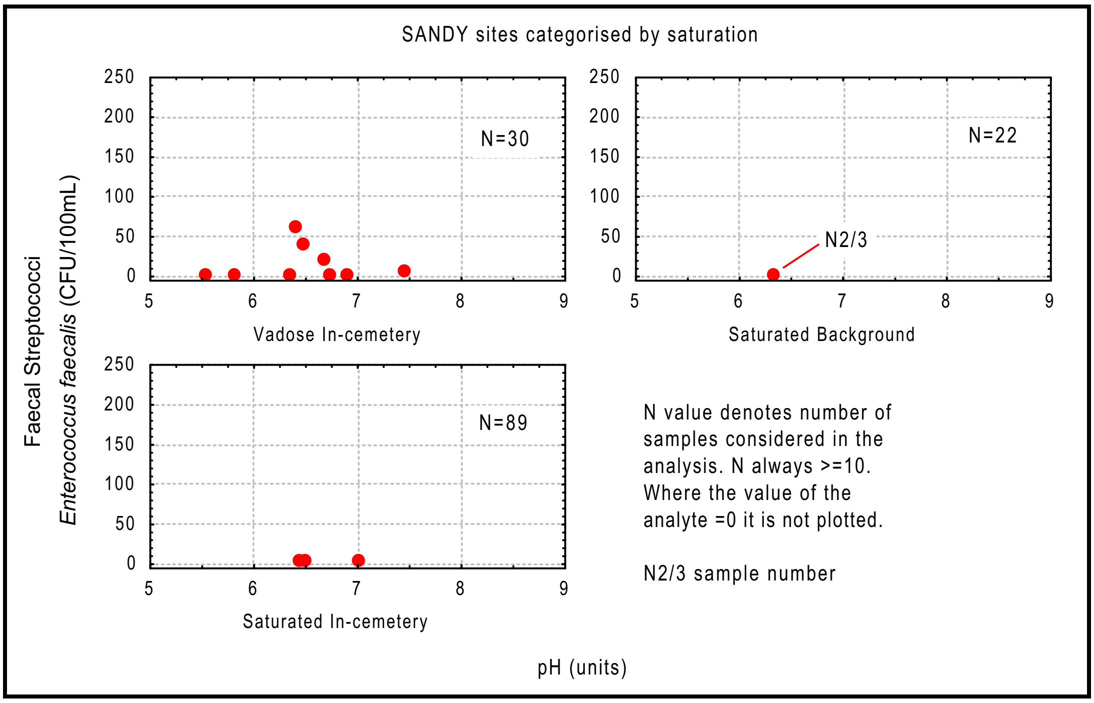
The following acceptance criteria were set so that insignificant or questionable results, because of too few data points, would be rejected: a Kendall *tau* correlation statistic of $>=0.6$, the final sample population must be $N >=10$, and that the result must be significant $0.0000< p <0.0500$. This is considered to be reasonably conservative so that important data will be 'caught' but insufficient or spurious data will have, at best, a limited influence.

There were no important or significant correlations at ANY scale. Many analyses were truncated because of the overall limit of data points; for example, *Clostridia spp., Yersinia spp.* and *Salmonella spp*. were not constantly sampled during the Study and case-wise analysis sets frequently had $N <10$. Overall, the saturated zone in clayey soils is under-represented.

Further work was undertaken to re-examine any possible relationships between all the microbiological analytes, BOD and EC, pH, Eh and dissolved oxygen using graphical analysis by scatterplots and box-whisker plots. This was deemed to be a useful exercise because the previous CA requires (in its internal program operation) some re-specification of analyte results. Specifically this refers to values determined as less than the method detection limit, and where approximate final values which are greater than the test method's maximum limit are reached. A conservative convention was established that integer values were set at about ½ of the minimum reporting level; thus "<1" became "0", "<2" became 1, "<10" (the maximum of all) became "5". Values reported as approximate maxima were converted to the next convenient '00s value consistent with the analysis; for example, " >500" became "1000", "~2400" became "2500", ">241920" became "300000"; this technique introduced a small bias in the values (CFU/100mL) in the 200 – 3000 range; however, the total number of adjustments required was very small about 15 in over 1400 results.

The Figures 5.2, 5.3 and 5.4 show the graphical analysis of the key relationships between pH of the groundwaters and the important microbiological analytes (Faecal streptococci, *Pseudomonas aeruginosa*, and *E. coli*) established for this Study. The results are presented with only the positive occurrences showing – <u>that is, any value of '0' (the majority of measurements), is absent</u>. **This Study has failed to detect any major, consistent presence of microbiological indicators in most cemeteries or in most broad soil types or saturation zones.**

> **However, it is important to note that this is not a totally negative result. Pathogenic bacteria as *Enterococcus faecalis* (Faecal streptococci) and *Pseudomonas aeruginosa,* as well as other faecal indicators like *E. coli,* have been widely detected in the sites' groundwaters; this is further discussed in Chapter Six.**



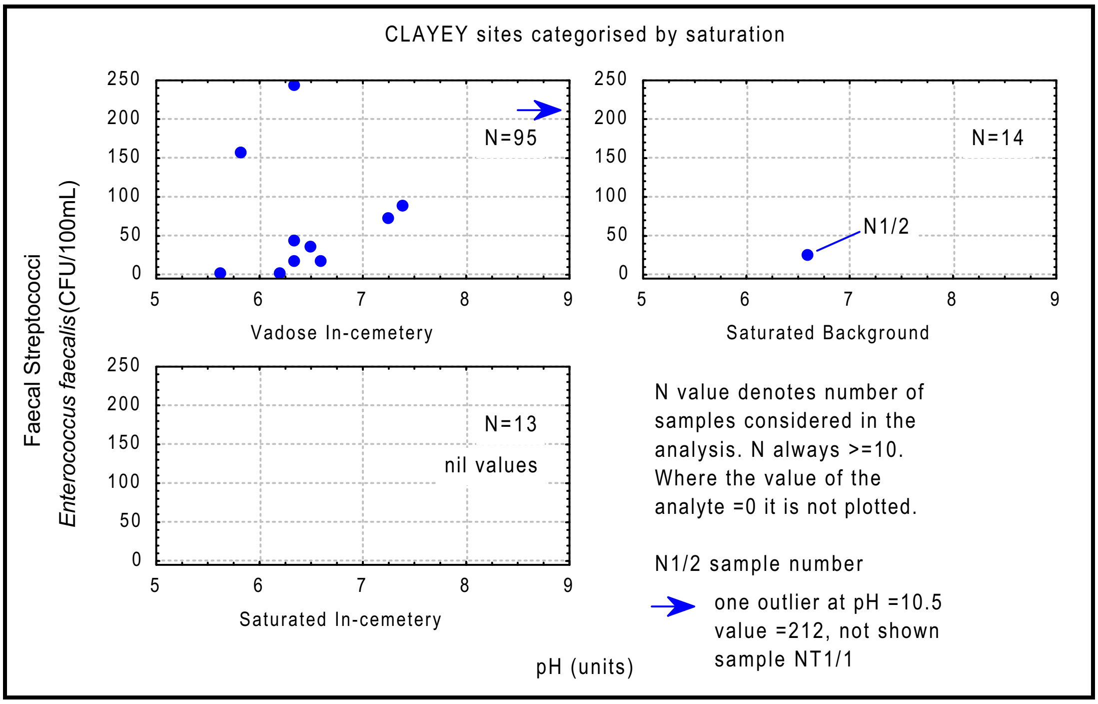
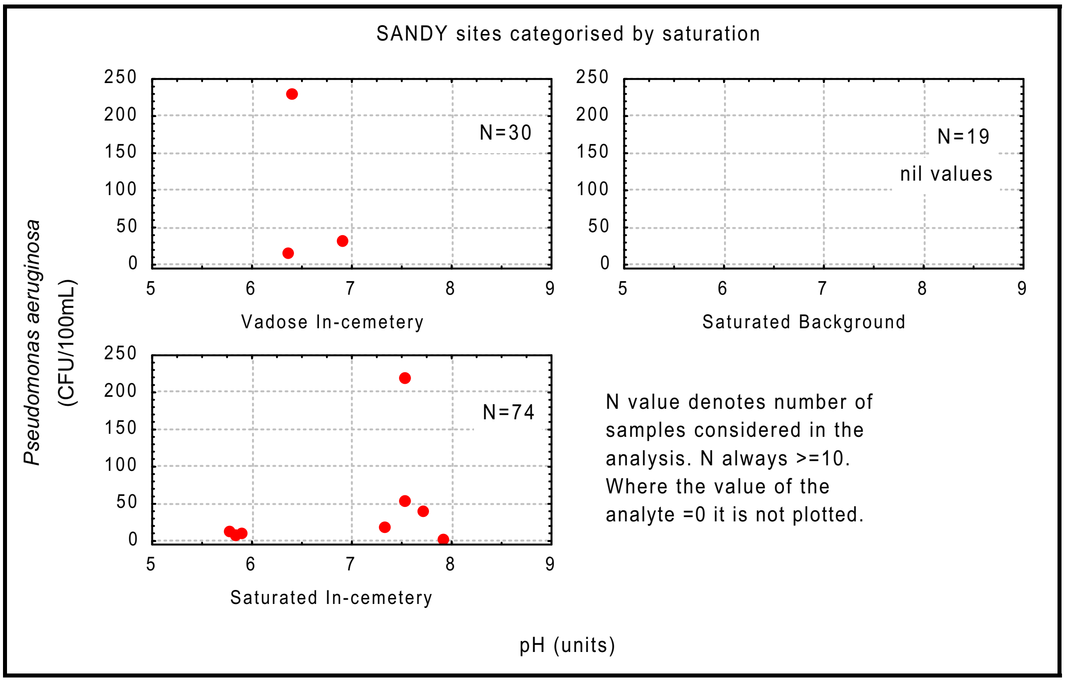


Figure 5.2 Relationship of *Enterococcus faecalis* (Faecal streptococci) groundwater pH (positive occurrences only)



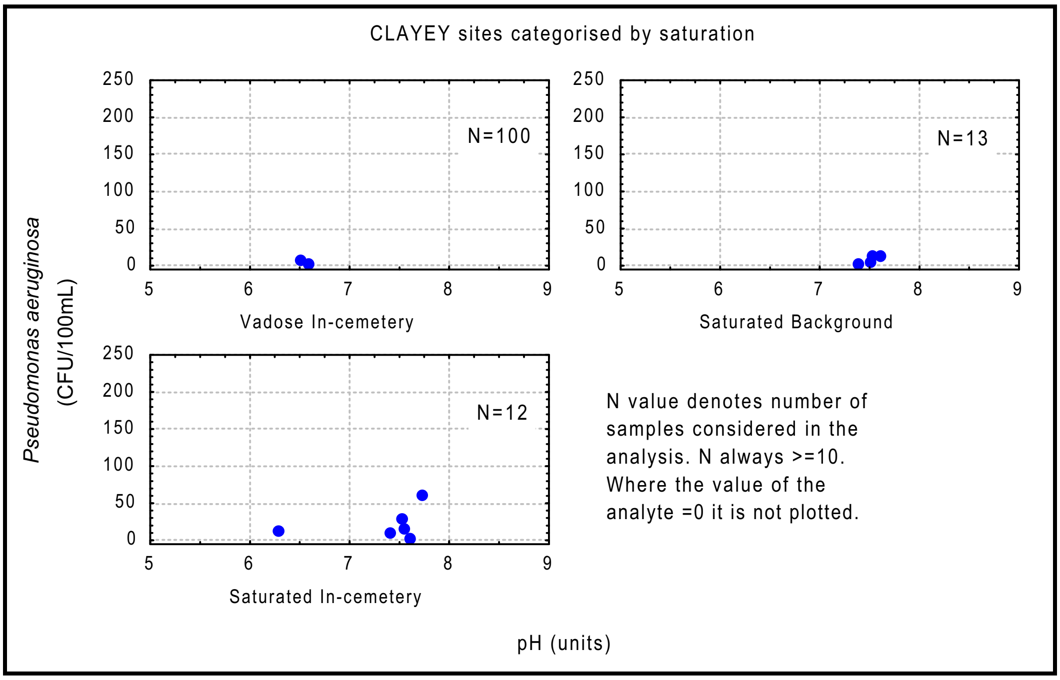
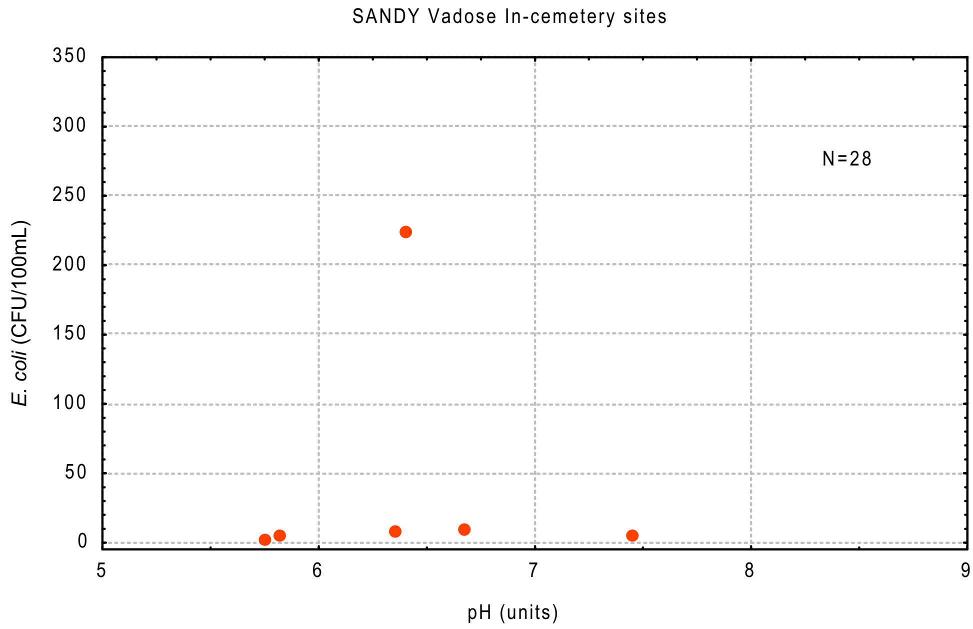
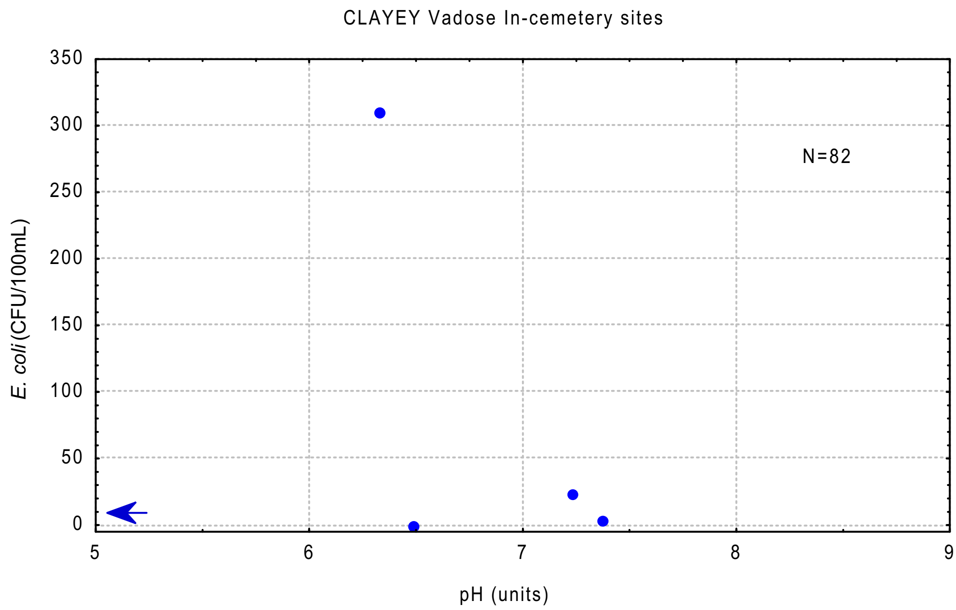


Figure 5.3 Relationship of *Pseudomonas aeruginosa* to groundwater pH (positive occurrences only)





N value denotes number of samples considered in the analysis.

N always >=10. Where the value of the analyte =0 it is not plotted.

← one outlier at pH =3.9, value =5, not shown, sample L6/2

Figure 5.4 Relationship of *E.coli* and groundwater pH
(positive occurrences only)

Factor and Principal Component Analysis – Outcomes 2 and 3

As was done for the Correlation Analyses, FA and PCA were also completed for the hydrogeologically zoned data. The Results are summarised in Table 5.5 and bear a close relationship to previous analyses, except for the exclusion of Total Organic Carbon.

The chemistry of the groundwaters is quite clearly dominated by three groupings of analytes; and the situation shows little variation whether the groundwaters are in the vadose or saturated zones. These groups are, the inorganic forms of nitrogen, major anions and cations, and phosphorus forms: strontium and the alkalinity also have an influence. The relevant combinations of Factors show some differences between the two subsurface zones, and that alkalinity is of reduced importance since it is lost from FA.

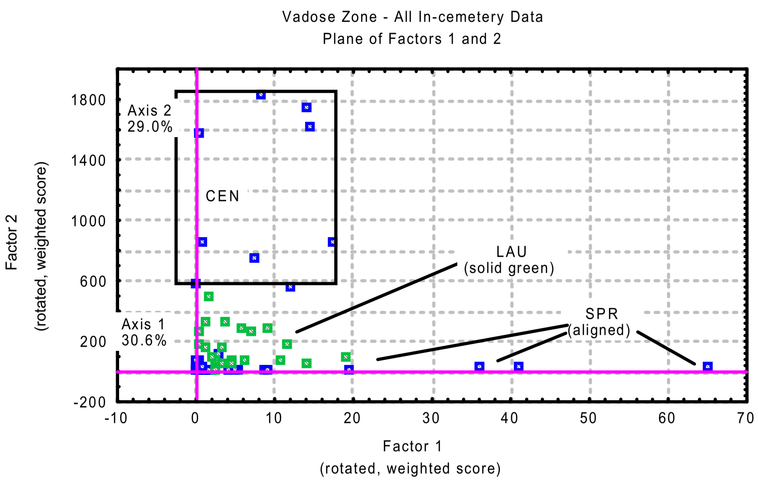
Factor analyses are usefully completed by an examination of the raw data corrected by the Factor scores and then plotted on two or three dimensional axes. Figures 5.5 and 5.6 have been constructed to illustrate the results for 'all In-cemetery data' for the vadose and saturated zones respectively. The previous discussion has highlighted the fact that any of the data is best explained in terms of three Factors which show only a small difference between hydrogeological zones, and where no one Factor is dominant. The maximum amount of sample variance explained by any one Factor is 35.3% (saturated zone, Factor 1).

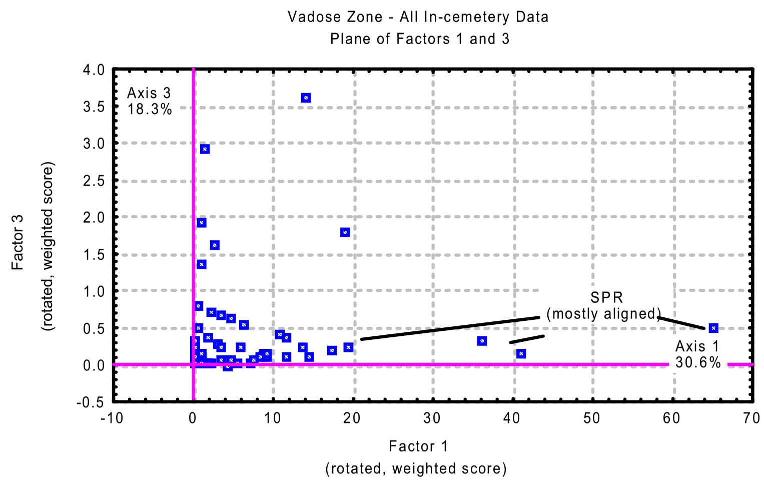
Figures 5.5 and 5.6 show a good clustering of the results overall except for the independent assessment of Factor 3 in either vadose or saturated conditions. Factor 3 in both cases represents the combination of PO_4 and total phosphorus. Although important in this context, the variability of phosphorus-related results is best considered in terms of the behaviour of this element. In Chapter Two the mobility of phosphorus was discussed and it was noted that little leached phosphorus would be found in cemetery groundwaters. Accordingly, the results reflect the notion that it is an important component - *if present*.

Table 5.5 Principal Components and Factors – Vadose and Saturated Zones

Vadose Zone		Saturated Zone	
Principal Components **68 cases, 15 variables**		**Principal Components** **81 cases, 18 variables**	
Alkalinity + Cl + SO_4 + Na + Mg + Ca	40.3 %	Cl + SO_4 + Na + Mg + Sr	27.2 %
NO_3-N + Total Inorganic N + Total NOx + Total N	26.1 %	NO3-N + Total Inorganic N + Total NOx + Total N	19.8 %
PO_4 + Total P	15.9 %	Alkalinity	14.6 %
		PO4 + Total P	11.8 %

Factors 76 cases, 10 variables*		Factors 92 cases, 11 variables #	
NO_3-N + Total Inorganic N + Total NOx	30.6 %	Cl + SO_4 + Na + Mg + Sr	35.3 %
Cl + Na + Mg	29.0 %	NO_3-N + Total Inorganic N + Total NOx + Total N	24.3%
PO_4 + Total P	18.3 %	PO_4 + Total P	15.4 %
* the best analysis was by the Principal Centroid method		# the best analysis was by the MINRES method	





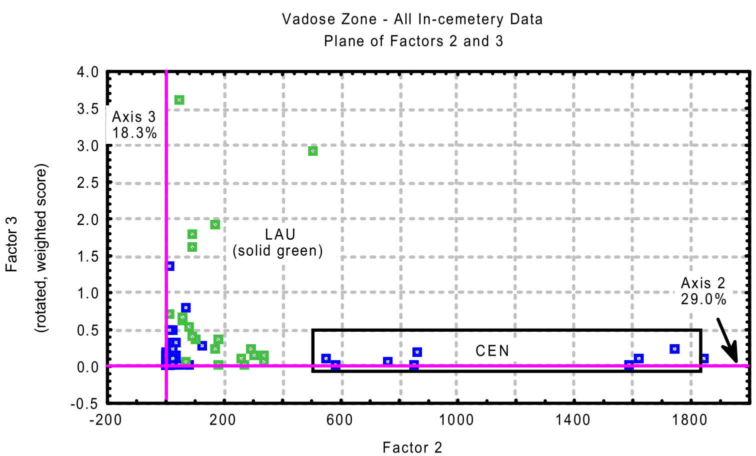
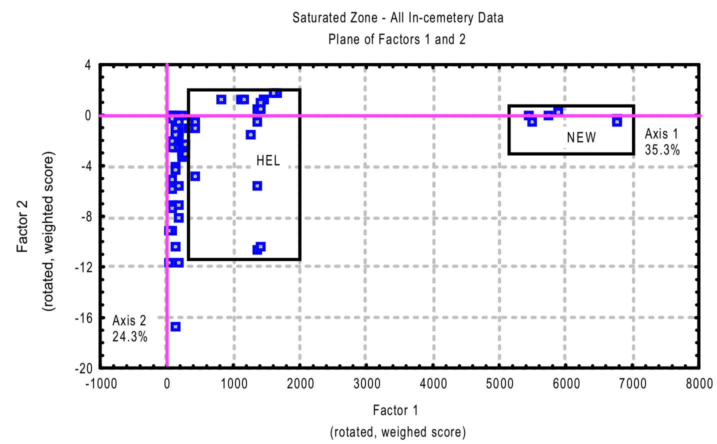
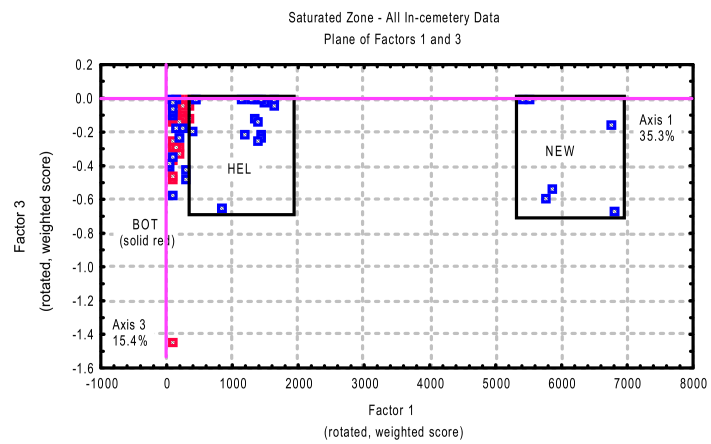


Figure 5.5

Factor Analysis - Vadose Zone
Plot of Factor Planes





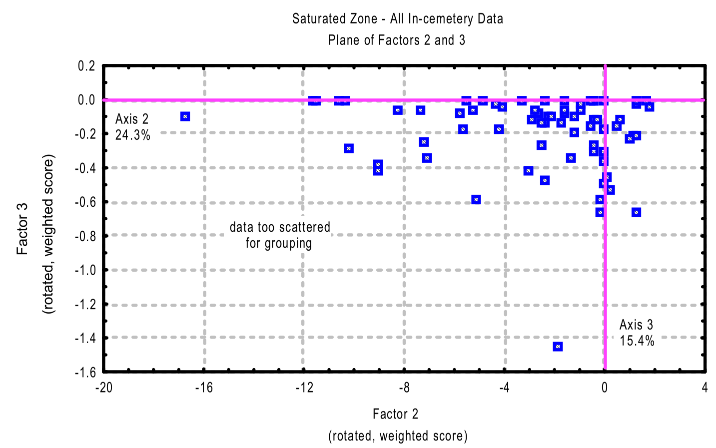


Figure 5.6
Factor Analysis – Saturated Zone
Plot of Factor Planes

The Influence Of The Soils

Prior to examining any relationships between the sites' soils and groundwaters, analyses on the chemistry and classification of the soils themselves were conducted. This was done because many of the groundwater data are very low values and an extra degree of assurance about the analyses was sought. The hydrogeochemical results related to the influence of the cemeteries need to truly reflect that influence and not natural processes of the soils.

In Chapter Four it was noted that the soils were classified according to the USCS for useful comparison of data across many widely–spaced locations. Furthermore, the gross soil colour was characterised by hue according to the Munsell system. Initially the chemical data - EC, pH, CEC and the various exchangeable bases were examined by Correlation Analysis. The coding variables – USCS and colour hue, were then used for MANOVA against the chemical data.

Wherever used herein, the *multivariate analysis of variance* (MANOVA) was done using the Kruskal-Wallis ANOVA and Median Test; a non-parametric (rank transformed) factorial design which permits analysis independent of distributions and randomness (Helsel and Hirsch, 1992, StatSoft, 1995). A number of analyses were unbalanced (that is, different number of samples/cases – N), but the procedure was not used where N was less than 6.

There are no general correlations between EC, pH and CEC or the exchangeable bases. However, there are significant correlations within the exchangeable bases between the following pairs, each at $p < 0.000$:

- Na and Mg
- Ca and Sr (linear)
- Mg and Sr.

Soil colour reflects the original composition of the bedrock or provenance of sediments, the sedimentary history of transported particles, the chemical weathering in-situ and during particle transport, diagenetic processes and post-formation or post-depositional interactions with groundwaters. It was therefore expected that this determinand would correlate with soil chemistry. However, this correlation does not exist. Furthermore the MANOVA results also indicate that each variable is from a distinct population of data; that is, the results are independently and naturally systematic or variable. Of those, pH, exchangeable Ca and Sr are very significantly ($p < 0.03$) independent.

The wide range of colour (Figure 5.7), USCS groupings (Figure 5.8), chemical (Figure 5.9) and USCS characteristics (Figure 5.10) of the sites' soils is illustrated by histogram or box plots for all the soil data. For these considerations no distinctions were made between background, vadose or saturated situations since the purpose was to illustrate all relationships as they may be met at any point, or in any dealing within a cemetery.

Soil Hydraulic Properties and Groundwater Chemistry

The soils' hydraulic properties - as representative hydraulic conductivity determined from soil gradings or slug tests - were examined for any significant relationships with the soils' characteristics or groundwaters' chemistries.

It might be expected that sites which are least facilitative of groundwater percolation might show some retardation in nitrogen products, hence increased ammonia, chloride or some other significant analyte. On the other hand, coarser, sandy soils might be expected to show significant decreases in nutrients or other decomposition products. The sites can be roughly split into sandy (BOT, SPR, HEL, GUI and possibly NEW) and clayey (WOR, MEL, LAU, CEN) types, and the USCS is effectively used for this (see later).

The data needed to do the analysis was derived from calculations of k and K given for all sites in individual site Appendices (B – J) and Appendix K. The soils have been split into vadose and saturated zone groupings. Representative values of K could not be determined for clayey soils (see Chapter 4). In these cases it has been necessary to borrow representative values from well regarded averages published by Freeze and Cherry (1979). The values used are summarised in Table 5.6.

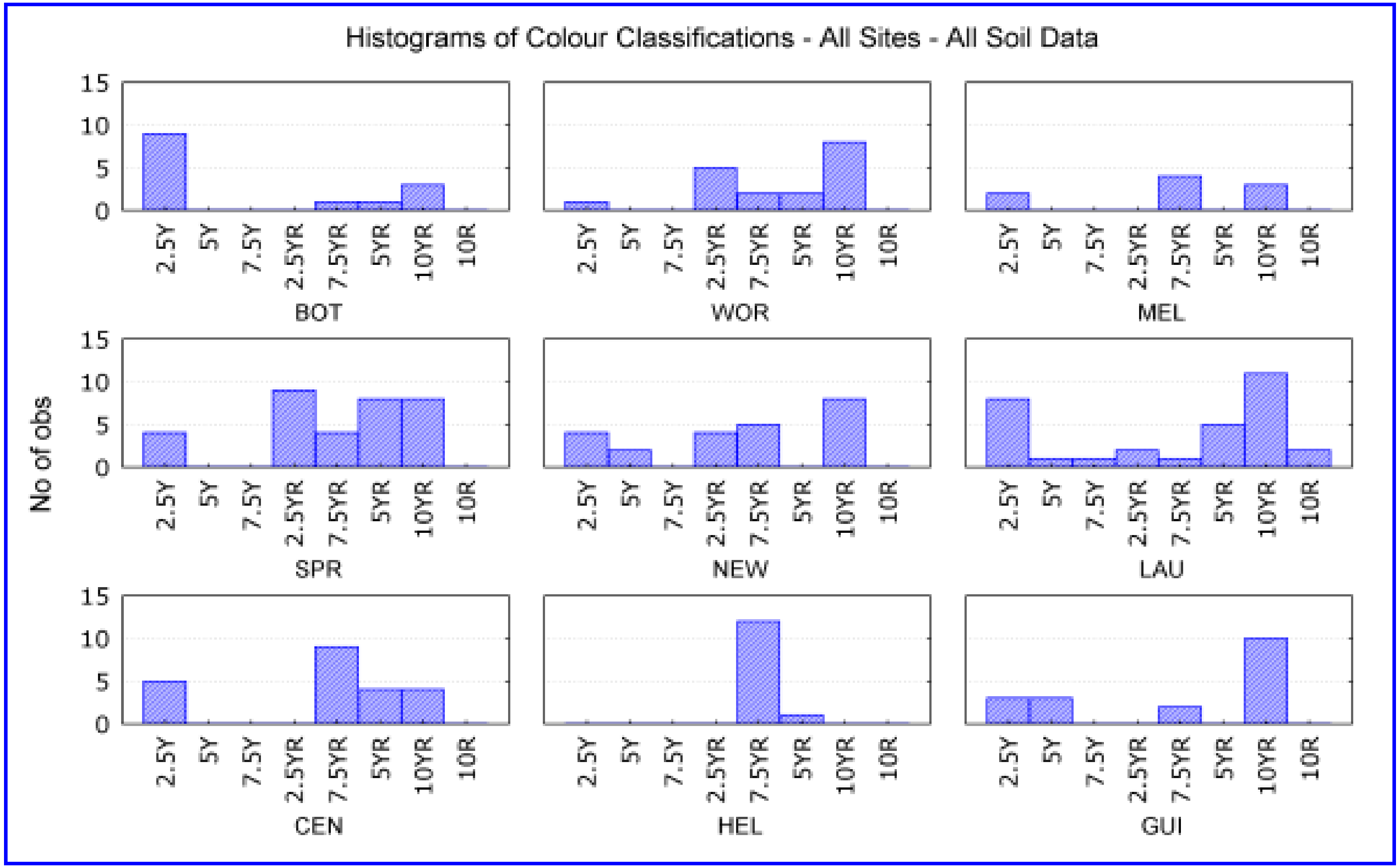


Figure 5.7 Site Soils – Histograms of Colour Hue Groupings

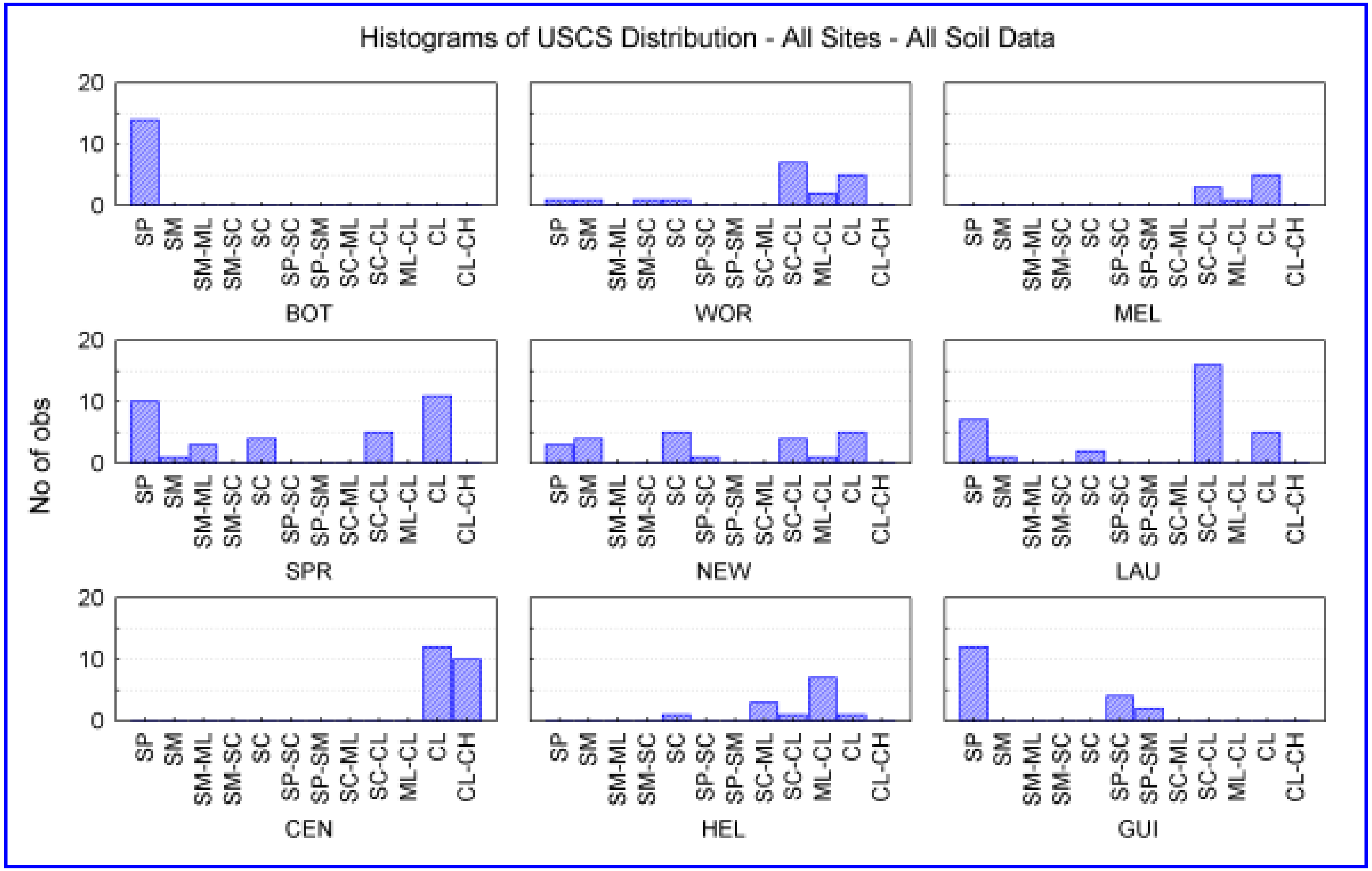


Figure 5.8 Distribution of USCS Groupings By Site

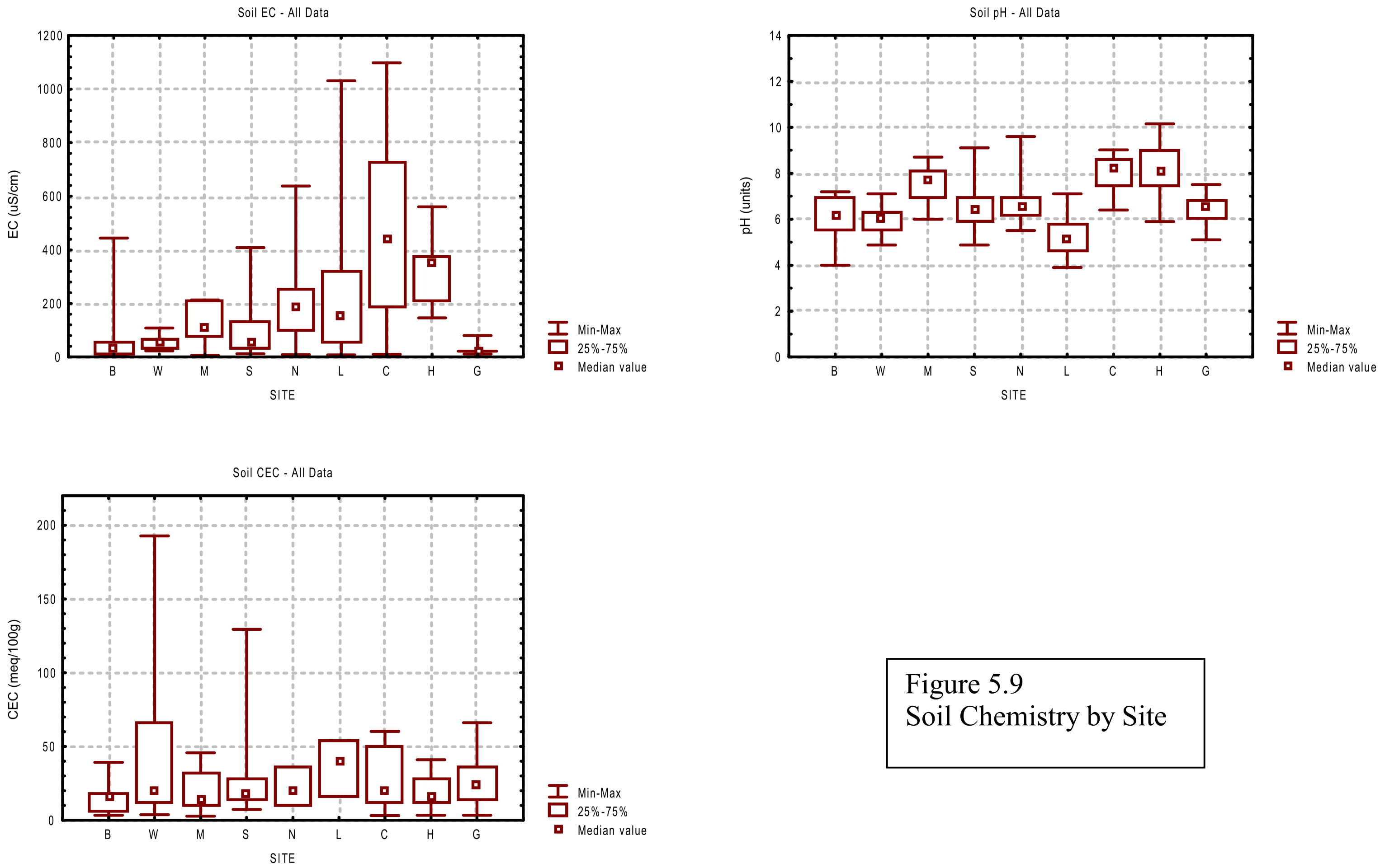
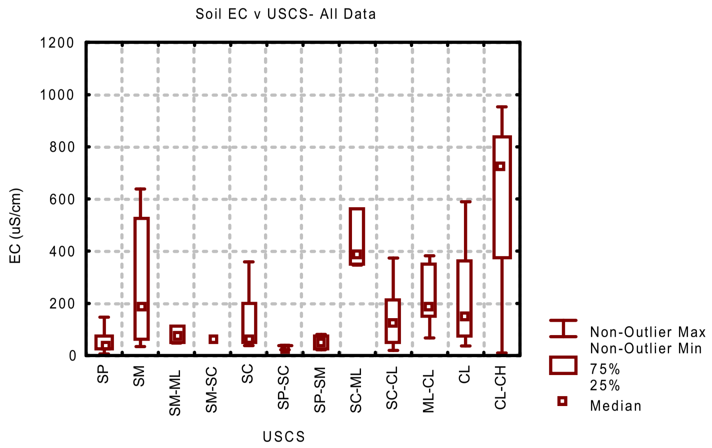
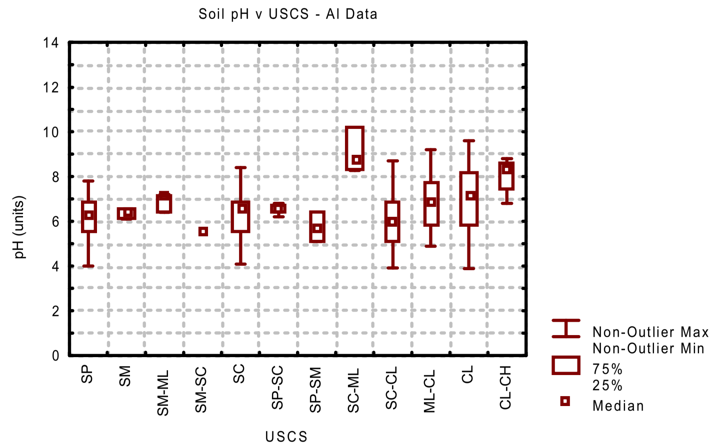


Figure 5.9
Soil Chemistry by Site





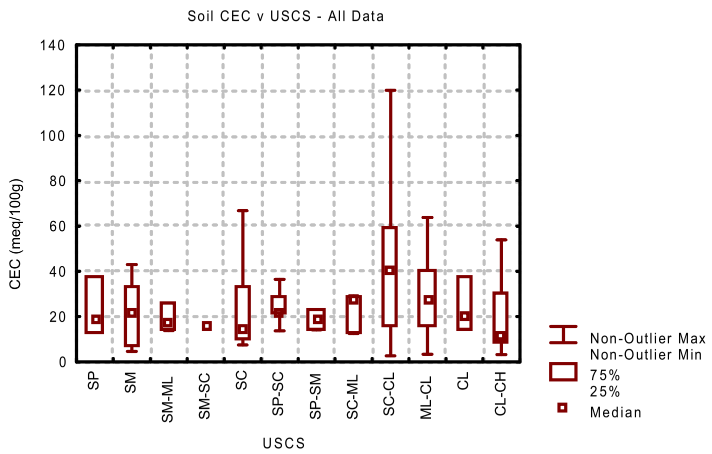


Figure 5.10
Soil USCS Groupings and Chemistry – All Data

Table 5.6 Representative Values of K

Site	USCS Groupings		K in m/sec		
	vadose zone	saturated zone	average from gradings	slug tests ranges or averages	representative value
BOT	SP		3.73E-04	1.46E-05*	1.0E-05
		SP	3.55E-04	2.62E-06 to 2.36E-05**	2.5E-05
WOR	SC, SP, SM-SC		2.05E-04		8.0E-05
	SC-CL				8.0E-07
	ML-CL				1.0E-08
	CL				1.0E-09
		SM	2.15E-04		5.0E-05
MEL	SC-CL, ML-CL				8.0E-07
	CL				8.0E-09
SPR	CL				1.0E-09
	SC		2.45E-04		5.0E-05
	SC-CL, SM-ML		9.55E-05		5.0E-07
	SP		4.91E-04		1.0E-05
		SP, SM		3.20E-04	8.0E-04
		CL			1.0E-09
NEW	CL, CL-ML				1.0E-09
	SC		1.29E-04		5.0E-05
	SC-CL				5.0E-07
	SM, SP, SP-SC		4.03E-04		8.0E-05
		SM, SP	1.04E-04	2.18E-06 to 7.45E-06	3.0E-06
LAU	CL				1.0E-09
	SC		5.06E-05		8.0E-05
	SC-CL				5.0E-07
	SM, SP		1.10E-04		5.0E-05
CEN	CL				1.0E-09
	CL-CH				1.0E-08
		CL, CL-CH		1.39E-06	1.0E-07
HEL	ML-CL				1.0E-08
	SC		1.16E-05		1.0E-06
	SC-CL, SC-ML				5.0E-07
		CL, ML-CL, SC-ML		6.92E-06 to 1.40E-05	8.0E-06
GUI	SP, SP-SC		2.15E-04		1.0E-05
		SP, SP-SC, SP-SM		6.94E-07 to 1.74E-06	1.0E-06

Table 5.6 Continued

Notes to table:-

representative values are determined from consideration of the data or estimated from recognised sources like Freeze and Cherry (1979)
* data from permeameter tests by Gallard (1996)
** data from slug and/or pump tests by Dent (1995)

Soils and Groundwaters – Correlation Analysis and Outcome 4

A Correlation Analysis was conducted in order to examine initial relationships between the soils' chemical and physical features and those of the contained groundwaters. This was done for the major hydrogeological zones then for major soil types. The key analytes (see earlier discussion) were considered in each analysis, as well as additional overlapping soil chemistry factors – exchangeable bases, pH, CEC etc. A few negative correlations were found.

All available data, except rejected groundwater chemical analyses, were used. The data was cross-matched initially so that groundwater samples were drawn from the same well/trench as had had soil samples taken. Even so, it was not possible to match 15 soil analyses, which were grouped separately. In 4 cases, soil samples were matched to appropriate water samples taken from equivalent in-site settings, so that all possible generalised data matches could be considered.

The Correlation Analysis then proceeded hierarchically. Initial considerations concerned broad hydrogeological zonation (vadose versus saturated condition); thence, separation of wells/sampling points as to whether they were essentially clayey or sandy parts of their sites. The final differentiation was then made on the basis of whether the well/sampling point represented a background or In-cemetery location.

Using non-parametric ranking, the analysis proceeded by case-wise deletion until complete pairs of determinands could be correlated across the relevant matched data. Initial screening suggested that there were few lineal relationships, so that the Kendall *tau* (Γ) statistic was determined. A minimum level of acceptable correlation was set at 0.6, and a marginal level of interest described for $0.5 < \Gamma < 0.6$. Only results that were statistically significant in the range $0.000 < p < 0.05$ were considered. Finally, a decision was made to reject analyses where $N < 10$. Although analyses for $N >= 6$ are acceptable for this method, in this situation such small amounts of data usually reflected only considerations of one site. This is discussed further below for LAU, but was otherwise considered to be an unsatisfactory reflection of the whole-of-Study data.

Consequently over 4950 data pairs were considered for 12 soil and 23 groundwater determinands. These were classed into 18 sub-units for analysis. A summary of the important and marginal correlations is given in Table 5.7. The physical property determinands – like USCS were 'numerically labelled' so that they represented samples of increasing fineness; whilst COLOUR was of increasing hue.

The soils were separated into two gross groupings – 'sandy' and 'clayey' based upon their USCS classification as follows:

- SP, SM, SM-ML, SM-SC, SC, SP-SC, SP-SM, SC-ML – **sandy**,
- SC-CL, ML-CL, CL, CL-CH – **clayey**.

Interpretation

The results do not imply any cause and effect relationships. It is also generally unclear whether the site soils influence the groundwaters or vice versa, or whether the two factors correlated are otherwise unrelated except that they occur in the samples. For example, is NaCl remnant on sand particles and is released into transient unsaturated flows, or is the percolating water laden with NaCl which it leaves behind upon evaporation? Likely as not, both processes are at work at different rates and times.

The real benefit of these comprehensive analyses lies in the ability to say whether the soils seem to be having any undue effect on the values measured for the groundwater analytes. This is important because, as noted above, the measured values of most analytes are low. That is, certainly low enough so that they can be influenced by variable natural factors or inappropriate collection, analytical or handling methods.

Table 5.7 Correlation Analysis Results – Soils and Groundwaters (Non-biological)

Soil		Significant Relationships				Marginal Relationships	
Group	Sub-Group*	Analytes	N	Kendall *tau*	p	N	Analytes
Vadose Zone							
All	all	nil				66 64	EC & Na, Mg Na & Na
Sandy	all	EC & EC	23	0.605	0.000	23	EC & Na , Mg, Cl
Clayey	all	nil				43-44 44 42-43	EC & EC, Na, Mg, Cl pH & pH, alkalinity Na & EC, Na
Sandy	VB	nd					
Sandy	V	EC & Mg	22	0.602	0.000	22	EC & EC, Na
Clayey	VB	nd					
Clayey	V	nil				41-42 42 40	EC & EC, Mg pH & pH, alkalinity Na & Na
Saturated Zone							
All	all	nil				81 78-79 76	USCS & EC, Na, Mg EC & EC, Na, Sr Mg & SO4
Sandy	all	nil					nil
Clayey	all	nil				32 28	USCS & Mg Mg & SO4

Sandy	SB	USCS & SO4 K (Hydr. Cond.) & Tot N Na & EC Na & Na	14 16 11 12	0.619 -0.666 0.636 0.667	0.002 0.002 0.006 0.003	15 11-12 14-15 15	K (Hydr. Cond.) & EC Na & Mg, Sr, Cl, SO4 Mg & NH3-N (-), SO4 Al & Tot P (-)
Sandy	S	nil				27 27 19 28	EC & Na, Mg pH & TOC (-) Na & Mg Mg & Mg
Sandy	SUB	nd					
Sandy	SU	nd					
Clayey	SB	cr					
Clayey	S	cr					
Clayey	SUB	nd					
Clayey	SU	USCS & SO4 USCS & Na USCS & K USCS & Sr K (Hydr. Cond.) & Na K (Hydr. Cond.) & Sr K (Hydr. Cond.) & SO4 Na & Ca	12 15 15 15 15 15 12 14	0.614 0.611 0.637 0.637 0.611 0.637 0.614 0.626	0.006 0.002 0.001 0.001 0.002 0.001 0.006 0.002	15-16 12-15 16 12-15 12	USCS & alkalinity, Ca, Mg, NO3-N, NH3-N pH & Eh (-), K, SO4 K (Hydr. Cond.) & K, Ca, Mg, alkalinity, NO3-N, NH3-N Na & Na, K, alkalinity, SO4 Ca & Eh (-)

nd = insufficient data for correlations (N <= 6)
cr = correlation Analysis rejected (6< N <10)
(-) = correlation coefficient (Γ) is negative
* Sub-Group classifications: V = vadose zone, S = saturated zone, B = background, U = underlying aquifer
Increasing complexity of analysis:

Level 1	Level 2	Level 3
hydrogeological zone (vadose, saturated)	hydrogeological zone and site soil (sandy, clayey)	hydrogeological zone and site soil and background (B) or In-cemetery locations

In broad terms it seems that soil-groundwater interactions are not very important in the considerations of all the data in this Study. However, there are some instances where the role of the major ions may have some influence. In addition, there are possibly some marginal correlations with inorganic nitrogen sources in saturated, sandy backgrounds or underlying aquifers.

In the vadose zone the effect of major ions is of interest. Some of these – Na, Mg – appear to be available to be mobilized by transient flows. As the soils become saturated this trend continues but is further complicated by the effects of increasing fineness and loss of nutrients.

This conclusion is not particularly profound; but it is extremely important in the present context because the data measured for groundwater analytes are found to be relatively low values. *In these studies therefore, comparisons about major ion contents need to be based on significantly elevated values compared to background. Marginally elevated values are of more questionable worth as to whether they correctly indicate the presence of decomposition products.* The amount of difference needed in order to be considered relevant is hard to quantify and is discussed later.

From Table 5.7 some particular relationships are considered:

- ❖ The presence of SO_4 in finer soils is likely to be indicative of decomposition products – in the absence of other sources (Fig. 5.11).
- ❖ The significant correlations for *sandy background* soils reflect the non-attenuation of N products with increasing coarseness.
- ❖ The Na relationships in Sandy Background soils may in part reflect the pathways of NaCl in coastal areas, yet the relationship is not as clear for Cl.

The total sulfur content of groundwaters was an analyte only measured at LAU in 14 samples. At that site the results not only reflect SO_4 but probably include hydrogen sulfide forms derived from the presence of pyrite in the sediments (see Appendix K for mineralogical data). Organic sulfur forms are also likely but were unmeasured. A strong correlation was found for this limited, grouped data (N = 7 to 9) between exchangeable soil Ca, Sr and the total sulfur, with a marginal role for Al. However, further analysis for all SO_4 (in all data groups) and these cations, showed no generalised relationship. The significance of these correlations may be local.

The relationships for the *saturated, clayey, underlying aquifers* are the most complicated. The analysis reflects data from SPR and CEN roughly in the proportion 1:2.4 and shows a very high correlation with the physical soil properties of USCS type and hydraulic conductivity. Marginal correlations with most major ions and inorganic nitrogen products, except Cl in all cases, also exist. These results cannot be adequately interpreted because there is insufficient *background* data; this matter is discussed in more detail later with respect to Outcome 11.

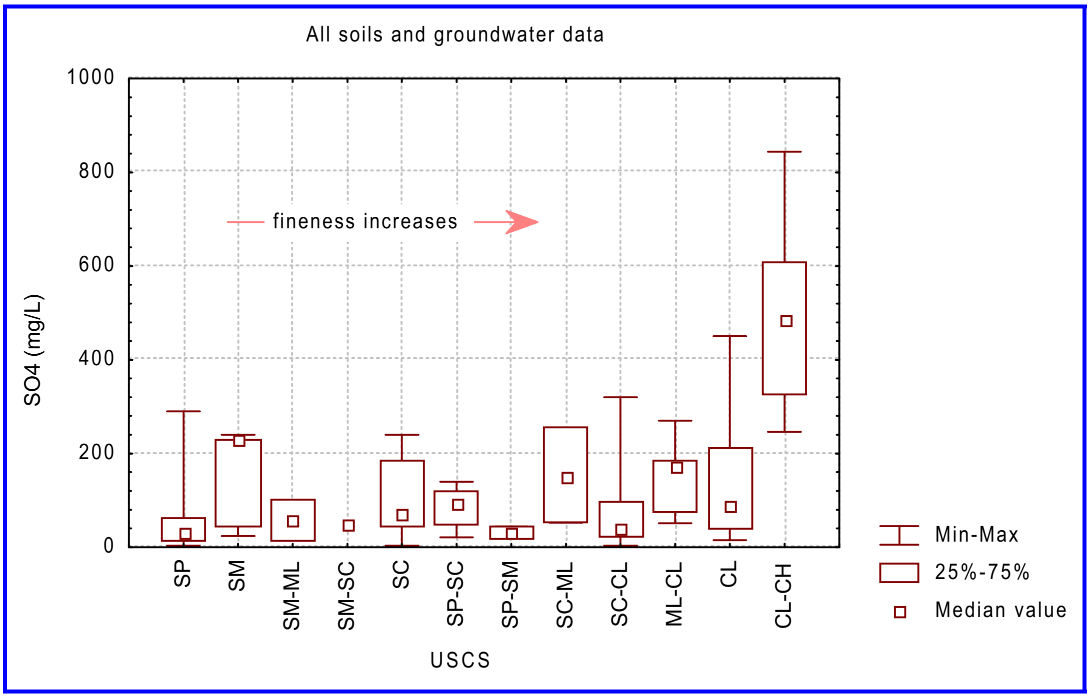


Figure 5.11 Generally Increasing SO_4 With Increasing Soil Fineness

Groundwater Biology And The Soils

The Correlation Analysis was continued in order to examine any links between biological factors and the sites' soils. The same criteria used previously for the chemical analyses were applied, however, in this instance it was necessary to make additional data adjustments for 'non detect' values. 12 soil-related variables were correlated against 8 microbiological variables and the BOD results.

An extremely large number of the groundwater microbiological results were reported as being less than some detection limit, which in turn was a reflection of the technique adopted by the processing laboratory (see Chapter Four). In accordance with the methodology described earlier, all values reported in terms of detection limits were re-set to a firm value of half that limit; for example a result of "<2" became "1", "<1" became "0". Values with minimum limits were set at a higher value commensurate with the size of the result; for example, ">700" was set at "1000", ">1400" became "2000".

There were **no** significant results and only one very marginal relationship between K (hydraulic conductivity) and *E. coli* for saturated, clayey soils at the second level of analysis. At the highest level, this relationship was no longer found. There were a larger number of incomplete, matched cases for the whole analysis compared to that for the previous chemical analyses. Consequently, many of the higher level analyses for the biological attributes couldn't proceed because of insufficient data sets.

Environmental Considerations – pH

A comprehensive re-evaluation of all data by Correspondence Analysis was undertaken in order to examine the role of gross chemical environment – as measured by the in-field pH of the groundwaters, in respect of all major analytes, metals and biological aspects. The results of the analyses are presented in Table 5.8 and further discussed below. The metals are particularly discussed as Outcome 5.

Table 5.8 pH Dependent Correlation Analyses – Groundwater & Soils
All Results Reported by Levels of Analysis
(pH separated according to in-field groundwater measurement)

Acid Environment pH <= 7.0 (1)				Alkali Environment pH >= 7.0			
Correlated determinands	Spearman **Rho *(2)***	Kendall *tau* (3)	p	Correlated determinands	Spearman **Rho**	Kendall *tau*	p
GROUNDWATER ONLY – MAJOR ANALYTES (4)							
all samples vadose zone N=113 (5) – Level 1 (6)				**all samples vadose zone N=26 – Level 1**			
Na & Cl		.770	all <0.0000	NH3 & PO4		.613	all <0.0000
Mg & Cl		.671		Na & Cl	0.823		
Na & Mg		.630		Mg & Cl		.676	
Ca & Sr		.695		Na & Mg		.727	
-				Ca & Sr		.700	
all samples saturated zone N=128 – Level 1				**all samples saturated zone N=53 – Level 1**			
NO3 & Tot Inorg N		.666	all <0.0000	NO3 & Tot Inorg N	.959		all <0.0000
NO3 & Tot N		.625		Cl & SO4	.949		
Tot Inorg N & Tot N	.935			Mg & Cl		.637	
Cl & SO4	.819			Na & SO4	.888		
Na & Cl		.864		Mg & SO4	.851		
Na & SO4	.816			Sr & SO4		.613	
Sr & SO4		.645		Na & Cl	.841		
Na & Mg		.638		Na & Mg	.920		
Ca & Sr	.915			Na & Sr	.860		
Sr & SO4		.645		Mg & Sr	.936		
-				Ca & Sr		.638	

sandy soils all samples vadose zone N=19 – Level 2				**sandy soils all samples vadose zone – Level 2**			
Na & Cl	0.906		all <0.0000	nd (N=4) (7)			
Ca & Sr	0.895			-			
clayey soils all samples vadose zone N=34 – Level 2				**clayey soils all samples vadose zone N=13 – Level 2**			
Na & Cl		.649	all <0.0000	alkalinity & Cl	.816		0.0007
Mg & Cl	.896			alkalinity & Na	.824		0.0010
Na & Mg	.813			alkalinity & Sr		.636	all <0.0000
Ca & Sr	.832			Tot N & TOC		.606	
-				Na & Mg	.811	.727	
-				Na & Cl	.988		
-				Mg & Cl		.687	
-				Sr & Cl		.626	
-				Na & SO4		.636	
-				Mg & Sr		.606	
-				Ca & Sr		.636	
-				NO2 & NH3		.760	
-				NO2 & NO3	.884		0.0001
-				NH3 & TOC	.858		0.0004
-				PO4 & Al		.614	<0.0000
sandy soils all samples saturated zone N=41 – Level 2				**sandy soils all samples saturated zone – Level 2**			
NO3 & Tot Inorg N	.824		all <0.0000	nd (N=8)			
NO3 & Tot N	.833			-			
Tot Inorg N & Tot N	.938			-			
Cl & SO4	.809			-			
Na & Cl		.825		-			
Na & SO4		.635		-			
Ca & Sr	.872			-			

clayey soils all samples saturated zone N=17 – Level 2				**clayey soils all samples saturated zone N=16 – Level 2**			
NO2 & Tot Inorg N		.607	<0.0000	NO3 & Tot Inorg N	.951		all <0.0000
NH3 & Mg	.838		0.0001	Cl & SO4	.913		
Tot Inorg N & Tot N	.951		<0.0000	Na & Cl	.973		
Cl & SO4	.824		0.0005	Mg & Cl	.961		
Na & Cl	.849		0.0002	Ca & Cl	.936		
Mg & Cl	.913		all <0.0000	Sr & Cl	.879		
Sr & Cl		.641		Na & SO4	.955		
Sr & SO4	.958			Mg & SO4	.936		
Ca & SO4	.886			Ca & SO4	.874		
B & Ca	.845			Sr & SO4	.856		
B & Sr	.836			B & K		.683	
Na & SO4	.909			Na & Mg	.953		
Na & Mg	.850			Na & Ca	.912		
Na & Ca	.871			Na & Sr	.888		
Na & Sr	.865			Mg & Ca	.971		
Ca & Sr	.938			Mg & Sr	.918		
-				Ca & Sr	.953		
Level 3 - all groundwater samples separated by subcategories . The analysis only considered the effectively correlated analytes previously identified for sandy or clayey sites at Level 2. Only Spearman's *Rho* Correlation Coefficient was determined							
SANDY SITES –Level 3							
vadose zone, background				**vadose zone, background**			
nd (N=1)				nd (N=0)			
vadose zone, in-cemetery N=18				**vadose zone, in-cemetery**			
Na & Cl	.910		all <0.0000	nd (N=4)			
Ca & Sr	.905			-			

saturated zone, background N=12				**saturated zone, background**			
Tot Inorg N & Tot N	.930		<0.0000	nd (N=4)			
Tot Inorg N & Na	-0.811		0.0014	-			
Tot N & Cl	-0.881		0.0003	-			
Tot N & Na	-0.860		0.0003	-			
Tot N & Mg	-0.825		0.0010	-			
Tot N & Sr	-0.873		0.0005	-			
Na & Cl	.982		<0.0000	-			
Mg & Cl	.950		<0.0000	-			
Ca & Cl	.808		0.0026	-			
Sr & Cl	.970		all <0.0000	-			
SO4 & Cl	.932			-			
SO4 & Na	.955			-			
SO4 & Mg	.845		0.0010	-			
SO4 & Sr	.855		0.0016	-			
B & Al	.867		0.0003	-			
Na & Mg	.937		<0.0000	-			
Na & Sr	.900		0.0002	-			
Mg & Ca	.832		0.0008	-			
Mg & Sr	.900		0.0002	-			
Ca & Sr	.891		0.0002	-			
saturated, in-cemetery N=24				**saturated, in-cemetery**			
Alkalinity & Ca	.848		all <0.0000	nd (N=4)			
NO3 & Tot Inorg N	.960			-			
NO3 & Tot N	.935			-			
Tot Inorg N & Tot N	.960			-			
TOC & Mg	.806			-			
Cl & SO4	.840			-			

Na & Cl	.913			-			
Na & SO4	.807			-			
Ca & Sr	.836			-			
saturated, underlying aquifer, background				**saturated, underlying aquifer, background**			
nd (N=1)				nd (N=0)			
saturated, underlying aquifer, in-cemetery				**saturated, underlying aquifer, in-cemetery**			
nd (N=4)				nd (N=0)			
CLAYEY SITES – Level 3							
vadose zone, background				**vadose zone, background**			
nd (N=2)				nd (N=0)			
vadose zone, in-cemetery N=23				**vadose zone, in-cemetery N=13**			
Na & Cl	.802		all <0.0000	Alkalinity & Cl	.816		.0007
Mg & Cl	.929			Alkalinity & Na	.824		.0010
Ca & Sr	.821			NO2 & NO3	.884		.0001
-				NH3 & TOC	.858		.0004
-				Na & Cl	.988		<0.0000
-				Na & SO4	.804		.0016
-				Na & Mg	.811		.0014
saturated zone, background				**saturated zone, background**			
nd (N=5)				nd (N=1)			
saturated, in-cemetery				**saturated, in-cemetery**			
nd (N=0)				nd (N=8)			
saturated, underlying aquifer, background				**saturated, underlying aquifer, background**			
nd (N=3)				nd (N=0)			
saturated, underlying aquifer, in-cemetery				**saturated, underlying aquifer, in-cemetery**			
nd (N=9)				nd (N=7)			

GROUNDWATER AND SOILS

Level 3 analyses. The analysis only considered the effectively correlated analytes derived for sandy or clayey sites at Level 2 and chemical and physical analytes from all soil samples (8). Only Kendal's *tau* Correlation Coefficient was determined

SANDY SITES – Level 3							
vadose zone, background				**vadose zone, background**			
nd (N=1)				nd (N=0)			
vadose zone, in-cemetery N=18				**vadose zone, in-cemetery**			
nil (9)				nd (N=4)			
saturated zone, background N=12				**saturated zone, background**			
Tot Inorg N & Hydr. Cond.		-0.766	0.0005	nd (N=4)			
Tot N & Hydr. Cond.		-0.696	0.0016	-			
Na & Hydr. Cond.		.627	0.0046	-			
Na & Na		.667	0.0123	-			
saturated, in-cemetery N=24				**saturated, in-cemetery**			
nil				nd (N=4)			
saturated, underlying aquifer, background				**saturated, underlying aquifer, background**			
nd (N=1)				nd (N=0)			
saturated, underlying aquifer, in-cemetery				**saturated, underlying aquifer, in-cemetery**			
nd (N=4)				nd (N=0)			

CLAYEY SITES – Level 3							
vadose zone, background				**vadose zone, background**			
nd (N=2)				nd (N=0)			
vadose zone, in-cemetery N=32				**vadose zone, in-cemetery N=13**			
nil				Alkalinity & soil EC		.711	0.0024
-				Mg & soil EC		.644	0.0095
-				Mg & Hydr. Cond.		.673	0.0040
-				Mg & soil Mg		.746	0.0014
-				Alkalinity & soil Na		.604	0.0013
-				Cl & soil EC		.771	0.0010
-				SO4 & soil Mg		.606	0.0061
-				B & soil EC		.600	0.0158
-				Na & soil Mg		.636	0.0064
-				Na & soil Sr		.600	0.0102
-				Ca & soil EC		.600	0.0157
saturated zone, background				**saturated zone, background**			
nd (N=5)				nd (N=1)			
saturated, in-cemetery				**saturated, in-cemetery**			
nd (N=0)				nd (N=8)			
saturated, underlying aquifer, background				**saturated, underlying aquifer, background**			
nd (N=3)				nd (N=0)			
saturated, underlying aquifer, in-cemetery				**saturated, underlying aquifer, in-cemetery**			
nd (N=9)				nd (N=7)			

MINOR & TRACE METALS IN GROUNDWATER AND SOILS

Level 3 analyses. The analysis only considered the minor and trace metals determined for the groundwaters (10) and chemical and physical analytes from all soil samples (8). Only Kendal's *tau* Correlation Coefficient was determined

SANDY SITES – Level 3							
vadose zone, background				**vadose zone, background**			
nd (N-1)				nd (N=0)			
vadose zone, in-cemetery N=18				**vadose zone, in-cemetery**			
Mn & Fe		.638	0.0002	nd (N=4)			
Fe & As		.726	<0.0000	-			
saturated zone, background N=11				**saturated zone, background**			
Hg & As		-0.644	0.0095	nd (N=3)			
Cr & As		.673	0.0040	-			
Fe & Mo		.636	0.0064	-			
Zn & Cd		.636	0.0064	-			
Zn & Pb		.700	0.0016	-			
As & Hydr. Cond.		.653	0.0052	-			
Mo & Fe		.636	0.0064	-			
saturated, in-cemetery N=23				**saturated, in-cemetery**			
nil				nd (N=4)			
saturated, underlying aquifer, background				**saturated, underlying aquifer, background**			
nd (N=1)				nd (N=0)			
saturated, underlying aquifer, in-cemetery				**saturated, underlying aquifer, in-cemetery**			
nd (N=4)				nd (N=0)			
CLAYEY SITES – Level 3							
vadose zone, background				**vadose zone, background**			
nd (N=2)				nd (N=0)			

vadose zone, in-cemetery N=31				**vadose zone, in-cemetery N=13**			
Mn & Ni		.633	<0.0000	Hg & Pb		.700	0.0027
saturated zone, background				**saturated zone, background**			
nd (N=5)				nd (N=1)			
saturated, in-cemetery				**saturated, in-cemetery**			
nd (N=0)				nd (N=8)			
saturated, underlying aquifer, background				**saturated, underlying aquifer, background**			
nd (N=3)				nd (N=0)			
saturated, underlying aquifer, in-cemetery				**saturated, underlying aquifer, in-cemetery**			
nd (N=5)				nd (N=7)			

(1) pH is the field measured value for the groundwater. If pH was = 7.0 (12 of 323 instances) these were considered in each separation. The broad terms 'Acid' (pH <= 7.0) and 'Alkali' (pH >= 7.0) are used for simplification.
(2) Spearman's *Rho* Correlation Coefficient was required to be >=0.8 for near linear relationships.
(3) Kendal's *tau* Correlation Coefficient was required to be >=0.6 for a significant relationship.
(4) the major analytes previously delineated as comprising the effective composition of cemetery groundwaters were considered. Derived analytes – EC, pH, Eh, TDS were eliminated (see previous discussion).
(5) the N value is the maximum number available after case-wise deletion of matched sets of data. Sometimes the absence of some data for some analytes meant that the actual case numbers considered for any one pair may be slightly lower. N was always >=10.
(6) the Levels of analysis relate to increasing numbers of controlling parameters considered, e.g. Level 1: all samples in the vadose zone; Level 2: all samples in the vadose zone which are sandy; Level 3: samples in the sandy vadose zone which are background samples (VB). Each Level is always considered on the basis of it's pH association of the groundwater.
(7) nd – no data because number of data sets <10.
(8) soil chemical and physical analytes were: EC, pH, CEC, USCS, colour, hydraulic conductivity, exchangeable bases as – Na, K, Ca, Mg, Al, Sr
(9) nil – no significant correlations were found for the N data sets.
(10) the suite of groundwater metals considered was: Hg, Cr, Mn, Fe, Ni, Zn, Cu, As, Mo, Cd, Pb.

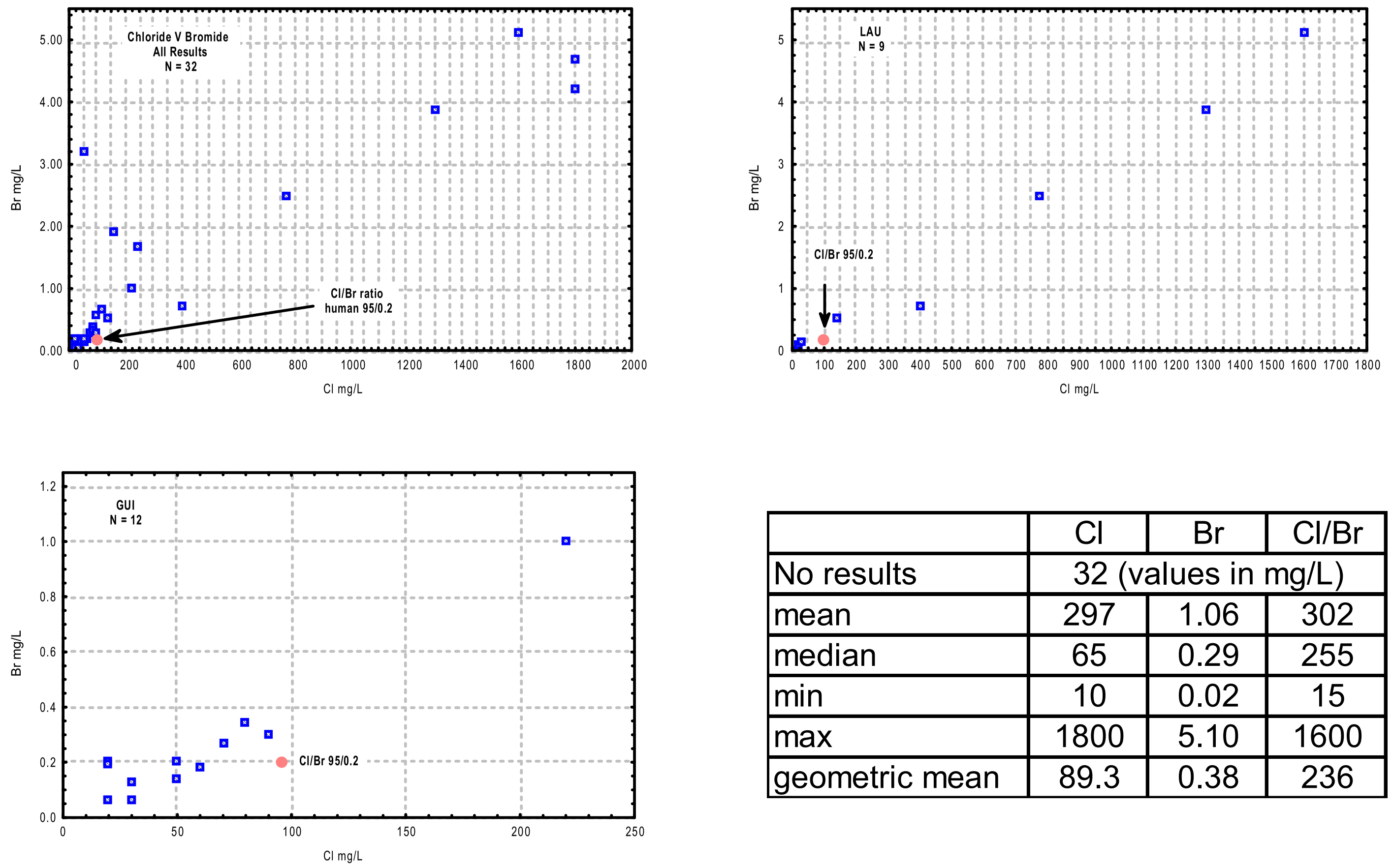
Chloride/Bromide Ratios

Bromide measurements were made at MEL, SPR, NEW, LAU and GUI during the final sampling rounds; a total of 32 samples were analysed. The biggest sets of data were from LAU and GUI where respectively 9 and 12 measurements were made. Unfortunately these data sets are a little small to venture into detailed correlation analysis so that their use at this stage is preliminary only.

The authors of two relevant studies – Davis et al. (1998) and Vengosh and Pankratov (1998) argue that these analyses may be useful adjuncts in the task of delineating water sources. The latter authors particularly focused on the technique applied to domestic sewage contamination of groundwater and their work was considered to have some relevance to the situation in cemeteries. Despite considerably wide ranges in the results, and some unanswered assumptions on the general inclusion of the various data sources that they used, Vengosh and Pankratov (1998) claim that Cl/Br ratios can be used to distinguish between anthropogenic sources such as: domestic waste water, road salts, urban runoff water, and agricultural return flows.

The data obtained here is presented in Figures 5.12 and 5.13. The spread of the results is too broad to be indicative: most of the data is consistent with USA precipitation patterns (Davis et al., 1998) yet straddles both the main categories for domestic wastewater and street runoff, whilst also reflecting potable groundwater (Vengosh and Pankratov, 1998).

In Figure 5.12 the raw data for chloride and bromide are almost perfectly correlated for both LAU and GUI. This suggests that rainwater or percolating water is either being diluted or conversely concentrated by evapotranspiration in accordance with generally understood models of the chlorine budget. If this is the case, then there is certainly no net gain of bromide from decomposition products. From Table 2.1 the representative human Cl/Br ratio is 475 which is equivalent to the domestic wastewater signature (Vengosh and Pankratov, 1998). It is also possible to speculate



	Cl	Br	Cl/Br
No results	32 (values in mg/L)		
mean	297	1.06	302
median	65	0.29	255
min	10	0.02	15
max	1800	5.10	1600
geometric mean	89.3	0.38	236

Figure 5.12 Chloride V Bromide

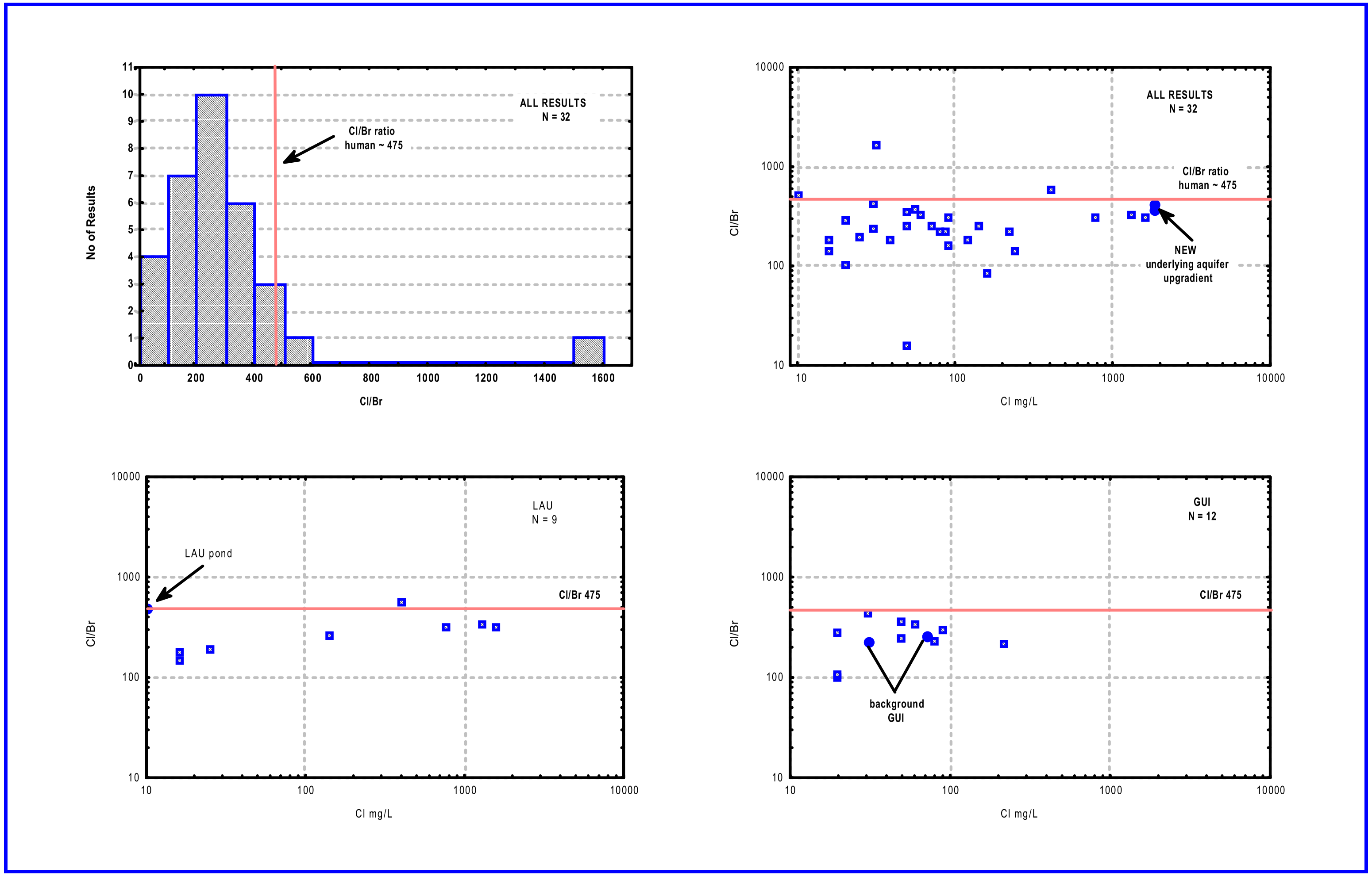


Figure 5.13 Chloride/Bromide Ratios

that in some situations, for example at LAU, the cemetery groundwaters nearly reflect this value and that therefore the ratio is working as a favourable aspect of characterisation. However, on balance for these data the overall situation is too unclear, and no satisfactory conclusion can be made about the use of the chloride/bromine ratio. Further studies may establish its usefulness.

Outcome 5 - Environmental Considerations and Heavy Metals

The analytes As, Cd, Cr, Cu, Hg, Mn Mo, Ni, Pb, Zn were measured in almost all groundwater analyses. It was considered that these elements would represent decomposition products from basic steel or galvanized steel, as well as any decorative construction metals used on coffins and present in metal funereal artefacts. Likely uses for most are hinges, fasteners, screws, handles, decorations and metal-lined coffins; whilst Hg relates specifically to dental amalgam (discussed in Chapter Six) and As possibly to older embalming practices.

Fe and Al (although the latter is not a heavy metal) are so prevalent in the soils, that they were not further considered in this context, with the exception of Fe at LAU where it has other significance. A limitation in these analyses is that the metals profiles for the sites' soils were not obtained, so that to some degree there may be some differences in the results as a matter of natural variations in the soils.

On the other hand, when background data are compared to In-cemetery data it would be expected that soils' metals would, in the normal event, be equally represented in each group. Thus any statistical differences detected can be reasonably assigned as being due to the presence of the cemetery. To reinforce this concept and eliminate spurious results the relevant data has been examined only when it met the criteria of $N = 6$ (for all populations), and that results should be significant at the 95% level (i.e. $p <= 0.05$).

The relationships have been examined using the Wilcoxon Rank Sum Test, also equivalent to and known as the Mann-Whitney U Test (Helsel and Hirsch, 1992) which it pre-dates. This is a comparable method to *Student's t Test* but for non-parametric applications. This methodology tests the null hypothesis (H_0) that the medians of two independent groups of data are in fact the same:

$$H_o: \text{ Prob } [x>y] = 0.5$$

where x is the data median from one group (usually the smaller N) and y is from another group.

Where the outcome of the analysis could be interpreted from either perspective, a two-sided test is used. There are several competing hypotheses to the null one; however, the one of most use here is that the medians are significantly different at the set rate of probability. That is:

H_1: Prob [x>y] $\neq$ 0.5

meaning that either the median x or y may be larger or smaller.

The data has been considered at several levels. Level 1 analyses (all data) were examined for the vadose and saturated zones. Where sufficient case-wise eliminated data were present, these results show very few worthwhile comparisons. The underlying, saturated aquifers had insufficient data points.

A Level 2 analysis was performed for data representing acidic and alkaline environments, and for sandy and clayey sites. Level 3 analyses were performed for restricted data sets where it was likely that sufficient data of the right type would exist. These were at BOT, HEL and GUI for essentially saturated and/or sandy sites, and WOR and LAU for clayey sites. Although the LAU data does not include background values.

For LAU the data were treated in three groups reflecting the cemetery function. Firstly an upper grouping (U) – in the recently active lawn burial areas of a gully; and secondly a side grouping (S) – representing a very old part of the cemetery to the north-west where groundwater flows as springs and perched ephemeral watertables are trapped by seepage trenches. A third lower grouping (L) – representing scant data downgradient of the gully and between the pond and the boundary (see Appendix G) was considered but couldn't be used (N = 4). The upper gully area was further considered by examining the most upgradient well (L2) versus the most downgradient well here (L4). Because of the common iron deposition from Launceston groundwaters, the Fe content was also considered here.

Table 5.9 lists only the results of the analyses which comply with the acceptance criteria, with the exception of one result which almost meets the criteria.

Table 5.9 Wilcoxon Rank Sum Analyses for Environmental Metals

Analyte	N for grouping considered	N for second grouping	p <= 0.05
Level 1 all data Saturated Background (SB) versus Saturated In-cemetery (S)			
As	SB: 40	S: 100	.0170
Cr	40	100	.0022
Mn	41	100	.0094
Ni	41	100	.0000
Pb	41	100	.0063
Level 2 all sandy sites Saturated Background (SB) versus Saturated In-cemetery (S)			
Cr	SB: 25	S: 86	.0327
Mn	26	86	.0520 $
Ni	25	86	.0001
Level 2 all clayey sites Saturated Background (SB) versus Saturated In-cemetery (S)			
Mn	SB: 15	S: 14	.0008
Mo	15	14	.0328
Ni	15	14	.0157

continued

Level 2 all acidic sites (pH<7.0*) Saturated Background (SB) versus Saturated In-cemetery (S)			
As	SB: 26	S: 75	.0146
Cr	26	75	.0003
Ni	27	75	.0061
Pb	27	75	.0002
Level 2 all acidic sandy sites (pH<7.0*) Saturated Background (SB) versus Saturated In-cemetery (S)			
Cr	SB: 21	S: 74	.0348
Ni	22	74	.0031
Pb	22	74	.0071
Level 2 all alkali sites (pH>7.0*) Saturated Background (SB) versus Saturated In-cemetery (S)			
Mn	SB: 14	S: 24	.0003
Mo	12	24	.0199
Ni	13	24	.0091
Level 2 all alkali clayey sites (pH>7.0*) Saturated Background (SB) versus Saturated In-cemetery (S)			
Mn	SB: 10	S: 13	.0065
Level 3 BOT Saturated Background (BSB) versus Saturated In-cemetery (BS)			
Cr	BSB: 10	BS: 39	.0000
Pb	10	39	.0094
Level 3 HEL Saturated Background (HSB) versus Saturated In-cemetery (HS)			
Mn	HSB: 10	HS: 22	.0006
Mo	10	22	.0385

continued

Level 3 GUI Saturated Background (GSB) versus Saturated In-cemetery (GS)			
Cd	GSB: 9	GS: 29	.0027
Mn	9	29	.0012
Ni	8	29	.0151
Zn	9	29	.0003
Level 3 WOR Vadose Background (WVB) versus Vadose In-cemetery (WV)			
Cr	WVB: 5 #	WV: 42	.0012
Mn	5 #	42	.0251
Ni	5 #	42	.0251
Level 3 LAU Vadose Up-gradient Gully Well (LVL2) versus Vadose In-cemetery Down-gradient Gully Well (LVL4)			
As	LVL2: 7	LVL4: 6	.0023
Mn	7	6	.0350
Ni	7	6	.0012
Level 3 LAU Vadose Upper Gully (LVU) versus Vadose In-cemetery Side (LVS)			
As	LVU: 19	LVS: 15	.0080
Fe**	20	15	.0427
Mn	19	15	.0027
Mo	19	15	.0050
Ni	19	15	.0004

* Where pH = 7.0 these few data are considered in both acidic and alkaline sites' sets.
** Fe was only considered for data at LAU
$ p = 0.0520 is just outside the analytical criteria set, thus this result is illustrative only
# only 5 Background measurements were available for WOR, so that this analysis does not meet the analytical criteria set; it should be regarded as illustrative only.

Discussion of Heavy Metals – Outcome 5

The raw data – as acceptable p values (Table 5.9) – do not of themselves report the whole story on heavy metal presence in the cemeteries. The suitable data was further examined graphically by box and whisker plots (Figures 5.14 – 5.16) in order to gauge the relative significance of the level of differences detected between the groundwaters' sample populations.

It was anticipated that the In-cemetery data would indicate an elevated presence of the metals considered in most situations, with perhaps some small variations on account of the environmental pH. But this is not the situation; there are some important instances where the metals in the background samples are considerably elevated (by measurement of median) compared to those In-cemetery, and particularly for Cr, Mn and Ni. These are listed below:

- ❖ all data (Level 1) for As, but then not elsewise;
- ❖ all data (Level 1) for Cr, and then BOT and WOR;
- ❖ all data (Level 1) for Mn, and then in clayey and/or alkali conditions, and then at HEL, LAU (some) and GUI;
- ❖ all analyses (any Level) for Ni, but similar at LAU.

In all Levels and degrees of analyses, Ni is in significantly reduced concentrations within the cemeteries, as opposed to relevant background values. Ni is known to form more than 3000 useful alloys (Reimann and Caritat, 1998) and it was anticipated that the results would have reflected the presence of buried metals of coffins and artefacts. The human body also hosts of the order of 0.01 g (see Chapter Two) of Ni and this may also be a source. This metal is mobilized in acidic and or oxidising conditions, but is very lowly mobile otherwise (Reimann and Caritat, 1998). It is therefore surprising that: (1) the results don't indicate excessive accumulation within cemeteries; (2) the results show a similar pattern in all general environmental conditions; and (3) that there is no significant statistical pattern noted for BOT, which generally comprises an acidic, porous, and oxidising environment. The general environmental cases (sandy, clayey, acid, alkali) are depicted in Figure 5.14.

Comprehensive graphical and correlation analyses were performed on the groundwater and soil chemistry data at BOT to further explore this matter. However, there are no significant correlations or relationships for the key cemetery waters' indicators or for the heavy metals. The mineralogy of the soils is such that adsorption is unlikely. The low-key behaviour of Ni at this site remains a mystery; it may be related to a high flushing rate by percolating groundwater, or bear some relationship to past nearby industrial landuse, or maybe to attraction of this metal by bone.

The attraction of metals by bone has commonly been reported in archaeological studies (see earlier discussions). However, for Ni, this aspect does not appear to have been thoroughly examined elsewhere; in one relevant study, Bethell and Smith (1989) reported that Ni wasn't enhanced in a gravesite.

Figures 5.15 and 5.16 respectively depict the situation for Cr and Mn. These examples illustrate that the few effects determined to be statistically important, range widely over environmental conditions of soil type and pH. The effects seem to be unique for different metals and different settings; and are presently unexplained.

The metals Mo and Pb show the opposite pattern – as anticipated (Figure 5.17); that is, the levels for In-cemetery measurements are greater than backgrounds. Whilst this is true for the general situations, which also respectively represent acidic and alkali environmental conditions, some cautious interpretation is needed. In the cases of the specific illustrations - of Pb at BOT and Mo at HEL (Figure 5.17) - it must be borne in mind that these sites are immediately adjacent to former heavy industrial areas. It is impossible to say from these data whether there has been some unknown effect in terms of spillage or contaminated groundwater seepage into these cemeteries.

At BOT, immediately up-hydraulic gradient, a former oil refinery using lead additives in petrol existed for many years; whilst HEL is surrounded by former metal foundries and a former car assembly plant was located up-hydraulic gradient.

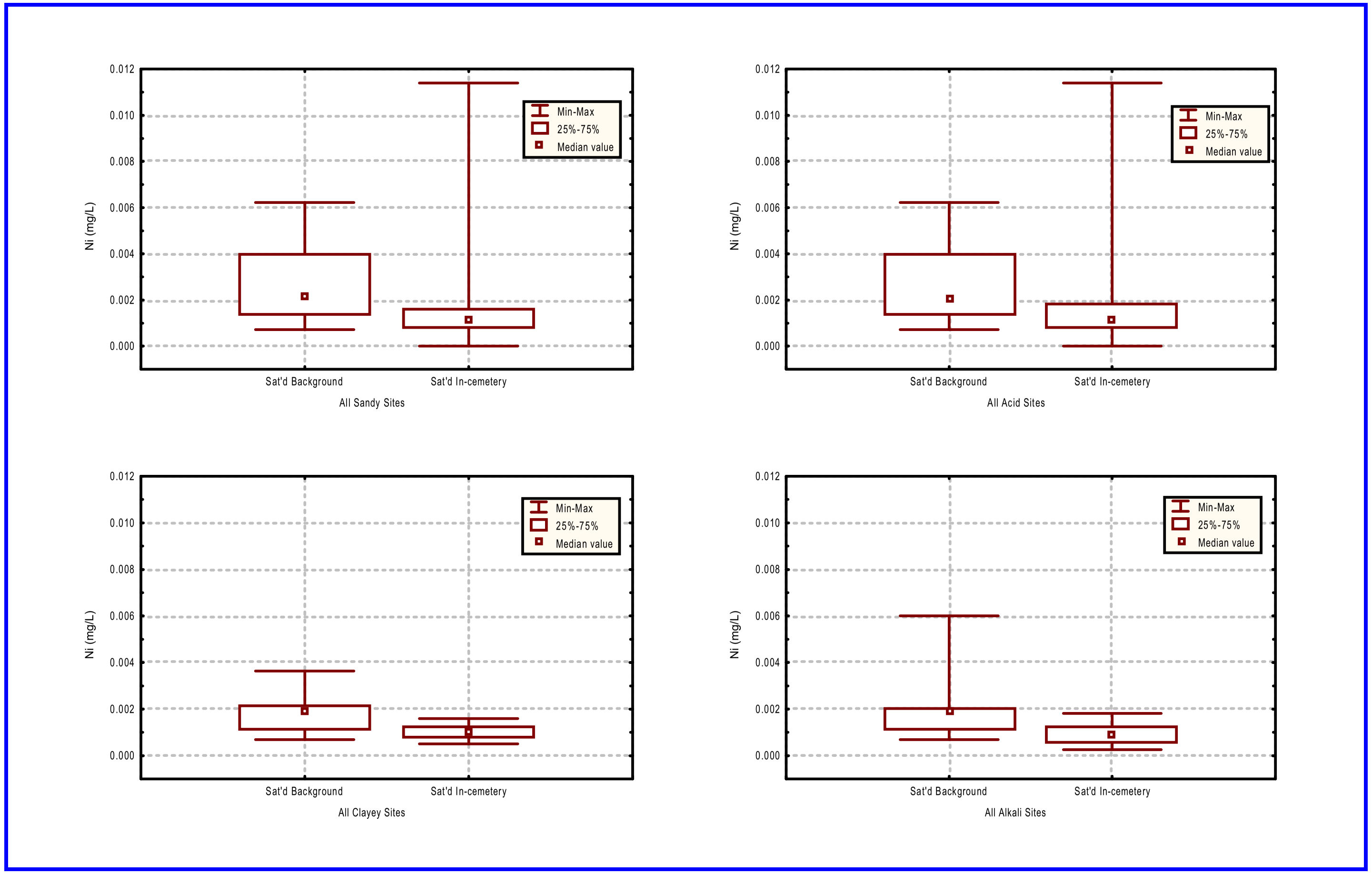


Figure 5.14 Level 2 Analyses of Site Environments – Indications of Excess Ni in Background Values

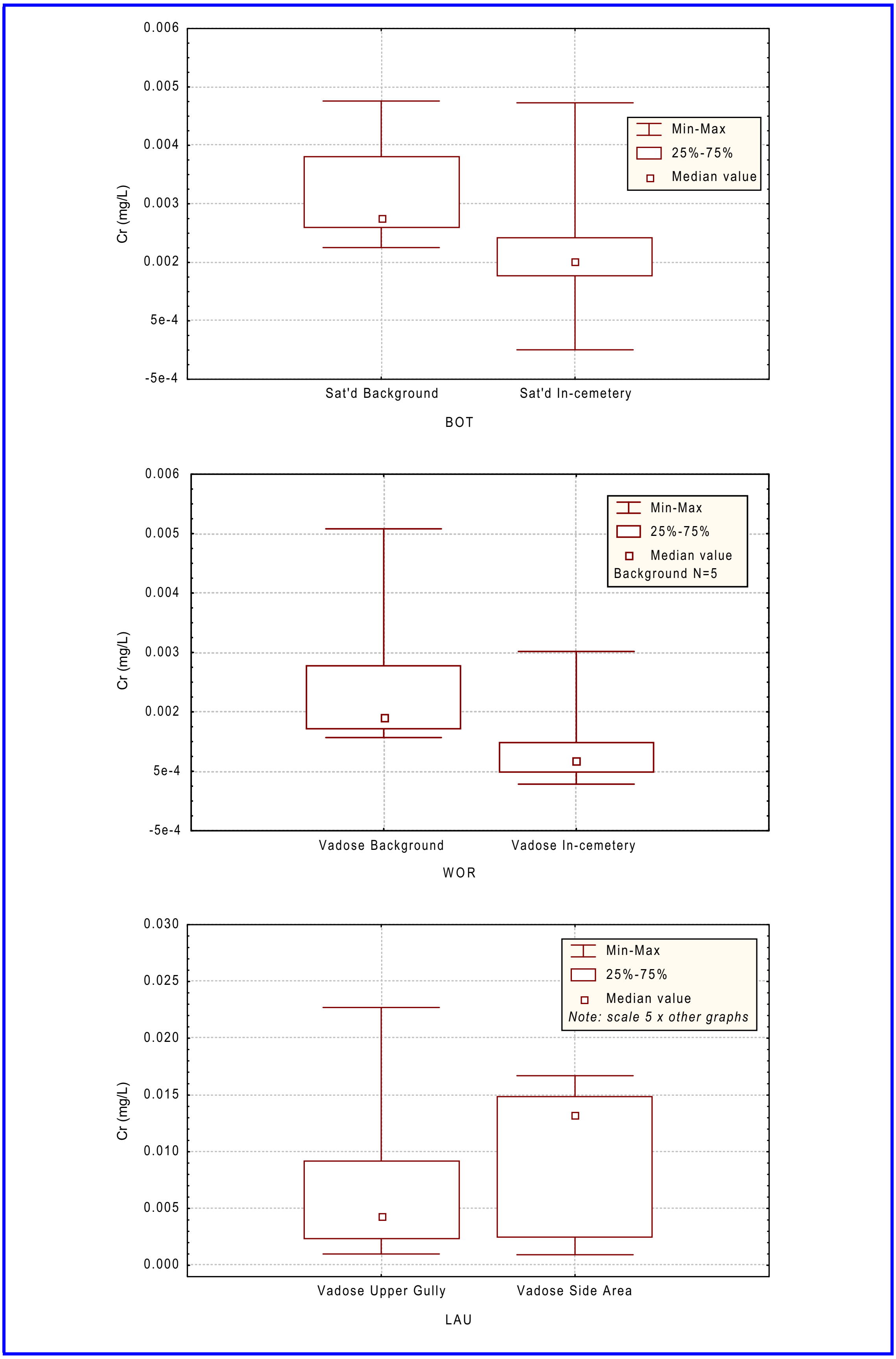


Figure 5.15 Cr Distribution In Groundwaters At Selected Sites

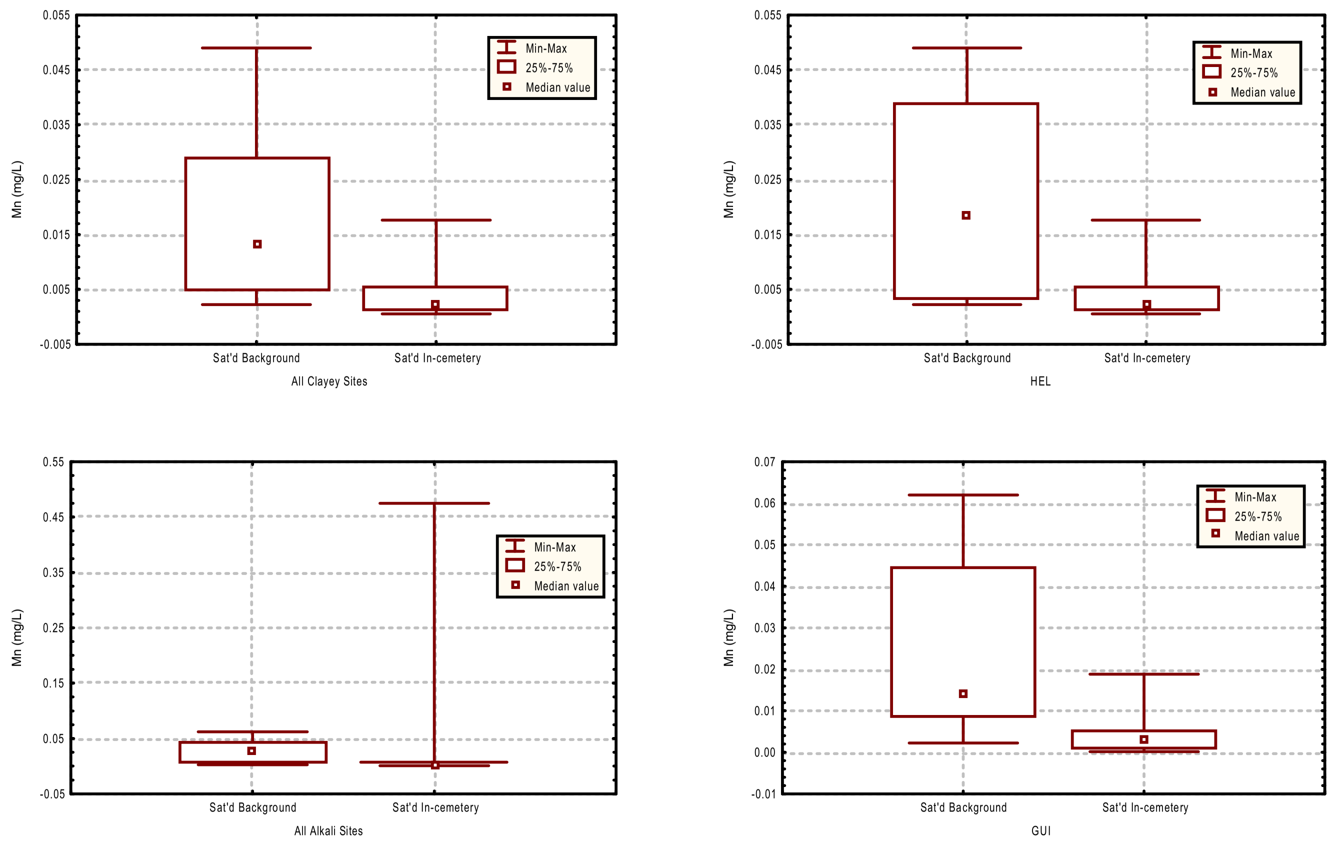


Figure 5.16 Mn Distribution in Groundwaters for Selected Environmental Conditions and Sites

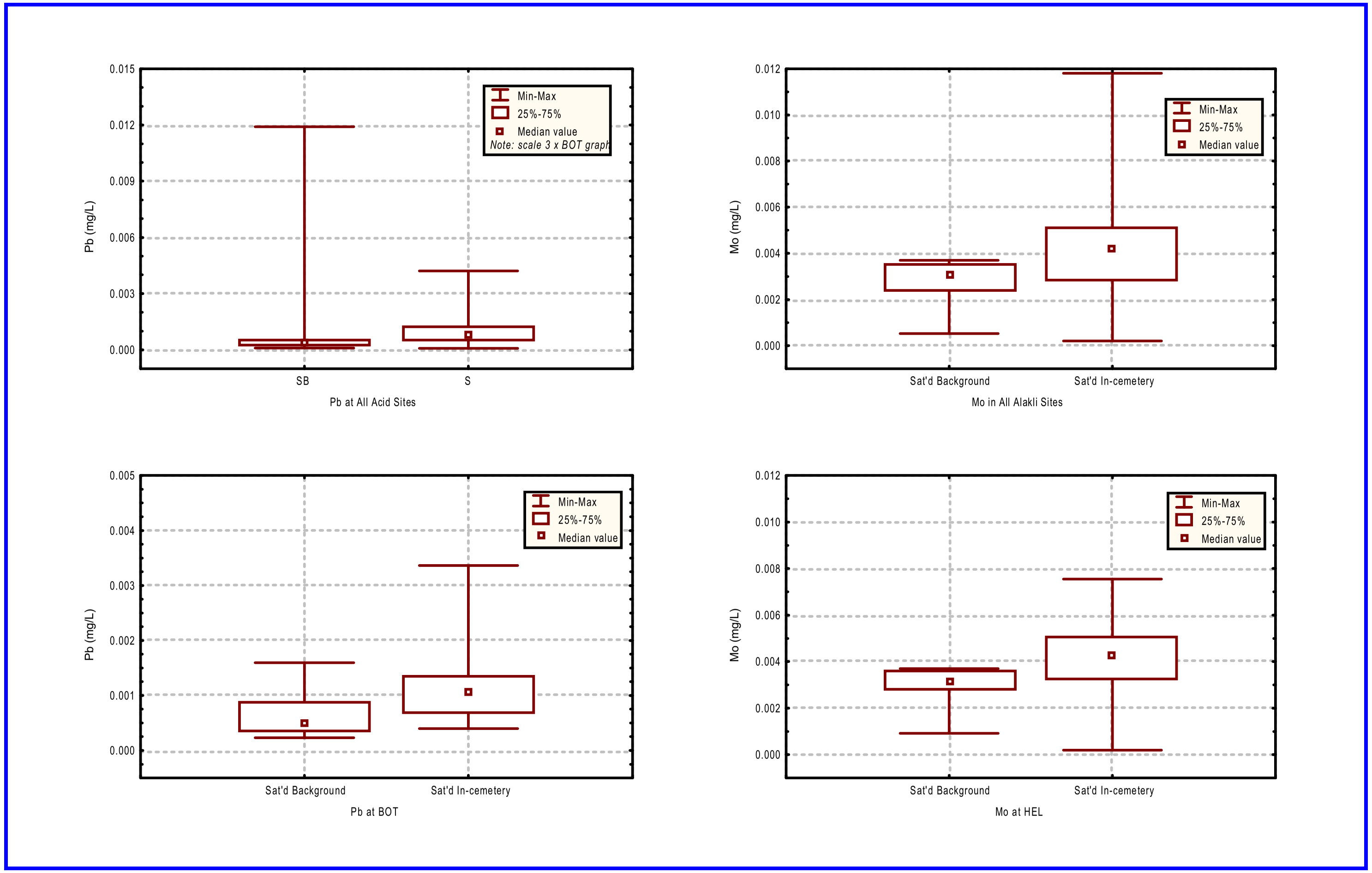


Figure 5.17 Indicative In-cemetery Accumulation of Pb and Mo – Various Environmental Conditions

These sites and these particular results ably illustrate the caution that must be exercised in considering all cemetery sites in the context of surrounding landuse. See also the discussion in Chapter Six concerning Hg.

Overall, the case for significant heavy metal 'pollution' or accumulation in the cemeteries studied has not been made out for all metals or all places. Consistent with the general hydrogeochemical behaviour of metals, there are accumulations and deficiencies varying with environmental conditions of soil type and pH. The data examined included 317 instances of Hg, and 324 instances of each of As, Cr, Cu, Mo, and 325 instances of each of Cu, Mn, Ni, Pb, Zn. A statistically significant deficiency of Ni, Cr and some Mn within the saturated zones of cemeteries has been found, and this is contrary to the idea of accumulation from interred metals or remains. The reasons are unclear but may be related to the attraction of these metals by bone.

Outcome 6 – Seasonal or Other Time Trends

The groundwater data of all sites has been examined for trends in the key indicators of decomposition products. When the Study commenced it was anticipated that this kind of analysis would be performed with a view to eliciting seasonal variations – if any exist – in groundwater chemistry. However, this has not been possible because the Study did not proceed over sufficient seasons: several years' worth of data would be required (Helsel and Hirsch, 1992). Furthermore, the sampling at various sampling points has not always been consistently done, nor has it always been possible, for example, because of dry wells.

What is possible for the data, however, is an analysis of trends – in concentration – within the sampled subsets. Graphical – using 2-dimensional scatterplots, non-parametric analysis of trend (Mann-Kendall), and trend estimator (Sen) – as a secondary analysis, have all been possible. The Mann-Kendall test can be used for small sample populations and is also forgiving of missing values/non-detects (Helsel and Hirsch, 1992). However, consistent with earlier analyses that relied on a minimum sample population N = 6 (of fully acceptable results), in order to increase the validity of the analysis; this rule has been maintained here.

Consequently, the only sample points that could be examined were: B8, B9, W1, W6, W7, M2, NT1, L2, L3, L4, H3, G1, G5, G6.

Initially the sample data for each of the key decomposition indicator analytes for each of these sampling points was considered graphically by scatterplots (Figure 5.18). Likely trends were identified in all but two of the samples (Table 5.10). Each data set was then considered in a two-sided Mann-Kendall analysis with a 95% confidence level (ChemStat, 2001). The results are recorded in Table 5.10; sometimes trends not noted graphically were determined. If this analysis failed to substantiate the proposed trend, the data underwent a final analysis by the Sen Slope Estimator method (ChemStat, 2001) (Table 5.10).

The Mann-Kendall analyses are considered to be the most valuable because they produce a powerful, mathematical result. This analysis tests the hypothesis:

$$H_o: \text{Prob } [Yj>Yi] \neq 0.5 \quad \text{(2-sided test).}$$

Where the test statistic (Kendall's S) is significantly different from 0, the null hypothesis is rejected, and it is concluded that the Y value changes with time.

The Sen method is also a non-parametric method and is considered to be robust against extreme outliers and a high percentage of non-detects (Hirsch, et al., 1982, ChemStat, 2001). Therefore it is also of importance. Helsel and Hirsch (1992) point out that tests need to have a high power over all situations and types of data that might occur – that is a robustness, in order to be useful. For the present data, it is accepted that either of the above tests would be a satisfactory indicator of a trend.

In consideration of the results in Table 5.10 it should be noted that the result for a 'graphical' trend is not always matched by one of the non-parametric estimators, so that in these cases the trend is NOT accepted as confirmed. On the other hand, the alternate methods occasionally delineate a trend which was not noted graphically. In these cases the trend is accepted.

Table 5.10 Results of Trend Analyses by Mann-Kendall Method or Sen Slope Estimator (N >= 6)*

Well	Analyte	Graphical#	Mann-Kendall Trend at 95% confidence		Sen Trend
			p	direction	
B8	Tot P	downward			
B9	Cl	downward			
W1	Cl	downward			
	SO4	downward			
W6	PO4	downward			
W7	alkalinity		0.0166	downward	
	Ca	downward	0.0166	downward	
	Mg	downward			downward
	Sr	downward	0.0166	downward	
M2	Ca	downward			downward
	Sr	downward	0.0108	downward	
	Cl	downward			downward
	SO4	downward			downward
NT1	SO4	upward			
L2	Ca	upward			
	Tot P	downward	0.0028	downward	
	PO4		0.0028	downward	
L3	nil				
L4	Na	upward	0.0028	upward	
	Ca	downward			downward
H3	Na	upward			
	Ca	upward			
	Mg	upward	0.0166	upward	
	Sr	upward			
	Cl	downward			downward
	Tot P	downward			
G1	Ca	downward			downward
	Sr	downward			downward
G5	nil				
G6	SO4	downward			

* only those data (analytes) which show an obvious trend are recorded – otherwise space is blank
# graphical trends are ‘by eye’ estimates from scatterplots. The most reliable analyses are where graphical and either Mann-Kendall or Sen trends match.

In the absence of a seasonal evaluation, the importance of this testing lies in:- firstly, an evaluation of the consistency and conformity of data between wells – either indicating a dilution or enhancement of an analyte’s concentration; or secondly, the repetition of various analytes delineated by such analyses.

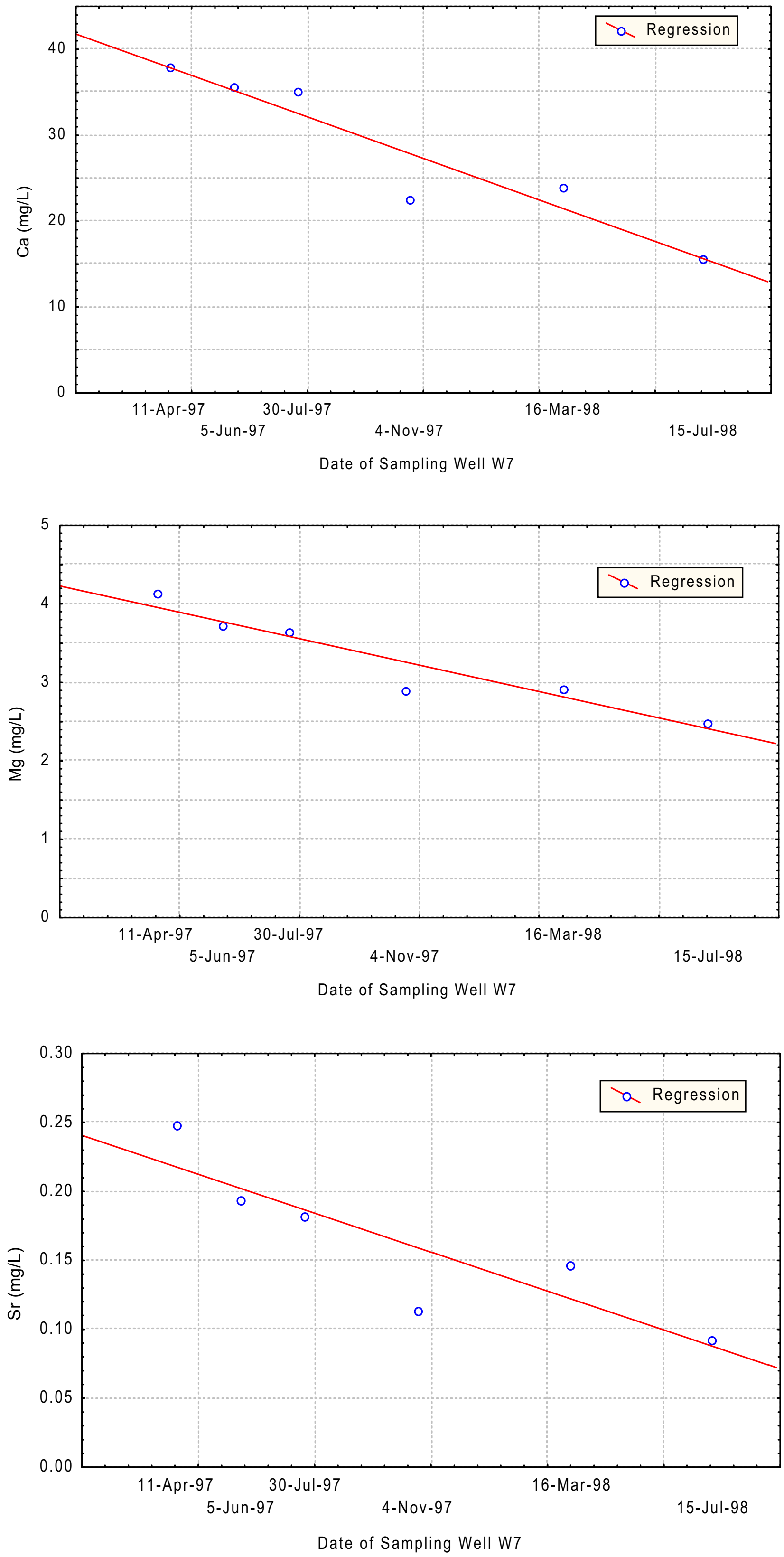


Figure 5.18 Graphical Trends for Ca, Mg and Sr in Well W7

In the first instance the trends can be further matched against rainfall – representing short-term recharge and/or flushing and/or drought accumulation. In the second set of considerations, the analysis may indicate a uniformity of in-cemetery processes or possibly soil-decomposition products' interactions.

Discussion of the Trend Analyses – Outcome 6

The results are too scattered between sites and sampling points to be of much value. Some superficial conclusions can be made:

- the cations Ca, Mg and Sr frequently seem to be analytes that show trends,
- clayey sites more frequently exhibit trending analyte data than sandy sites,
- most trends were seen in In-cemetery data sets,
- most trends are downward.

Because of the presence of some trends, the worth of the analytes – Ca, Mg and Sr, is slightly enhanced; however, the analytes Cl, SO4, and forms of P also featured as trending; so did Na and alkalinity. The significance of the fact that most trends were downward is not clear enough from the data. Trend Analysis in itself does not elicit causes (Helsel and Hirsch, 1992) and the results for any one analyte should therefore not be considered in isolation to others.

Only one site – LAU, had two wells (L2 and L4) in the list of data sets (Table 5.10) where both a graphical and analytical trend was found: these related to different analyte trends. Overall, it was thus considered not worthwhile to further examine the trends results.

Outcome 7 – Non-coffinated burials compared with coffinated

When the Study commenced an effort was made to deliberately position sampling points so that the influence of non-coffinated burials – typical of strict Muslim practice, and accessible at NEW and GUI, could be investigated. Unfortunately the anticipated interments at NEW did not eventuate so that the small section of Muslim burials at GUI alone can be studied. It was hoped that these might be directly contrasted with Muslim interments requiring a coffin at SPR, but eventually it became too difficult to position sampling points appropriately for this.

At GUI the Muslim community, by arrangement with the cemetery management, attends to the interments on a needs basis. Typically one or two graves are left permanently prepared for interment. The Muslim community emplaces the remains, wrapped in a fabric sheath, at about 1.4 m depth in a strict alignment, and backfills the grave with site soils whilst creating a small air-space around the remains.

The positioning of the relevant part of the Guildford Cemetery (on a corner adjacent to the bisecting main road) made it difficult to exactly locate a large number of wells for this consideration and yet have them generally useful for the Study (see Appendix J). However, well G6 is immediately upgradient of the relevant interments and well G5, at the downgradient cemetery boundary, are most likely to intercept groundwater flowing beneath this interment area. These wells can be roughly aligned along the flowline from the background wells – G1 and G2, which are further upgradient. It is expected that the watertable of such a 'section' would be topographically conformable, constant and without any major disruptions that hinder the suitability of the data for interpretation.

Unfortunately well G6 was only sampled 5 times (on two occasions no sample could be obtained) and the reduced amount of data for analysis must be borne in mind. Wells G1, G2 and G5 have respectively provided 6, 3 and 6 satisfactory samples. For this analysis the data of G1 and G2 are combined (G2 is a deeper, clustered well at the same position as G1). As a final part of the considerations the furthest downgradient wells G3 and G4 were included – these are most likely to present the maximum presence of decomposition products in the groundwaters at GUI. G3 and G4 were clustered at different depths and served to enable sampling of fluctuating watertables; taken together they yielded 6 satisfactory results.

The data for all the relevant wells and for an alternate pathway (via well G8, also a downgradient boundary well) and for the maximum overall flowline possible at the site, were examined by the Kruksal-Wallis ANOVA Test and the Wilcoxon Rank Sum Test. Both methods are in effect similar to the Student *t* Test, except they consider non-parametric rankings about medians. The former is used where more than two groups are being considered – that is, for the flowlines via the well immediately upgradient and adjacent to the Muslim Section. The latter is applicable where only two groups are considered. Essentially each method tests the same null hypothesis – H_0: that the samples are drawn from the same distribution or distributions with the same median. At the 95% level of significance, if $p <= 0.05$ then the result says the data sources are NOT the same or of the same type (that is H_0 is rejected); whilst if $p > 0.05$ then it is concluded that the sample populations are essentially the same. The results are presented in Table 5.11. There is concern about the use of the ANOVA method, and this is discussed at the end of the next section.

Discussion of Results – Outcome 7

Five scenarios were evaluated:

Group 1 - two 'flowline systems'

G1/2 – G6 – G5 (Likely Flowline: across the Muslim Section)

G1/2 – G6 – G8 (Alternate Flowline: possible representative alternate to boundary sampling point);

Group 2 - three pairs of sampling points

G6 – G5

G1/2 – G3/4

G6 – G8 (not very likely – for comparison only).

The findings are reasonably conclusive but are doubtlessly hampered by the number of samples at G6 and an exact ability to specify flowlines in the areas of interest, due to the positioning of wells. The two statistical methods used were insufficient on their own to resolve all differences. Consequently a comprehensive graphical (box and whisker plot) analysis was conducted for each analyte and each scenario. The purpose was to detect any relative increase of analyte values in the areas of interest.

In respect of the major decomposition indicators (Table 5.11), there was a high degree of consistency amongst the results for all forms of inorganic N; as expected these values are significantly different from well to well and increase downgradient.

Table 5.11 Analytical Outcomes For Consideration of Non-coffinated Interments at GUI

(Significantly Different Analyte Populations)

Likely Flowline* G1/2 - G6 - G5 Kruksal-Wallis ANOVA#		Alternate Flowline G1/2 – G6 – G8 Kruksal-Wallis ANOVA		Muslim Section Only G6 – G5 Wilcoxon Rank Sum Test$		b/g – lowermost Only^ G1/2 – G3/4 Wilcoxon Rank Sum Test	
analyte	p	analyte	p	analyte	p	analyte	p
Tot N	.0175	NO3-N	.0425	NO3-N	.0303	NO3-N	.0004
Na	.0484	Tot Inorg N	.0235	Tot NOx	.0303	Tot Inorg N	.0004
Cl	.0198	Tot NOx	.0332	Tot N	.0303	Tot NOx	.0004
		Tot N	.0227	Na	.0087	Tot N	.0004
		Na	.0484	Cl	.0043	Na	.0048
		Mg	.0030			Mg	.0076
		Cl	.0377			Cl	.0350
Mn	.0025			Mn	.0087	Mn	.0496
Ni	.0117			Ni	.0303		
Zn (Cd close~)	.0011	(Zn close)		Zn	.0043	Zn	.0120

* The considerations are influenced by the fact that only 5 satisfactory samples were analysed for well G6.

The Kruksal-Wallis ANOVA Test is a non-parametric test based on ranks and in effect is equivalent to the Wilcoxon Rank Sum Test (cf Student *t* test) for more than two comparisons. This test assesses the hypothesis H_0 that the different samples for each analyte considered were drawn from the same distribution or from distributions with the same median (Helsel and Hirsch, 1992, StatSoft, 2001). At the 95% level of significance, if p >0.05, there is no significantly quantifiable effect from the non-coffinated interments.

$ The Wilcoxon Rank Sum Test is the non-parametric two-group comparison for populations or medians (the *exact* form is used). In this test, H_0 says that the populations are the same for the two groups considered. If p >0.05 then it can be concluded that the analytes are NOT from significantly different populations: in this case that there is no quantifiable effect from the non-coffinated interments.

^ This analysis looks at the background values (b/g) (highest, upgradient wells) compared to the (lowestmost, downgradient wells); this is the maximum flowline possible for this site.

~ “close” analytes have p value just >0.05; Cd = .0532; Zn = .0508.

The results for other analytes, to various degrees, indicate no departure from those expected for the non-coffinated interments. Generally there are statistically significant populations upgradient compared to downgradient. There is a general increase in the concentrations of these analytes as flowpaths transect increasing numbers of interments.

Along the whole of the Likely Flowline, however, the differences are least "clear-cut". This might mean that the Likely Flowline is improperly defined or that there is an evenness in the concentrations of analytes. The graphical analysis for this data, however, did confirm an appropriate downgradient increase in the inorganic N forms and PO4. The less conclusive data is restricted to the older, more upgradient (above well G6) part of the cemetery.

The suite of heavy metals and environmentally important elements as - As, B, Cd, Cr Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Zn, were also considered. The results were not totally conclusive but do suggest that there might be a particular effect from the absence of a coffin in terms of the absence of the base metals Mn, Ni, Zn.

Statistically, Mn, Ni, and Zn analytes showed a consistent variation in their concentrations (Table 5.11). Their sample populations were different in the Muslim Section compared to other parts of the cemetery where metals from coffins and funereal artefacts would be expected to be present. The graphical analysis (Figure 5.19) shows the result clearly for the Likely Flowline.

The graphical analysis for the other analytes indicated that the background values are higher (3 of 13 samples) or approximately equal (9 of 13 samples) to those recorded at the lowermost wells (G3/4). As such, these results indicate an insignificant, if any, influence of heavy metals or B in the groundwater compositions at this site (also see earlier discussions).

For the Likely Flowline (G1/2 – G6 – G5), G6 samples (above the Muslim Section) have higher values in As, B, Cr, Fe, and Se; whereas G5 samples (below the Muslim Section) show *nil* increases. When the two wells G6 and G5 are considered on their own, G5 samples show marginally increased amounts of Cu and Pb.

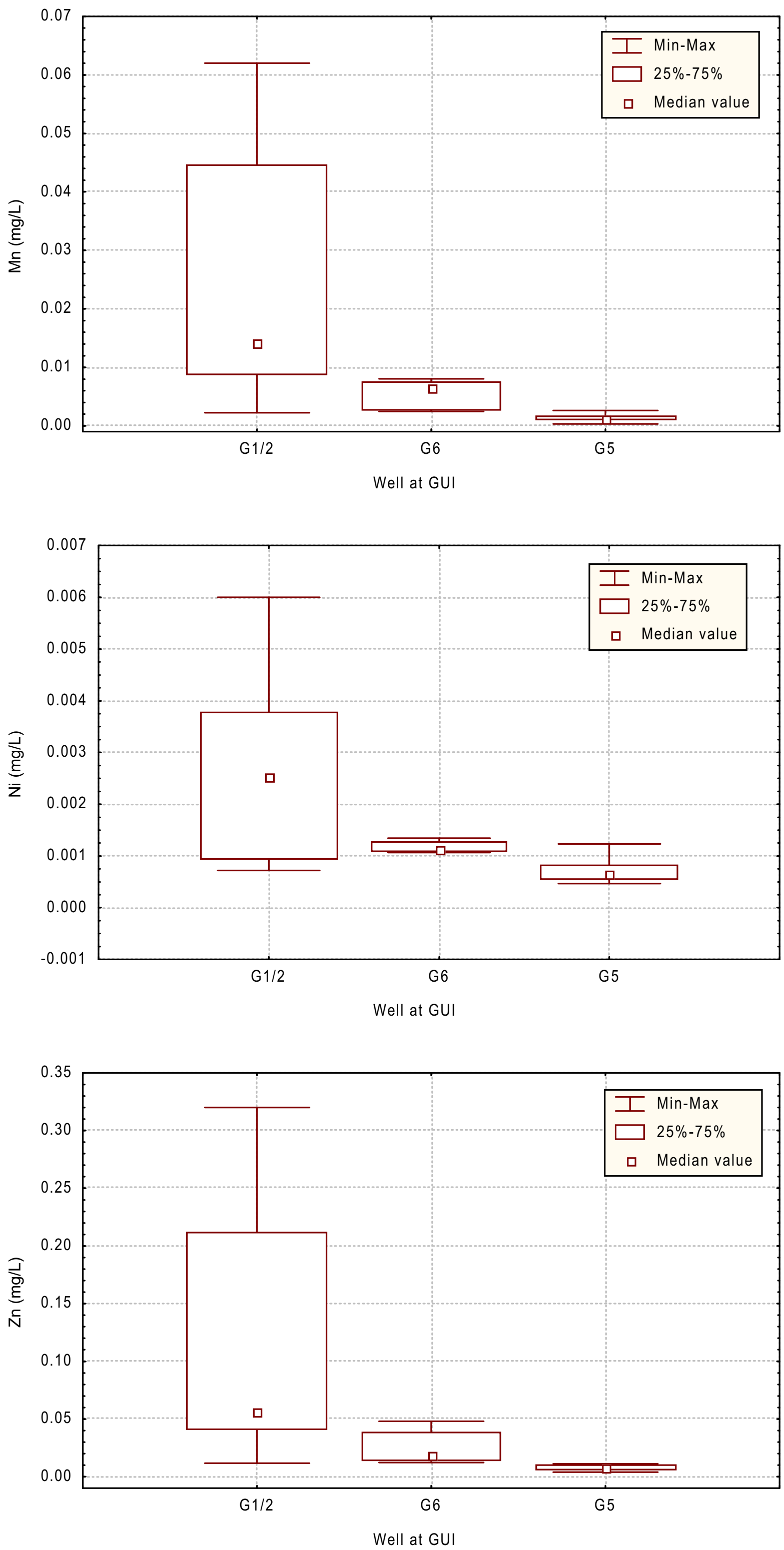


Figure 5.19 Sample Values for Mn, Ni and Zn at GUI Relative to Likely Flowline (G1/2 – G6 –G5) for Non-coffinated Interments

For the Alternate Flowline (G1/2 – G6 – G8) (which is a possibility for comparative purposes only), G6 samples show relative increases in As, B, Cr and Se - as above, except for Fe. G8 samples show increased amounts Pb and Zn.

These more compartmentalised considerations of the results neither support nor encumber the proposition that non-coffinated interments reduce the groundwater metals' and other environmentally significant analytes' loads.

Finally, the microbiological analytes together with BOD and TOC were considered by the same processes as above. There were no statistically significantly results detected by any means of analysis. There is no enhanced effect on these analytes due to non-coffinated interment.

A study with a larger sample population and for a range of site environments would be expected to show that the absence of a coffin and funereal artefacts have a reduced effect on the groundwaters' compositions. However, this proposition cannot be substantiated from the present Study. This is despite the circumstances that GUI soils are acidic, sandy (fine to silty sands), with a moderately mature mineralogy, low to moderate CEC, and host a phreatic watertable with acidic, aerobic groundwater; that is, reasonably good quality conditions for the detection of variations.

Gibbons (1994) has severely criticized the ANOVA technique for assessing the results from monitoring wells. He claims that when the method is "applied to groundwater detection monitoring it maximizes both the false positive and false negative rates" (Gibbons, 1994) of reporting due to the spatial variability of extreme values. The preferred methodology is to consider intrawell variations. However, this requires a population minimum N >= 8; this condition cannot be met in this Study so that the ANOVA method represents the more usual, and other available, technique.

The large spatial variations possible in groundwater chemistry, and the preponderance of downgradient wells compared to the number of upgradient wells, all add to the difficulties in the statistical treatment of the data. Even in the absence of difficulties introduced by former site usages (there are none at GUI) the method is not as powerful as intrawell comparisons (Gibbons, 1994). The reduced success of the analyses to make proper discriminations, in the present situation, may reflect some of the method's internal difficulties.

Outcome 8 – Attenuation of Products Downgradient

At three sites – BOT, WOR and LAU, some wells were established in anticipation of the possibility that the attenuation of decomposition products along flowlines could be evaluated. At BOT the flows are related to permanent, phreatic watertables in fine to medium, quartzose sands. Sites WOR and LAU are both clayey and here ephemeral vadose zone flows are captured in seepage wells. At LAU these flows are within soils, but at WOR they are primarily dependent on perched water in zones of higher conductivity in the soil C horizon, and bedding planes of the weathered shale bedrock. The pathways at WOR possibly have some disconnection to the nearest interment areas but this was extremely difficult to assess. See Appendices B, C and G for the layout of sampling points.

For these considerations the background values of groundwater analytes at the sites are not required. The starting point is In-cemetery and at the well closest to an identifiable area of recent interments. The analytes evaluated were those previously determined as representing decomposition products in the hydrogeological zone of interest.

At BOT the lowermost section of the flowlines (wells B7, B8, B9) is fairly certain since it is constricted by the underlying sandstone ridge (Dent, 1995); however, the uppermost section is variable and is influenced by the relative position of the well (B2, B3, B4 or B6) to the nearby area of recent interments, in addition to small fluctuations in the watertable. Because of the limited number of acceptable samples from wells B2 (N = 1) and B6 (N = 3) it was only possible to analyse the Major Flowline B3 – B7 – B8 – B9, where for each well N = 6. In order to further check this phenomenon, a departure from previous analytical standards was accepted and the flowline B4 - B7 - B8 - B9 was also considered; for well B4, N = 5. At BOT the farthest downgradient sampling point (B9) represents a boundary.

At WOR the most downgradient well - W3, is within the buffer zone. Unfortunately, only N = 4 acceptable samples were available for this well, whereas for wells W2 and W3, N = 6. However, as for BOT, in order to further check for potential attenuation, a departure from previous analytical standards was also accepted and the Flowline W1 – W2 – W3 was considered.

At LAU, only that part of the lawn interment area on the central gully (wells L2, L3 and L4) could be evaluated. The lowermost well here is immediately adjacent to the interments, with little travel distance involved. Further along this gully (L15 and L16) represent the clustered, most downgradient wells at the boundary, however, the total number of samples taken from here was too small to be evaluated. The area considered at LAU is also regularly irrigated.

The statistical approach used was to firstly evaluate whether the analyte sample populations from the wells along each flowline were different. This was done using a Kruskal-Wallis ANOVA Test (see immediate preceding discussions for difficulties with this kind of analysis). Then a Mann-Kendall Trend Analysis, Sen Estimator of Slope, and graphical analyses were performed on the same data. The trend and graphical analyses used median data compiled from the values for each sample at each well, and were discretised into Factor groupings in accordance with previous results.

Discussion and Results – Outcome 8

All attempts to identify attenuating behaviour for key decomposition products have been unsuccessful. The results for the medians of sample sets taken at BOT and WOR are presented as Figures 5.20 and 5.21 respectively. The graphical analysis was the most helpful in these considerations since the ANOVA and statistical trend analyses almost invariably produced non-significant outcomes.

The pictures depicted for Factors 1 and 2 at BOT seem to suggest an overall reduction in analyte concentration with distance downgradient, but it certainly isn't consistent for all Factors or analytes. If other Flowlines are examined the position is different. In the cases of WOR and LAU the analyte values increase or are erratic.

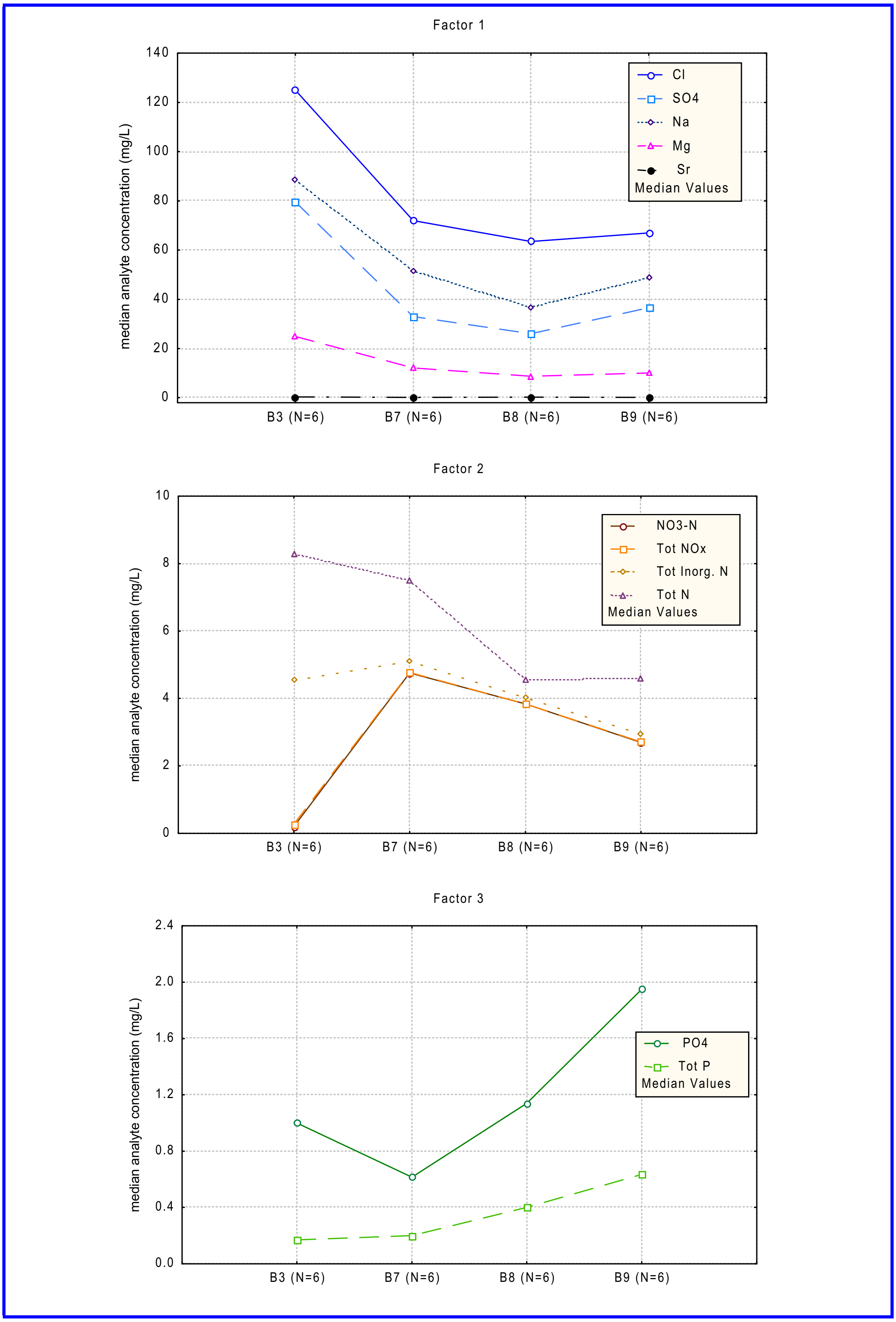


Figure 5.20 Attenuation Analysis – BOT (Wells B3, B7, B8, B9)

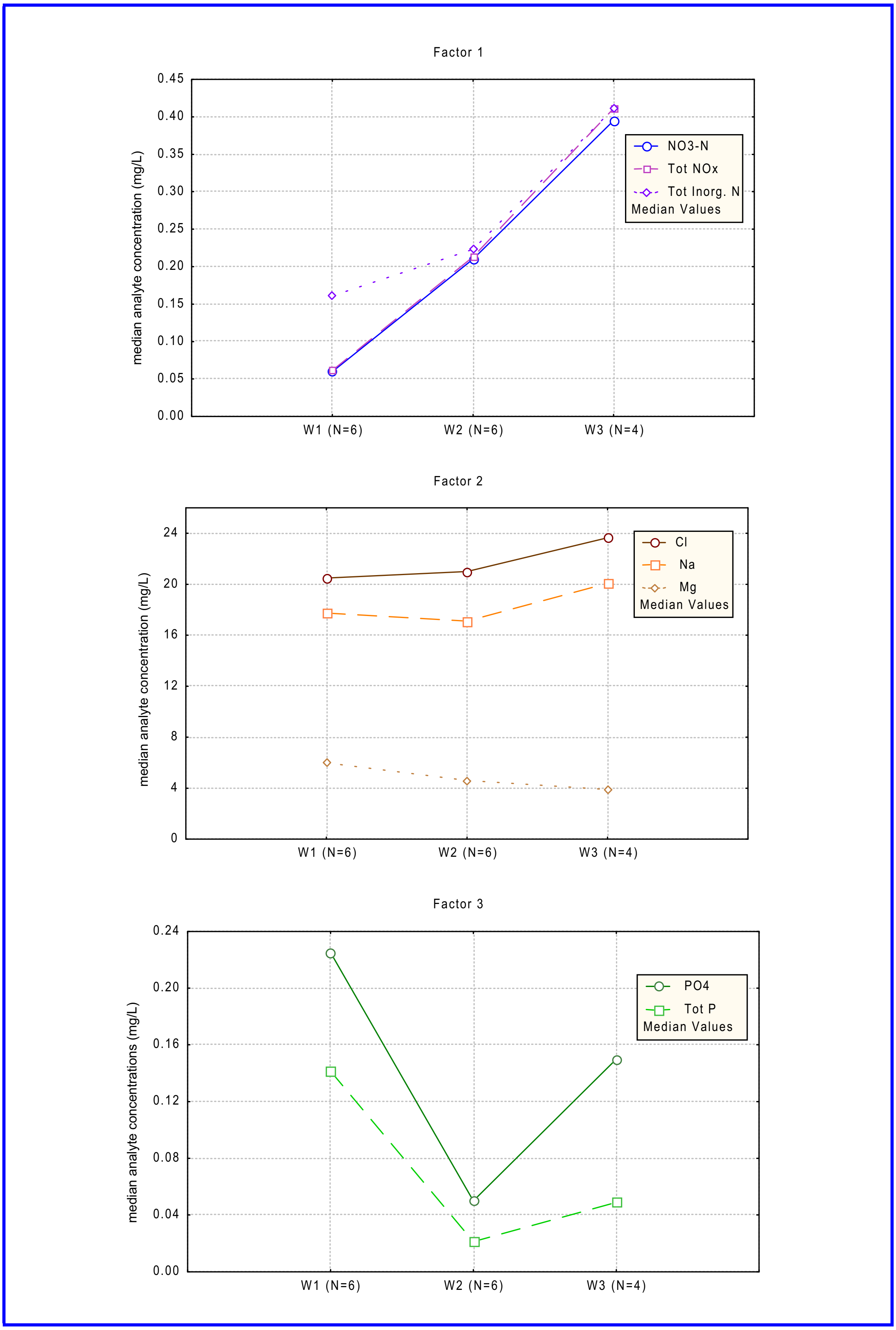


Figure 5.21 Attenuation Analysis – WOR (Wells W1, W2, W3)

The reasons that the attenuation is not readily seen are likely to be different for different sites. At BOT the areas adjacent to the central flowlines considered are still active interment areas. Since the groundwater system here moves towards the central drainage area, it is not surprising that there is a randomized supplementation of decomposition products at unspecified places along the flowlines. Hence the results are erratic or indicate an increase in quantities downgradient. This is a good illustration of decomposition product accumulation at the cemetery boundary and that the interment areas need to be separated from boundaries by substantial buffers. These need to be wide at sandy sites like BOT.

Buffer zones are discussed in Chapter Seven but are necessary to permit some attenuation – at least by dilution and oxidation.

At WOR the experiment reported on (Figure 5.21) was constructed so as to be within the buffer zone. In this case there is a clear increase in decomposition product Factors 1 and 2. It is considered that the situation here is related to transient to semi-permanent flows in the vadose zone along bedding planes and within the weathered rock – C horizon zone. Although the soils are relatively deep – of the order of 1.4 m, interment frequently occurs within weathered bedrock at variable depth. Consequently groundwater flows in this region are collecting and transferring decomposition products. This is further considered in a later section.

At LAU the situation is similar to the above. The site is clayey but still relatively recent in terms of interments. There is a build up of Factor analytes downgradient, but the trend is erratic. Although there is a paucity of data, when the results of samples taken at the far downgradient end of the gully are considered (wells L15 and L16) these show considerable reductions in the decomposition products with the exception of nitrogen forms. In this case, however, it is known that nitrogen forms are likely to have been influenced by former upgradient landuse – namely the disposal of nightsoil over a period of years (Saunders pers. comm., 1997).

The microbiological indicators, BOD and TOC were also considered in this context. With the exception of TOC at WOR and LAU, they showed no consistent variation or relevant patterns (Figure 5.22). TOC values for the flowline wells at BOT and

LAU were significantly different at the 95% level, with respective ANOVA p values of 0.0092 and 0.0196, indicating that they do represent different sample populations. However, this is at variance with other Factors and determinands so these results should be regarded as a further indication of the variability present within sites; on their own, they are not necessarily helpful in assisting the considerations of attenuation.

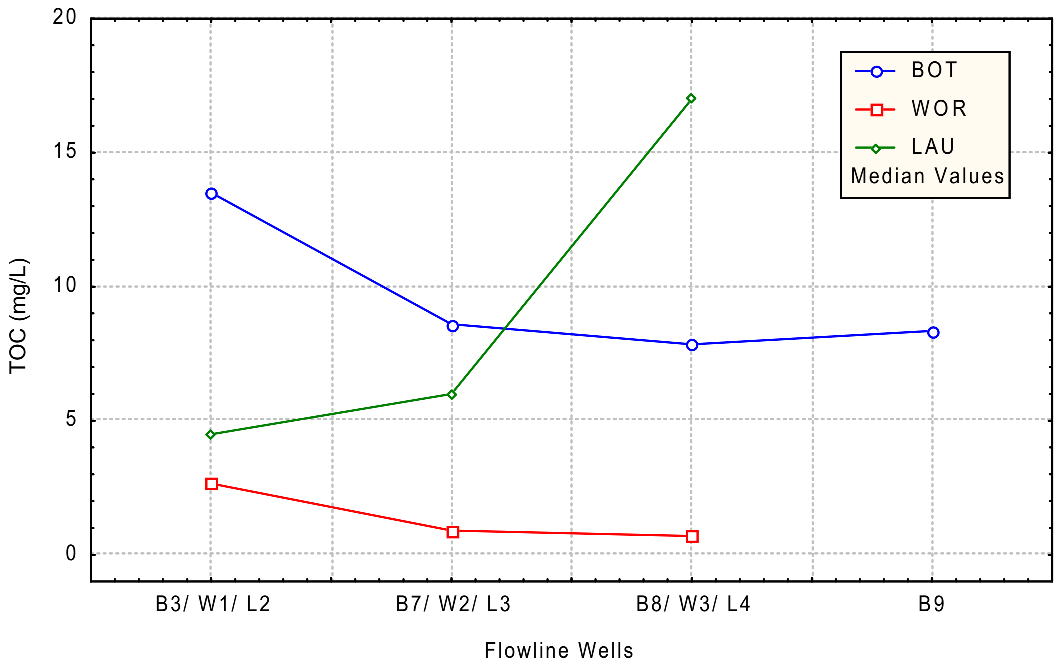


Figure 5.22 TOC Variation along Flowlines at BOT, WOR and LAU

Outcome 9 – Perched Watertables and Vadose Zone Flow

One of the hydrogeologically-founded management concerns for cemeteries is that they may adversely interact with soil-rock site situations which include obvious perched watertables or frequent, transient flows at a high level in the unsaturated zone. This is clearly the situation for all of the site at WOR and is partially represented at LAU. However, in the latter case, there is also a possibility that the flows could be simply interpreted as shallow, short-term systems within the unconsolidated soils. Although in seepage trenches L5 and L7 (see Appendix G) it was apparent that semi-consolidated, near-surface bedding features controlled the groundwater flows.

If groundwater moves through these kinds of subsurface domains it is possible that it could travel large distances in a rapid timeframe. Furthermore, in such flow conditions, normal filtration, decay of microbial populations and other attenuation mechanisms, may not operate at the same rate – either spatially or temporally. The provision of substantial buffer zones will certainly be of an aid at such sites if it is possible that the groundwater flows leave the site boundary. This last matter arises because these sites also frequently host discrete springs or line seepages and thus, sometimes, the groundwater has become surface flow. *At both the sites considered, both springs/line seepages and boundary exiting are present.*

An effort has been made to ascertain whether any discernible differences in the decomposition product profiles of the groundwaters, at various locations within these sites, can be recognised. If they could be separately identified, this might provide a management tool for cemetery planning in some circumstances, or it may serve to illustrate the delayed attenuation/alteration of these groundwaters as they head downgradient and/or offsite.

This is a statistically complicated matter if working with raw data and would require a multi-way MANOVA process. There are no known commercial or education institution-hosted, computer-based packages that could accomplish this (the best known is a two-way from New Zealand). An alternative method which can work with some summary-type value representing the wells' data was required. The most satisfactory value to use, was the final sums obtained by manipulating Factor scores for individual raw analyte data.

From the Factor Analysis (previously) the sums of the rotated Factor scores multiplied by the individual analyte values for the components (analytes) of each Factor, for each sample, are known. The Factors have been previously delineated for both the vadose and saturated zones, so that only those scores relevant to the vadose zone are used. The sum obtained can then serve to represent the Factor value for each sample. Only the data suitable for the Factor Analysis can be considered; this has the unfortunate consequence of severely limiting the number of acceptable samples for some wells in several cases: to N = 3 for wells at WOR, and N = 2 for wells at LAU. Hence a further Kruksal-Wallis ANOVA (which should have been possible on the Factor sums) cannot be undertaken.

Accordingly, a graphical analysis was performed on the Factor scores. Multivariate considerations by graphical analyses are relatively uncommon in the literature, possibly because they make use of unusual determinand combinations. An example by Powers et al. (1997) uses a star plot (with 4 axes and 5 variables) and a limited range of values, whilst an early study by Lesage and Lapcevic (1990) makes use of plots with 6 axes. Inorganic geochemical analyses are usually attempted by a range of techniques with three or four axis plots (see the discussion by Chadha, 1999). However, in this Study, the values are quite variable over a large range and there are only three Factors (equivalent to variables). A ternary plot which automatically 'standardises' the values, in that it plots according to relative proportions (StatSoft, 1995), has proved to be suitable. The results are presented in Figures 5.23 (Parts A and B) and 5.24 (Parts A and B).

In this plot type, data with like Factor composition (independent of actual mg/L values of each analyte) will cluster closely. If all results of the repetitive sampling of a well are the same, the trace plot will be a straight line. Deviations from straight lines show deviations in overall Factorial (hence component analyte) relative composition. The relative position of the plot within the ternary field is also an indication of the compositional Factor structure of the samples. Too much of any one Factor pushes the trace in one of three directions. The starting location depends upon how much of the variance is explained by each Factor (that is, another relative measure represented in the plots).

Factor trace plots which are in the same relative position in the ternary field, with the same shape (preferably straight) and without deviations along any axis are representative of the same generalised composition. Shape and place deviations allow comparison between wells-per-site, or, wells on a site-to-site basis. In addition, since the trace links individual samples sequentially, it can indicate trends in composition changes: these may be compared to any other sample set.

The Factor Trace Plots on a ternary base cannot use negative results. This is a common disadvantage with this kind of graphical presentation. The results of interest here (Outcome 9) are not negative but the matter is relevant in the next section. Two approaches have been considered with respect to this special issue:

- the easiest was to seek some kind of factorial rotation so that the Factor scores are always positive – this constraint, if possible, distorts the results and is unlikely to be the best solution. It was not possible to make a satisfactory rotation for the present data.
- a better solution was to transform the data with important attention to maintaining its rank and relative distances on the number line; as well as its likely presentation when the results are re-proportioned for plotting on the ternary diagram base. Common transformations used in the "Ladder of Powers" (Velleman and Hoaglin, 1981, Helsel and Hirsch, 1992), and particularly 'the square of X', proved to be unsatisfactory because the distribution of negative results (Factor scores) was not confined to any one Factor. Furthermore, the range of values was considerable – over two orders of magnitude: within the data for Outcome 10 following, the magnitude range of values across all Factor scores was up to four times.

The transformation: $$\frac{X^2}{(X^2+1)-X}$$ (where $\pm X$ is the Factor score)

proved to be quite satisfactory and was tested against the data for Outcome 9; there was no variation in interpretation. The start number "+1" (Vellman and Hoaglin, 1981) was necessary for the common instance where the Factor score is 1.

Discussion of Results – Outcome 9

At WOR, two thirds of the wells, but not W5, W6 and W9 are strongly influenced by semi-permanent saturated flows, which they intersect. W9 represents a central subsoil drain, whilst W5 is close to (and is positioned to capture flow from) another sub-soil drain. W9 mirrors drainage from a very large, substantially dormant, section of the cemetery; its data plot as a simple straight line – representing groundwaters with little change. W1, W2, W5 and W8 plots are the most variable; whilst W3, W4 and W7 show a high degree of consistency.

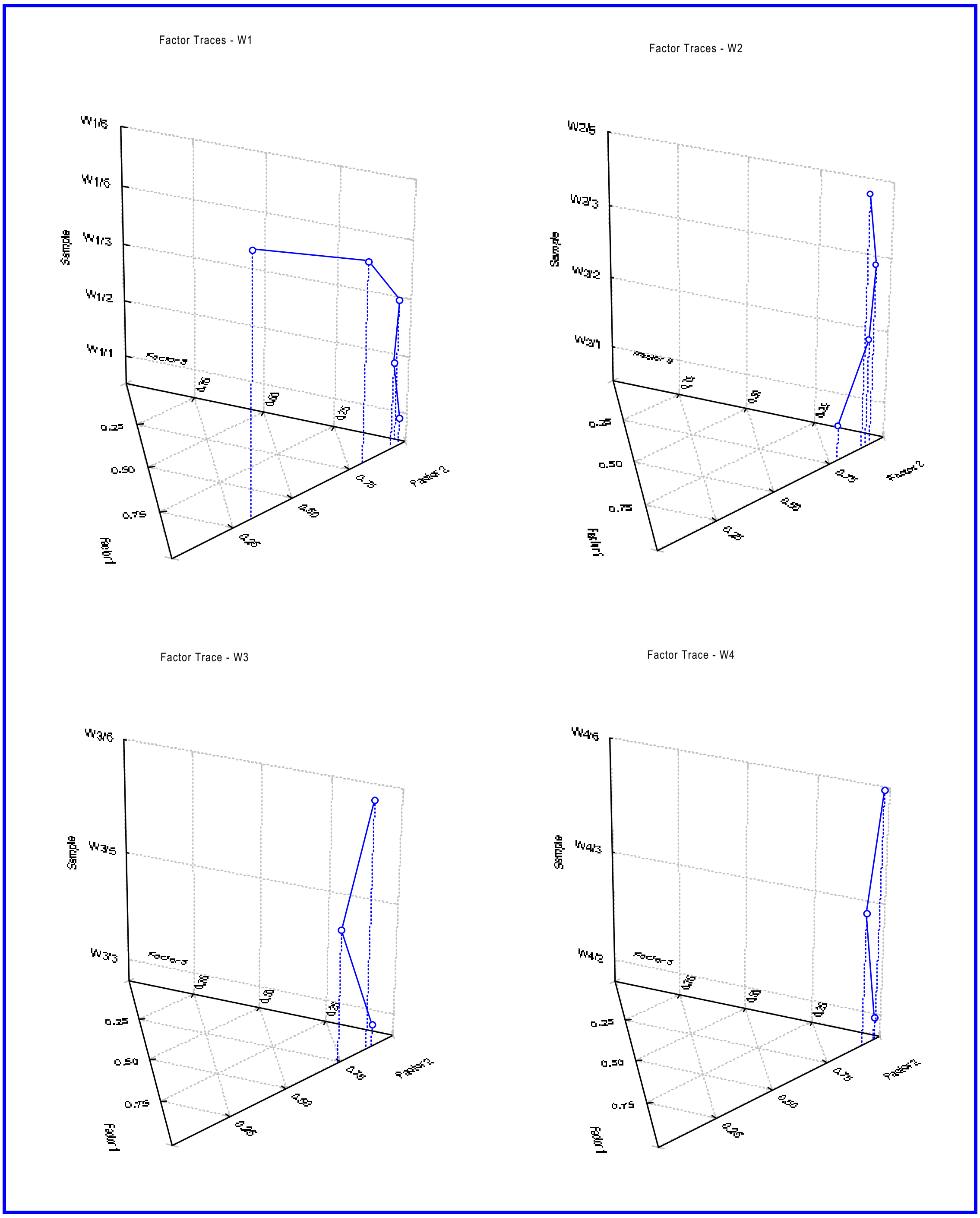


Figure 5.23 Part A: Factor Trace Plots – WOR

[upper: W1, W2, lower: W3, W4]

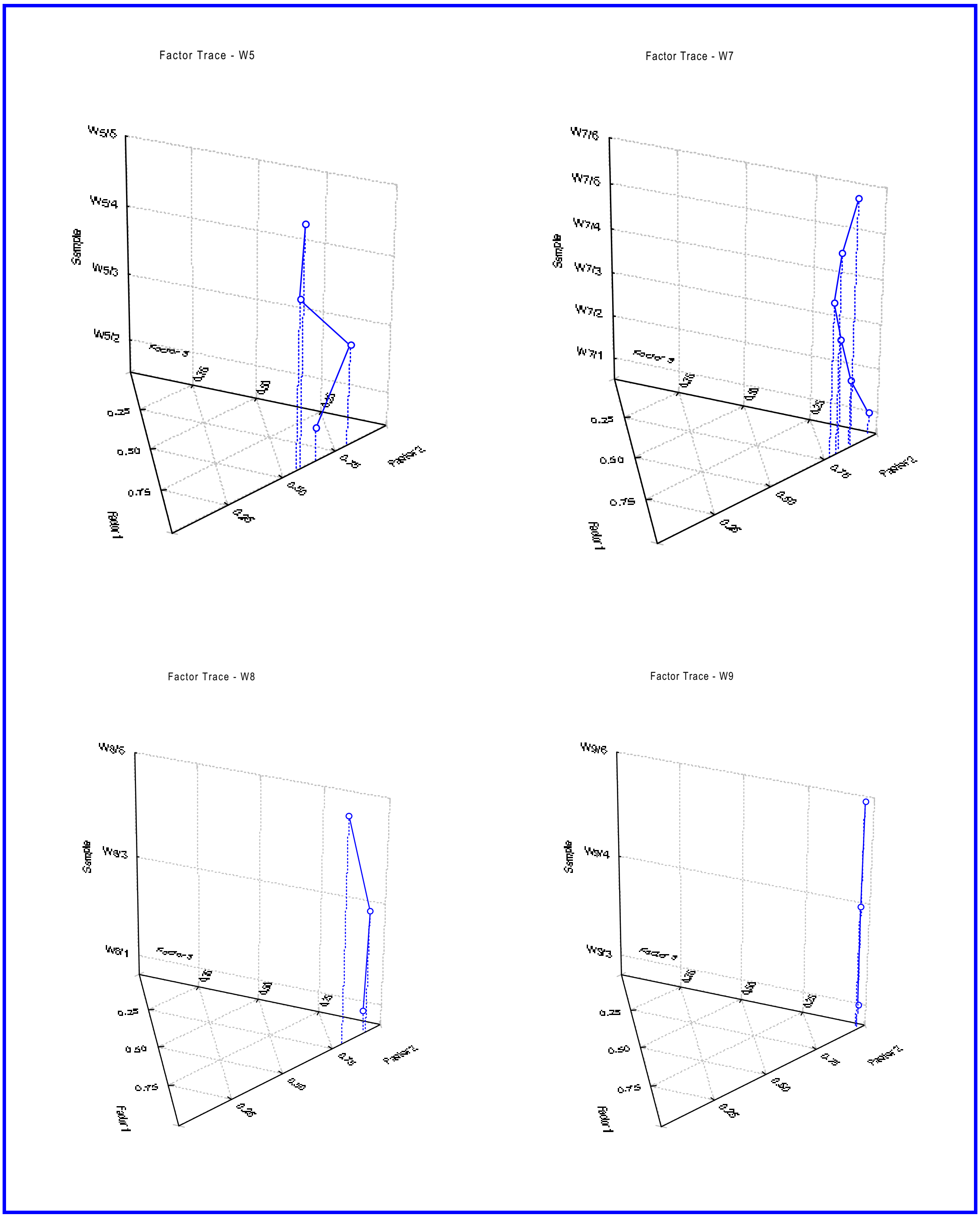


Figure 5.23 Part B: Factor Trace Plots – WOR

[upper: W5, W7, lower: W8, W9]

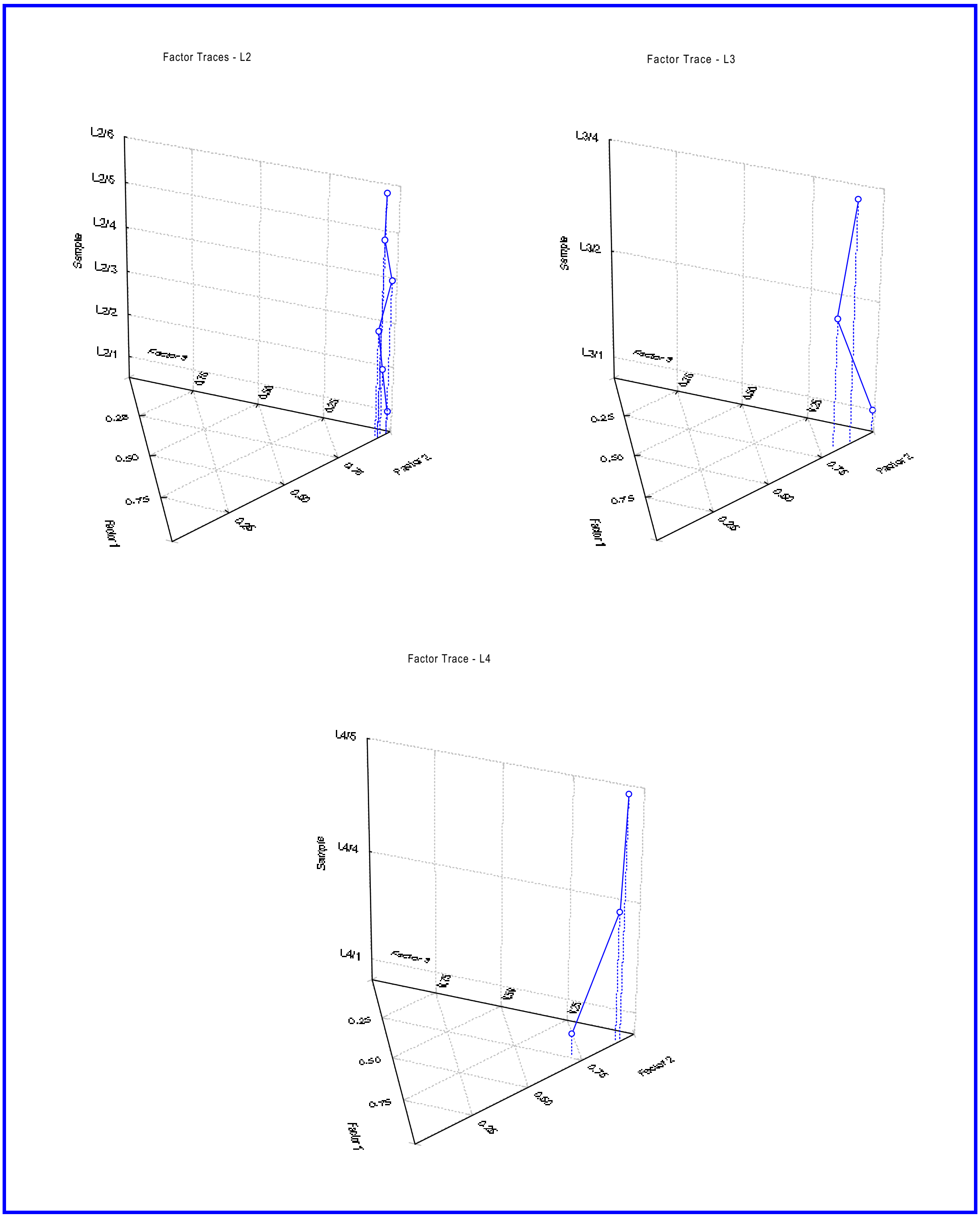


Figure 5.24 Part A: Factor Trace Plots – LAU
[upper: L2, L3, lower: L4]

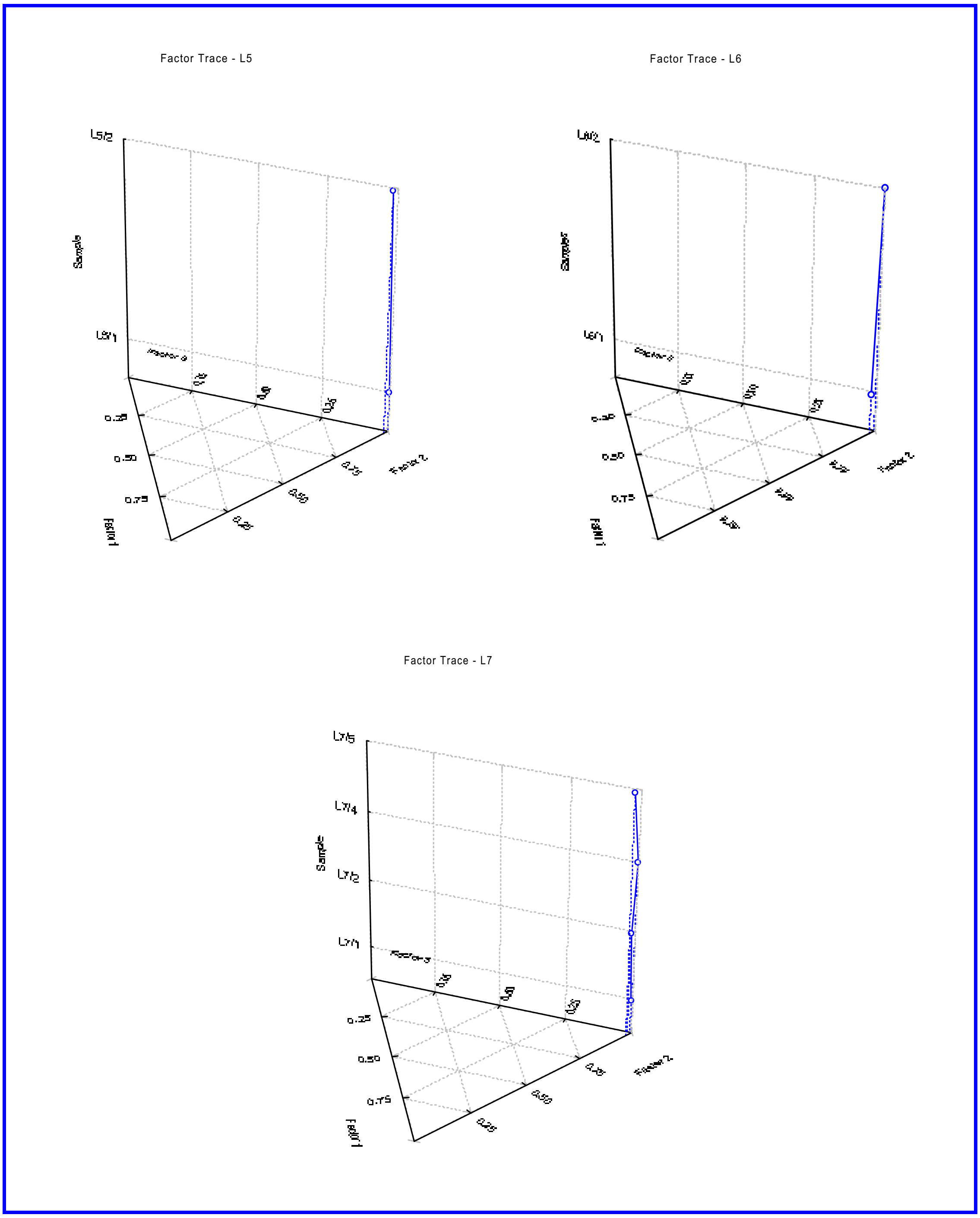


Figure 5.24 Part B: Factor Trace Plots – LAU

[upper: L5, L6, lower: L7]

It is concluded that the patterns shown for the wells W1, W2, W5 and W8 is a significant indicator that the site's groundwaters can exhibit considerable variability, despite the fact that there is also much sameness (W3, W4 and W7). W8 is a downgradient, near-boundary well. W4 is the background well and is not always saturated. On the other hand, W3 and W7, the former at an outer edge in the buffer zone, the latter in the middle of the cemetery, show remarkably consistent characteristics. This should only be possible if the discrete flow systems tapped are free of major interment influence; at this site, such would *not* normally be thought to be the situation in relation to W7. This is yet another complication in such hydrogeological domains.

For LAU there is some variation in the pattern for L2 – L4 which shows a decreasing influence downgradient of Factor 2 (major cations and anions) and changeable influence of Factor 3 (related to P content). These patterns are somewhat consistent with what might be expected in the lawn gully area.

On the other hand, L5 – L7 exhibit a remarkable consistency in their plots, with Factor variations at a very low level. These seepage trenches each intercept dispersed flows over 4.8 m – 6.0 m lengths and in a significantly 'old' area of the cemetery. With regard to the topography, soils and interment patterns lying above and most likely to be relevant, these plot-patterns are considered to represent a relatively 'stable' composition of the groundwaters.

Overall, the graphical method of analysis seems very satisfactory, but the results from the data available are highly variable. Since the beginning of the Study it has been recognised that for WOR, in particular, that In-cemetery groundwaters frequently appear 'cleaner' (less chemically complex) than the background or other groundwaters. This has been difficult to explain.

One explanation is that the numerous flows of the upper unsaturated zone represent many discrete groundwater systems. Whilst the site must necessarily be considered as a whole, wide variations and inconsistencies in groundwater composition are thus possible. Similar, but more uniform variations are seen at LAU.

At the very least, it can be stated that sites with transient, high-level flows in the unsaturated zone, and which may or may not host seepage areas or springlines, can give rise to adverse influences with unusual, and not-necessarily predictable, hydrogeochemical patterns, within and beyond the site. The issue then turns to one of the most applicable concepts of risk management. This is discussed more fully in Chapters Six and Seven.

Outcome 10 – Historical Impact of Cemeteries

The cemeteries at MEL and HEL are very old and are regarded as significant historical landmarks within their cities. MEL interments date from 1853; the cemetery was essentially closed for new interments in the 1970s, but after a change in management was, shortly thereafter, partially re-opened for in-ground vault burials along internal roadways. The only in-ground interments today are for multiple burials in existing plots. The important historical span is about 120 years.

HEL received its first interment in 1876 and was "full" when it came under new management in the late 1980s. From 1988 the practice of "lift and deepen" allowing re-use of existing grave space commenced here. The important historical span is thus 121 years.

The data in the preceding section for LAU, wells L5 – L7, can be reconsidered in respect of the present needs. This cemetery hosts interments dating from the late 1890s in the vicinity of these wells and which are generally downhill/downgradient of interments until the mid 1970s except for some young children's graves near to L5. The important historical span is thus about 80 years.

Using the graphical analysis technique developed in the preceding section for Factor score trace plots, the data for the relevant parts of these sites was examined for obvious differences to areas of more recent interments. It was reasoned that: either the groundwaters sampled in the older interment areas would show very little internal variation compared to newer areas, thus representing settled hydrogeochemical conditions; or, that their diverse composition would indicate mixing or immaturity of the immediate hydrogeochemistry.

The data for MEL is too limited and disjoint to be of any use so that the analysis could not proceed here. HEL samples are from the saturated zone so that different Factor scores (many of which were negative) compared to those for the vadose zone samples of LAU were used. The HEL data was re-expressed by applying the transformation formula discussed in the preceding section.

Discussion of Historic Impacts - Outcome 10

The results for LAU (Figure 5.24 Parts A and B) show a very uniform chemistry in the older interment areas (L5 – L7) which is very different to that for the still active areas (L2 – L4). This would suggest that over 80 years the decomposition products have become well mixed with the overall soil/groundwater system.

The results for HEL are presented in Figure 5.25. The sampling locations most clearly tied to the older areas are H2, H3 and H5, together with H1 and H6 which are boundary locations: H6 is also a background well, whilst H1 is expected to be influenced by nearby, newer interments.

The plot for H1 has a considerably different character to the others, whilst that for H3 is the most internally variable. There is insufficient difference to enable the background well (H6) to be separated from the key internal ones (H3 and H5). Thus it can be concluded that the situation at HEL is far from clear-cut, and is probably also a consequence of the fact that these samples derive from the saturated zone. The decomposition products of 121 years of cemetery usage cannot be isolated from the newer ones. This analysis is consistent with previous considerations (Knight and Dent, 1998) wherein the opinion that the groundwater beneath HEL flows in different directions (in and out of the cemetery boundaries) at different times due to reversing gradients, has been expressed.

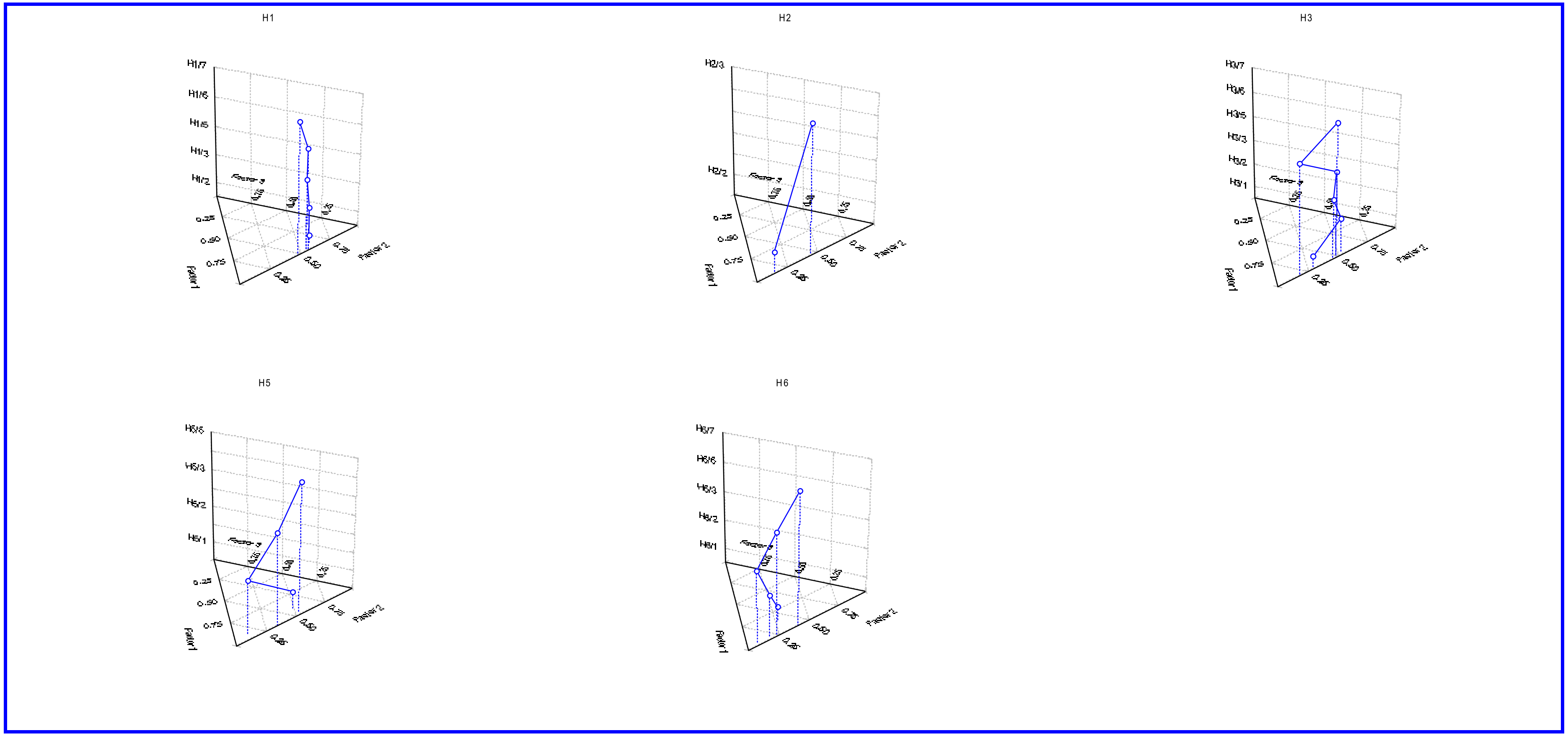


Figure 5.25 Factor Score Trace Plots – HEL
(transformed values – see text for transform formula)

Overall the Study lacked sufficient spread of sampling points, and acceptable samples from those established, in order to make many definitive conclusions on this matter. For the sites considered – LAU and HEL – there is however, a stark contrast in Factor-related hydrogeochemistry between the vadose and saturated zones represented, indicating the usefulness of this graphical technique. However, care should be exercised in otherwise interpreting these results because of the very different hydrogeological settings of these two sites.

Outcome 11 – Decomposition Products in Deep Aquifers

Earlier the relationships between sites' soils and groundwaters were discussed. The Correspondence Analysis produced at that time yielded results for the *clayey, underlying aquifers* which were difficult to interpret because there was insufficient background data.

In order to find any other means of statistically interpreting the data, a comprehensive graphical analysis using the soil determinands – EC, pH, CEC, and exchangeable ions, was undertaken to compare the underlying aquifers' results to other clayey soils. However, this was unsuccessful in allowing further differentiation in these data sets. Similarly, Cluster Analysis, was undertaken for all suitable soil data for the same data groups, and this also produced no separations. Consequently, without a greater quantity of background values, no further meaningful interpretation of the various other soil-groundwater groupings can be made.

To achieve a greater understanding of the relationships of the soils and groundwaters for the underlying aquifers, their hydrogeological relationships to the overlying cemeteries need to be considered (see Appendices E, F and H). These are regional, or off-site, aquifer systems and **the influence of broader scale hydrogeochemistry is likely to be much greater than that of the immediate cemetery area above**.

The regional hydrogeological setting of CEN is poorly reported, despite considerable mapping and examination of Adelaide's geology for many years. See Chapter Four for description.

Data concerning the hydrochemistry of the waters in the shoe-string and other shallow aquifers of the Outwash Plain or the Hindmarsh Clay is scarce. Where known, it is described as mostly dominated by sodium chloride ions; TDS range is reported as 897 – 4879 mg/L (Taylor, et al., 1974). The data from CEN (Appendix L), however, records TDS values to about 16000 mg/L.

SPR and NEW sites are located above the shallow, unconsolidated to partially consolidated, sandy, lensoid, semi-confined aquifers of the Brighton Group (Leonard, 1992, Dent and Knight, 1998). The available descriptions of the hydrogeochemistry of these groundwaters, as set out by Leonard (1992), presents a very variable picture. They have TDS values ranging from 110 – 6800 mg/L (with 73% < 2000 mg/L), principal dissolved salt of sodium chloride with lower concentrations of calcium chloride and magnesium bicarbonate. Sulfate is typically around 50 mg/L whilst nitrate averages 10 mg/L ranging between 0 and 96 mg/L. pH is similarly variable from 4.4 to 8.6 but averaging 7.4. Bicarbonate or carbonate ions are absent or present in small concentrations.

This Study's limited results (Appendix L) are entirely consistent with the above descriptions, except perhaps for possibly higher bicarbonate ion values.

SUMMATION

The hydrogeochemical groundwater profiles of cemeteries show little variation between the vadose and saturated zones on an overall basis. There is some small difference in the degree of correlation of determinands – probably reflecting the small volume of influence in the vadose zone compared to the cases of the regional profile for places where cemetery waters are readily joining the watertable. This latter aspect becomes more pronounced when sites are examined on a micro scale. In such instances the Factor-related hydrogeochemistry can present starkly different pictures for the vadose and saturated zones.

Table 5.5 presents the primary compositions – Principal Components or Factors for the vadose or saturated zones of cemetery groundwaters from this Study.

In respect of the character or features of cemetery groundwaters; they have or show, or, there is:-

- the presence of, and a strong relationship between, major cations and anions as: Na, Mg, Sr, Cl and sometimes Ca and SO_4.
- the presence of various forms of inorganic nitrogen species and total nitrogen. There is no specific role for ammonia . Organic Nitrogen may be linked with increased TOC in the vadose zone.
- where measured, there is a strong correlation between Total Phosphorus and Orthophosphate (PO_4).
- that alkalinity is a factor for vadose zone groundwaters; but pH is rarely important.
- the variations are usually only in matters of degree not in matters of composition. The saturated zone groundwaters show a greater amount of variation than the vadose zone waters.
- the influence of the site's soil physico-chemistry is relatively small overall. Any effect is greatest in the vadose zone of sandy sites where stored salts may be leached into the percolating waters of interest.
- the major cations possibly together with Sr, and except for K, are influences to various small degrees. Consequently the low values of analytes determined in cemetery groundwaters must take account of this interference. Comparative values need to be grossly different.
- that there is almost no relationship between biochemical (BOD) and biological factors (bacterial counts) and the apparent hydrogeochemistry, nor with pH, Eh, groundwater salinity (as Cl), TOC or Organic N.
- that the case for significant heavy metal 'pollution' or accumulation can not been made out for all metals or all places. Consistent with the general hydrogeochemical behaviour of metals, there are accumulations and deficiencies varying with environmental conditions of soil type and pH.
- that a statistically significant deficiency of Ni, Cr and some Mn within the saturated zones of cemeteries has been found. This is at odds with the supposed composition of buried funereal artefacts and may be related to attraction of these metals by bone.

- no detectable enhancement of decomposition products in groundwaters as a consequence of the presence of non-coffinated interments.
- little downgradient attenuation: this comes about because the burial areas are influenced by continued interment activity at various place along flowlines.
- a maturity of groundwater hydrogeochemistry is likely in areas of historic interments if that area is unaffected by other hydrogeological matters.
- that the influence of broader scale hydrogeochemistry in regional aquifers is likely to be much greater than that of the immediate cemetery area above.

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CHAPTER SIX

CEMETERY FUNCTION

Contents

As a consequence of the analytical studies presented in Chapter Five, it is now quite certain that the decomposition products generated in cemeteries can, in most cases, be detected and characterised. However, it is an entirely different, and much more difficult, task to quantify these matters or to accurately delineate the position, attenuation or dispersal of necro-leachate. There are many complexities to such endeavours consequent upon the great variation of cemetery soils, hydrogeological settings, the details of the interred remains and cemetery practices.

Because the amounts of organic waste (interred remains) are low relative to the space of a cemetery or the volume occupied by contents in graves, the expected results from measurements of almost all aspects of necro-leachate are low. This Chapter examines the way cemeteries function and places these ideas in the context of a special kind of landfill, as well as further exploring particular matters of necro-leachate composition. Cemetery processes should be considered from a broadly-based perspective, that is, treating the cemetery site as a 'black box'.

CEMETERY GROUNDWATER SIGNATURE

The characterisation data analyses (Chapter Five) have shown that there are no unique marker analytes for cemetery groundwaters. The Factors representing the groundwaters in various situations are capable of being replicated in other urban and agricultural contexts. The presence of various metal suites is likely related to coffin materials and funereal artefacts, but these are in relatively small proportion to the volume of soil available for interment (see Chapter Two). The greatest value in this context, so far arises from the inorganic forms of nitrogen together with a small range of relevant, major cations, chloride and phosphorus. Some indicator and/or pathogenic bacteria are sometimes present but not in satisfactory continuity for this purpose. Table 6.1 repeats the typical Factors that characterise cemetery waters in various hydrogeological zones.

Table 6.1 Characterising Analytes of Cemetery Groundwaters
(Factors summarised from Table 5.5)

	Characterising Analytes			
	Vadose Zone		Saturated Zone	
Factor 1	NO_3-N + Total Inorganic N + Total NOx ^	* 30.6 %	Cl + SO_4 + Na + Mg + Sr	35.3 %
Factor 2	Cl + Na + Mg	29.0 %	NO_3-N + Total Inorganic N + Total NOx + Total N	24.3 %
Factor 3	PO_4 + Total P ^	18.3 %	PO_4 + Total P	15.4 %

* % value explains amount of variance attributed to data analysed in this Study.
^ For practical purposes, and later discussion, ‘All N’ or ‘All P’ analytes are considered lumped together.

The idea that cemetery groundwaters may emulate groundwater recharge by leaking urban sewers is considered to be the best overall geochemical model, although cemetery function emulates a landfill; furthermore the effects of septic system drain-fields or sewerage effluent applied to crops are also useful conceptually in understanding necro-leachate behaviour. More work needs to be done to quantify the groundwater signature if possible. The potential direction is likely to lie in the delineation of organic molecules unique to the human lifestyle, for example, medical drugs, possibly hormones, caffeine or even ungents and cosmetics. Detergent compounds are likely to be in a reduced quantity as is any contained boron, and so are most organic solvents, although these molecules or chemicals are associated with funereal artefacts and processes (coffins, fabrics, washing remains, etc.).

Following a comprehensive study of urban groundwaters and a wide-ranging examination of marker analytes related to these, in Nottingham, UK, Barrett et al. (1999) came to the conclusion that there are no easy solutions to the problem of identifying recharge sources in urban groundwater, and that a multi-component approach is likely to be the most successful. They were able to couple nitrogen isotope signatures and indicator enteric bacteria in groundwaters to delineate sewer leakage into the shallow, phreatic, aquifer in unconsolidated sediments adjacent to a major housing area. The authors also flagged the possibility that the mammalian urinary metabolite – 1-aminopropanone, may be suitable for the task. (Barrett et al., 1999).

In the case of cemeteries, medical drugs metabolites and/or hormones, as well as nitrogen isotope values may prove to be beneficial. In a related area of study, Seiler et al., 1999, examined the effects of potential human contaminants in well waters adjacent to areas using septic systems in three communities near Reno, USA. They came to the conclusion that: “The presence of even low levels of caffeine and human pharmaceuticals in ground water with elevated nitrate concentrations is clear, unambiguous evidence that domestic waste water is a source of contamination except under unusual circumstances” (Seiler et al., 1999). However, the results of the study also highlighted the facts that caffeine is highly metabolised in the body, is not conservative as a groundwater tracer, and, that the presence of pharmaceuticals is unpredictable.

BACTERIAL & VIRAL SURVIVAL IN DIFFERENT ENVIRONMENTS

In this Study a determined effort was made to obtain representative samples of key indicator bacteria in the cemetery groundwaters. The sampling methodologies are discussed in Chapter Four whilst Table 4.3 summarises the number of samples taken at different sites in respect of the bacteria considered. The bacteria sought were those commonly associated with human sewage, or pathogenic bacteria which can be water-borne and are commonly associated with disease in water supply. Various World standards define the organisms of interest, with little variation between those sought and levels representing unsatisfactory water; for example, NZ Min. Env., 1999, NHMRC, 1994, WHO, 1993, ANZECC, 1992a, Craun, 1988, European Communities, 1980. The European standards have undergone major revision in the last two decades and appear to be quite broadly focused (see for example, Helmer et al., 1991, Merrett et al., 1989). However, there are many other organisms of interest not mandated for routine testing. Table 6.2 summarises the microorganisms that have a general relevance to cemeteries and their survival in various environmental conditions. An additional list of common isolates from land-applied sewerage sludges is given by Dudley et al. (1980).

This Study's data and its analysis (Chapter Five) show that, although widely distributed amongst the different sites, soils and samples, there were only low levels of indicator bacterial presence; including situations where it was most likely to be encountered. For example, some sampling at BOT, LAU, HEL and GUI was very favourably located to interred remains.

There are several significant issues related to microbiological contaminants in cemeteries. In the first place, there is a widely expressed viewpoint that disease-causing microbial pathogens of the human rapidly die once the host dies (see Healing et al., 1995, for a typical pronouncement and more detailed discussion in Chapter Seven). Thus organisms associated with plague, cholera, typhoid, tuberculosis, anthrax, smallpox, hepatitis, and HIV, are considered to be rapidly neutralised and pose little threat once in-ground, that is, as interred remains. Unfortunately, there is

Table 6.2 Key Bacterial and Viral Components Relevant to Human Decomposition:
Survival in Different Environments
(after Corry 1978, Lewis-Jones and Winkler, 1991, Pitt, 1996, Environment Agency, 1999, WHO, 2002)

Key organism + Class or genera or species@	Environment for survival evaluation (times and travel distances) #					Pathogenic status ^	Ref. *
	surface soil	sub-soil	groundwater	surface water	sea water		
BACTERIA							
Pseudomonadaceae:							
Pseudomonas+	X		X	X		X	
P. aeruginosa+	X, 100dL wet sand		X, 300dL	X	X	X	KMea, Fea
P. pseudomallei(+ tropical areas)	X			X, seds		X	KD
Enterobacteriaceae:							
Escherichia coli+ (1)	X, 6y, 3y dry, 136d, 197d		X, 63d, 3m 105d,135dL, 28m in189d	X	X	X (some)	YG, Gea, RFR
Klebsiella	X			X		X	CM
Enterobacter+				X		X	
E. aerogenes							
Proteus+	X		X		X		
Citrobacter spp.							
Salmonella+	X		X, 44dL	X, 150d		X	LJW, Gea
S. typhi+	X,730d 165/216/300d 2y wet frozen	X, 0.9m	X	X	X, 616d	X	RFR, McF B
S. paratyphi+				X		X	Gea
Shigella+		X, 0.9m	X, 24dL	X		X	RFR

Yersinia *Y. enterocolitica*+ Coliforms – general term (2)+ *Serratia marcescens* (as a tracer, released at 2m depth in sandy aquifer) Tracer testing in karstic aquifer:-	 X, 830mf,10m 457mf in 2d	 X, 140d	 X, 300dL X, 30m in 1.5d, 850m X, 25m in 35d 10-14 km in 40 -60h	X X	 X, 84d	X X	 Fea, McF Gea CM Oea HKR
Bacteroidaceae: *Bacteriodes* *Fusobacterium*							
Neisseriaceae: *Neisseria* *Veillonella*							
Micrococcaceae: *Staphylococcus*+ *S. aureus*+ *Acidaminococcus* *Sarcina* *Peptococcus*			 X	 X	 X	 X X	
Enterococceae: *Streptococcus*+ *E. faecalis (Streptococcus faecalis)*	 X, 457mf in 2d, 30d – 62d		 X X, 183m 300dL	 X X	X X X, 629d	X X	 Gea, CM McF, Fea
Propionobacteriaceae: *Ppropionobacterium* *Eubacterium*							
Corynebacteriaceae: *Corynebacterium*							

Bacillaceae:							
Bacillus+		X, >15000y		X		X	FF (7)
B. anthracis	X, 54y, A, 40y at 0.5m	X 200y bone		X ponds			LT Mea, T
B. stearothermophilis							
Clostridium	X	X, 28m (6)	X	X	X	X	
Cl. perfringens (welchii)+	X, 100dL wet sand			X 100dL		X	KMea
Cl. botulinum+	X, 20y		X, 20y	X, seds		X	H
Cl. tetani+	X, many y					X	H
Listeriaecae:							
Listeria+				X		X	
L. monocytogens							
Vibrionaceae:							
Vibrio cholerae+		X, 0.9m	X, 6d	X, 8d	X, 13d	X	RFR
Brucellaceae:							
Brucella+	X, 29d, 100d 800d frozen			X		X	CM
Campylobacteraceae:							
Camphylobacter+				X, 4-28 d		X, temp & pH sens.	LJW
Leptospiraceae:							
Leptospira+	X, 5d wet			X		X	CM
Mycobacteriaceae:							
Mycobacterium+	X		X	X		X	
M. tuberculosis+	X, 213d						CM
Aeromonadaceae:							
Aeromonas + (3)				X	X	X	
A. hydrophila (syn. aerogenes)+	X, 248dL					X	RFR

Lactobacillaceae: *Lactobacillus* *Leptotrichia* *Bifidobacterium* *Ruminoccus* *Peptostreptococcus*							
VIRUSES							
Picornaviridae (Enteroviruses):+ (4)				X, 84d	X, & seds	X	JL
Poliovirus+	X, ad, 63d, 150d		X, 90m	X,100dc, 150d	X	X	Sea, RFR, JL, ON, Ba
Coxsackie viruses A & B+	X, 130d			X, 150d	X	X	ON, Ba
Echovirus+	X, ad, 35d 170d			X	X	X	Sea Ba
Hepatitis A (HAV)+	X, ad, 84d			X		X	Sea
Reoviridae							
Reovirus+				X	X		
Rotavirus+				X	X	X	
Adenoviridae: Adenovirus+			X	X	X	X	
Human Immunodeficiency Virus (HIV)+ (5)	X (bone)					X	NSH DeC
Caliciviridae: Norwalk virus+				X		X	
Astroviridae: Astrovirus+			X	X		X	

Hepadnaviridae Hepatitis B+				X		X	
Smallpox+ (a few years stored) (8)						X	Fee
BACTERIOPHAGES / Phages (9) Phage tracing in karstic aquifer:-		X, 181d	X, 100 m in 48d, 20 – 39km				Oea HKR

Notes to Table 6.2

+ this species or group can be released from buried cadavers
@ organisms are named according to the taxa listed by Euzéby (2002)
# data given when available from Ref.; 'X' means that survival of organisms is possible in indicated environment; y = years, d = days, m = metres, L = laboratory/column experiment, f = filtration/effluent bed, A = aerobic, c = cold temperature storage; 'surface water' includes ponds and sludges, ad = adsorbed, seds = survival in sediments (see note 3)
^ pathogenic status denoted by 'X' means that the organism/particle can cause disease in some humans if infected with an infectious dose or if otherwise susceptible; temp = temperature, sens. = sensitive
* It is not the intention within this Study to explore the matters of bacterial, viral and protozoan transmission in surface- and groundwaters, or survival in soils, in detail. Given, however, that the issues are very important to the understanding of the effect of cemeteries in the environment and of human decomposition, an extensive literature search has been made in many published disciplines, like, medicine and pathology, veterinary sciences, microbiological sciences, wastewater engineering, community disease, mortuary practices, soil science, environmental studies and others. The following list of references, all of which have been especially reviewed by the Researcher, are some useful ones for an initial understanding of the issues and, where relevant, are designated by reference symbols and used in Table 6.2; some of these cite other references:- (FF) Fredrickson and Fletcher, 2001, Pedley and Howard, 1997, (T) Turnbull, 1996a/b and 1990, Healing et al., 1995, (DeC) De Craemer, 1994, (Mea) Manchee et al., 1994, (LT) Lindeque and Turnbull, 1994, Ahtiainen et al., de Vicente et al., 1991, (H) Haagsma, 1991, (HKR) Hötzl et al., 1991, Hunter and McDonald, 1991, (LJW) Lewis-Jones and Winkler, 1991, (Oea) Oetzel at al., 1991, (NSH) Nyberg et al., 1990, Merrett et al., 1989, Yates and Yates, 1989, Evison, 1988, (Fee) Fenner et al., 1988, (FKN) Filip et al., 1988, (KD) Kanai and Dejsirilert, 1988, (Sea)

Sobsey et al., 1986, Yates et al., 1986 and 1985, Corapcioglu and Haridas, 1984, (CM) Crane and Moore, 1984, Grabow et al., 1984, (JL) Lance, 1984 and 1978, Yates and Gerba, (KMea) 1984, Kaddu-Mulindwa, 1983, (ON) O'Brien and Newman, 1977, (Gea) Gerba et al., 1975, (McF) McFeters et al., 1974, (Ba) Bagdasaryan, 1964, (RFR) Rudolfs et al., 1950, (B) Beard, 1940, (YG) Young and Greenfield, 1923.

(1) *E. coli* spores resist adverse conditions; these are thermotolerant bacillae the most plentiful type of 'faecal coliforms'; survival varies widely by soil type (sandy/clayey) and pH (Crane and Moore, 1984)
(2) The term "coliform/s" generally means a facultatively anaerobic bacillus of the Family Enterobacteriaceae, includes *E. coli* (Singleton, 1999). Various experiments and measurements have been made in sandy, gravelly and sandy loam effluent treatment beds.
(3) *Aeromonas spp*. are opportunistic pathogens of non-faecal origin, they are closely correlated with other faecal organisms where present, but otherwise might be wisely monitored on their own in recreational and drinking waters (Lewis-Jones and Winkler, 1991).
(4) The enteric viruses have been found to be very resistant to the marine environment at temperatures < 10ºC and to remain viable in sediment for up to 18 months (Lewis-Jones and Winkler, 1991)
(5) HIV has been found to be viable in post-mortem tissue for up to 14 days – various fluid, bone and tissue samples, stored at 6º and at room temperature (Nyberg et al., 1990, Healing et al., 1995), 16.5 days in bone at 2º (De Craemer, 1994)
(6) study of *B. stearothermophilis* in fractured crystalline bedrock (Gerba et al., 1975), traveled 28 m in 30 hr.
(7) several studies have confirmed the long-term (geological ages) survival of bacteria in deep, vadose zones, e.g. Bacillus spp. >12000 and >15000 and perhaps to 4 million years (Fredrickson and Fletcher, 2001). The mechanisms of survival are not fully understood.
(8) Smallpox is said to be able to survive stored in a cupboard out of sunlight and dry for several years; however, is not thought to survive for a long time in coffins or other human remains (Fenner et al.). The issue, however, has not been properly studied or possible infections from the interred deceased route properly studied, evidence so far is anecdotal (Fenner et al., 1988, Anan, 1985, Zuckerman, 1984).
(9) Bacteriophages (usually called 'phages') are specialised viruses that infect bacteria. They have different shapes and compositions, they can be highly selective in infecting certain genera, species or strain of bacteria. Phage øX174, for example, is typically hosted by *E. coli*, and P22 affects *Salmonella spp*. (Singleton, 1999). Phages have been used in groundwater tracer tests.

surprising little data published to support this proposition, and significantly more information, although a very small amount overall, which supports the idea that various organisms including anthrax, smallpox, infective *Clostridia* spp. and HIV, for example, are well and truly capable of surviving buried, possibly anaerobic, environments for some time (Turnbull, 1996b and 1990, Haagsma, 1991, Yates et al., 1985)*** (***see notes to Table 6.2). In a very few instances, given the uncertainties of the cemetery environment and burial practices, these organisms may well be available to be fluxed from the grave – either by groundwater or overland by flood.

Secondly, there is the issue of natural enteric and thoracic bacteria of the human, which, when exposed to favourable conditions may multiply and spread in groundwater. Alone these bacteria can be a serious problem, but also incorporated in this grouping may be remnants of hosts' non-infectious doses, including:- the very pathogenic *E. coli O157:H7 (Singleton, 1999, Gleeson and Gray, 1997), Pseudomonas aeruginosa*, *Salmonella spp*. and so on; which exacerbates the situation. Various enteric viruses are also known to survive in soils and groundwaters, but seem unable to multiply in these environments (Yates and Gerba, 1984, Yates et al., 1985, Gerba et al, 1991). The case for survival of infectious protozoans like *Cyrptosporidium spp., Giardia spp*. and various amoebae is less clear-cut.

Thirdly, the matter of subsurface transmission of bacteria or viruses considered on its own, when the sites' hydrogeological conditions do not attenuate their travel. Consequently, the matters of set-back distances of cemeteries from drinking water wells, streams, wetlands or beaches become an issue (see for instance: Macler and Merckle, 2000, Pedley and Howard, 1997, Sobsey et al., 1986, Gerba et al., 1991, and Yates and Yates, 1989). In this context, general standards have arisen about the juxtaposition of these various landuses to be applied so as to protect public health (see Chapter Seven). The great variety of cemetery sites' soils and hydrogeological conditions makes for a relatively complicated situation in the development and application of suitable criteria.

In essence though, despite the fact that a cemetery can become the repository for any know human microbiological pathogen as well as some chemical ones, the risks posed by correctly sited and operated cemeteries are small in most soil types. The essential ingredients to this conclusion are that:

(a) the amount of buried organic waste – harbouring organisms of interest in an organic substrate host – is small;
(b) the infectious or endemic organisms are, in general, widely disposed in space and time, are in variable amounts per host, and are presented to fluxing groundwater or incorporated in percolating groundwater at different rates and at different concentrations both areally and volumetrically;
(c) the release of organisms from the interred remains is controlled by the burial environment which constitutes to various degrees – a coffin (of various constructions), different degrees of preparation of the remains (including embalming), containment of the coffin and/or remains (vaults, etc.), different levels of moisture, types of soil, soil pH, temperature, and other factors;
(d) the thickness of the separation zone of the grave invert level to any permanent, ephemeral or fluctuating watertable; together with the hydrogeological nature of the cemetery soils at and below grave invert level.

McFeters et al. (1974) have made the useful observation: “Although detection of indicator bacteria suggests the occurrences of pathogenic organisms in water, the potential health hazard is dependant on retention of critical density levels and associated virulence for the pathogens in a given time frame”. However, their accompanying assertion “ …. once these bacteria are deposited into the water they are in an environment that is not favourable to the maintenance of viability of most bacteria” (McFeters et al., 1974) is now unlikely to be acceptable (see Table 6.2), and the matter of survival and transmission must be considered on a site- and organism- specific basis. This latter conclusion is reinforced by their own comments that extrapolating results from controlled experiments to the field should be done cautiously because the natural aquatic environment reflects water quality, phage and predator organisms (McFeters et al., 1974).

Percolating groundwater or flood inundation is sometimes capable of rapidly reaching the interred remains, taking up decomposition products, and then continuing to percolate until it reaches a groundwater table, or quickly re-emerging if the site topography or degree of inundation is unfavourable. How to manage the effect of a cemetery in this context or any threat imposed from interred pathogens becomes a matter of risk aversion. This is considered further in Chapter Seven.

The default position is that pathogenic organisms will be released to percolating groundwaters and that their transmission in the vadose and saturated zones must be assessed. It is most likely that they will move further in open porous soils like sands, but they may also be transmitted in macropores in a variety of substrates, or fractures in stiff clays (see for example, studies of landfill leachate by McKay et al., 1998, and macropore recharge by Wood et al., 1997, and discussions by Lance, 1984). In the typical situation these organisms must move both vertically and horizontally to be within the groundwater off-site. Thus they bypass attenuative mechanisms in the vadose or saturated zone media (soil) like, straining, adsorption and dispersion.

Some of these organisms have a further aspect of concern, namely to be initially released in small numbers but to grow within the subsurface if favourable conditions exist. For example, studies by Goldsmid in Israel and others reported in Gerba et al. (1975) have shown the dramatic regrowth of coliform group bacteria in groundwater. Such information is scant for the majority of organisms of interest.

The whole issue of micro-organism survival and transmission in soils and groundwaters is still very incomplete (Gleeson and Gray, 1997, Pedley and Howard, 1997, Gerba et al., 1991, and Yates and Gerba, 1984). Although various relevant studies have been undertaken since the early 1900s, the whole issue lacks balance from a databank of credible field studies. Working with these organisms in the field is difficult and even techniques for identification of some bacteria and viruses have only been properly developed in the last two decades. The major groups of studies have been:- (i) laboratory-based using either soil columns, or other leaching set-ups with groundwaters and sterile or tap waters, or storage in jars of soils or groundwaters, or suspension of bacteria in cells within wells; or (ii) based on sites where treated or untreated sewerage effluent has been added to percolation beds, drain fields, recharge basins or simply spread on the surface.

Of this latter group, the predominant studies have relied on infiltration from the surface, so that the studies have reported survival rates in *surface soils,* and irrigation waters. Of these, there are a few relevant field case studies where percolation at depth attributable to a known source of pollution has been measured (see Gerba et al., 1975). For example, Polio virus type I, has been isolated after 20 ft (6.1 m) of vertical percolation from the surface in "sand with little or no silt or clay" after 5 months and probably after flushing by heavy rains (Gerba et al, 1975). Bitton and Harvey (1992) report on modelling work by several authors based on column experiments that suggest that under normal climate conditions, few micro-organisms are vertically transported more than 3 m in different soils, but, in times of prolonged or intensified precipitation events this may expand to in excess of 100 m. This matter is further considered in Chapter Seven.

There are a few review papers that have brought together relevant knowledge on bacterial survival and transmission rates in various media. One of the earlier ones by Gerba et al. (1975) has formed an excellent base which has been copied into several later ones (for example Pitt, 1996). Since the original discussion there has apparently been little advancement in matters which reflect on virus survival or transport, however, a paper by Lawrence and Hendry (1996) has aided the understanding of in-soil processes of straining and adsorption. Other relevant general reviews and discussions are by: Rudolfs et al. (1950), Lance (1978 and 1984), Matthes and Pekdeger (1981), Crane and Moore (1984), Bitton and Harvey (1992), Kieft and Brockman (2001); whilst the book by Lewis-Jones and Winkler (1991) presents a useful overview of most likely human-borne pathogens.

The survival of bacteria and viruses in the soil environment is the most important aspect of their effect in respect of cemeteries. After release as a product of decomposition, bacteria and viruses should initially interact with the vadose zone around and below the grave. Despite the possible long-term survival of many bacteria and viruses in soils and groundwaters, most researchers and reviewers have concluded that the risks of microbial contamination are most likely related to specific situations, settings and wells. Crane and Moore (1984) have summed up instances of specific pollution thus: “use of septic disposal systems in unsuitable soils, drainage waters from application areas utilizing artificial drainage systems, waste application in areas underlain by fractured, crystalline or channelized bedrock and bacterial pollution induced over great distances by groundwater pumping”.

If one adopts the position that extensive migration of bacteria or viruses, or other micro-organisms, from the interred remains is undesirable, then apart from the hydrogeological properties of the unsaturated zone, it is the suitable siting and management of the cemetery that become the most significant issues. It is shown in Chapter Seven that if the grave invert – watertable separation distance is sufficiently thick, and if the cemetery has perimeter buffer areas, then in most natural geologic media, off-site movement of decomposition products will be minimal and of low risk of causing environmental or human pathogenic conditions. Any risk should result from unknown or unusual conditions.

The survival of bacteria and viruses from the cemetery in soil can be assessed in terms of a few significant parameters. These are listed in Table 6.3 which has been compiled from several sources. The presence of any inhibiting factor in the cemetery’s natural setting or design would clearly be favourable to further reducing risk. These factors should be considered together with the information of Table 6.2 when either creating or expanding cemeteries, creating groundwater or environmental protection zones around cemeteries, or exploiting resources like abstracting groundwater or mining sands in the vicinity of cemeteries. Finally it should be borne in mind that the efficacy and importance of any one factor is variable between bacterial and viral species and individual site (particularly soil) conditions.

Table 6.3 Factors Affecting the Survival of Bacteria and Viruses in Soil

Factor: Soil Type	
bacteria (b)	survival reduced in sandy soils if dry; clay textured soils retain more b than a sandy loam, soils with high clay or organic contents retain more b with higher survival rates; straining important mechanism in fine sands, silts and clays – but heterogeneous nature of natural soils makes this variable; b size 0.2 – 5 µm and shape affects transport propensity and filtering
viruses (v)	fine textured soils retain v most easily; presence of iron oxides increases adsorption; as clay and usually organic content increases adsorption increases; heterogeneous nature of natural soils makes filtration variable; v size 0.02 –0.25 µm; aerobic conditions reduce v survival
Factor: pH	
bacteria	shorter survival in acid pH 3 – 5 conditions than in neutral or alkaline; pH 7 – 9 generally favourable to survival; pH >10 is likely to be unfavourable
viruses	strongly electronegative at high pH and strongly electropositive in low pH soils – thus increasing acidity increases their adsorption, but decreases survival; increased desorption from soil particles in alkaline conditions
Factor: Moisture Content	
bacteria	dry conditions unfavourable, moist conditions and high rainfall favourable; survival in sandy soils reduced if moisture lost
viruses	longer survival in moist conditions and during high rainfall; presence of moisture favours survival, but some survive at low soil moisture levels
Factor: Salinity or Chemistry	
bacteria	salty water to different extents usually not antagonistic; adsorption increases with increasing ionic strength; increasing Ca concentrations favour b adsorption
viruses	presence of cations aids adsorption, freshwater increase reduces adsorption encourages transmission; increasing Ca and Al concentrations favour v adsorption; as total P increases v survival decreases
Factor: Organic Matter	
bacteria	longer survival and possible regrowth when present; organic coatings aid sorption to mineral phases
viruses	presence usually increases adsorption
Factor: Temperature	
bacteria	survival increased at low temperatures, particularly < 10ºC, very unfavourable to survival at > 40ºC, longer survival in winter than summer; freezing and thawing reduces b populations; elevated temperatures and dry conditions reduces b survival
viruses	significantly increased survival at <6ºC; as temp increases v survival decreases

Table 6.3 continued

Factor: Antagonism from Soil Micro-organisms	
bacteria	increased survival in sterile conditions; decreased survival in natural settings; effects are variable
viruses	not fully understood; probably some – particularly aerobic - antagonism reduces survival, anaerobic organisms no efffect; generally increased survival in sterile soil
Factor: Sunlight	
bacteria	all survival decreased with exposure at surface; in b may be due to drying as well as sunlight effect *per se*
viruses	
Factor: Groundwater Flux or Rainfall	
bacteria	bacterial elution increases with high flow rates; biofilms can create pore blockage; unsaturated phase retards bacterial migration; b readily desorb from surfaces
viruses	high flow rates reduce v adsorption and increase transmission; v near or on surface are eluted with heavy rainfall; movement in unsaturated zone reduced; sorption of v considered to be reversible

(Compiled from Yates and Gerba, 1984, Gerba et al., 1991, Lewis-Jones and Winkler, 1991, Bitton and Harvey, 1992, Armon and Kott, 1994, Lawrence and Hendry, 1996, Pitt, 1996)

On means of resolving the issues discussed here, and in common with other needs for source water protection or well-head protection is to consider the distance that viable organisms of interest may be transmitted in groundwater. The travel-time distance can be broadly calculated from Darcy's Law relationships and the aquifer's effective porosity. The number of studies which have looked at this particular matter is also limited and the results are far from comprehensive; in fact Vbra and Zoporozec (1994) report a literature review by Lewis et al. wherein it was found that where the sources of contamination incidents were proven, they were within 20 days travel distance of the boreholes or springs. From another viewpoint, Rudolfs et al. (1950) point out that *Salmonella typhi* survives 100 days and *E. coli* up to 5 years in soil, however, Gerba et al. (1975) consider that 2 – 3 months is sufficient time in most cases for pathogenic bacterial in soil to be reduced to negligible numbers; other indications of survival times are shown in Table 6.2.

Building a blanket travel-time distance into planning controls may impose severe or unproven burdens; however, it would appear to be a methodology which allows for assessing and implementing local variations rather than the alternative of just having standard set-back distances. In consideration of newer developments in the USA for groundwater protection, this approach is likely to be well regarded and implemented in a number of states' well-head protection areas (Macler and Merkle, 2000). A related discussion by Levy and Ludy (2000) explores some of the uncertainties in the wellhead travel-time approach, including the estimation of effective porosity. The matter for cemetery-drinking water well separation is discussed further in Chapter Seven.

The data from Table 6.2 and details in the various references cited indicate that the 100 day travel-time distance of groundwater is likely to be a relevant and useful general rule to allow for the significant demise of pathogenic bacteria or viruses escaping any cemetery boundary. This is dependent on the initial separation of decomposing remains from any watertable.

One of the important associated issues is the matter of how serious transmitted, or stored and viable, pathogen organisms are. Simply because they are present in soil or groundwater doesn't mean that infections will occur in people who contact or consume them. But this seems to be a highly individual matter, dependent on the person and their health, the organism and the amount of the organism contacted. Viable viruses, for example, can be infectious in doses as low as 1 – 10 units (Gleeson and Gray, 1997, Zelikson, 1994, Lewis-Jones and Winkler, 1991), whereas bacteria usually require greater numbers, but even this is variable. Turnbull (1996a) points out that skin contact anthrax infection is likely to be possible from a single dose of about 10 spores, whereas pulmonary anthrax infection would require in excess of 4100 spores. Viruses are unable to reproduce out of their host so that their numbers decline, whereas bacteria can prosper in some circumstances.

Validation of Bacterial Travel Distances – This Study

The data of this Study was examined to ascertain whether it could be used to validate the understanding of the sub-surface distribution of bacterial decomposition products. All the In-cemetery wells which recorded any sample containing indicator bacteria were collated. In order to enhance the relevance of the analysis and eliminate chance or fortuitous recoveries some filtering was applied to this new data.

Initially, any well that only recorded one detect of any indicator bacteria within all its samples was eliminated; thus each well in the population now had a record of 2 or more samples hosting indicator bacteria. The resultant pattern of wells was very diverse with the likelihood that results with low relevance were still included because they only reported a result for “Total Coliforms”. Such a measurement is not necessarily an indicator of enteric bacteria (see Chapter Four for discussion of this issue and Gleeson and Gray, 1997).

A second filter was applied: only wells that returned samples wherein two indicator bacterial analytes were recorded in a sample were retained for analysis. Now each well in the sample population was regarded as likely to have detected bacteria from the decomposition processes on the interred remains. Only 19 wells met the criteria, out of an original 33 wherein there had been any samples with the bacterial analytes. Those original 33 wells had hosted a total of 43 samples.

Given the considerations discussed in the previous section, the bacterial decomposition products are most likely to have arisen from remains that were in the near term of their disposal – probably 0 to 3 years; see also Table 6.5. The difficulty now arises as to how to assign these results to processes going on in the cemetery. The issue of which interment gives rise to the detection result cannot be determined from the methodology of this Study: this is the same argument as treating the cemetery site as a ‘black box’ (discussed elsewhere).

A grouping variable (QSS_3, Quantity Surveying Score 0-3 years) – developed for modelling decomposition products might be used; the development of this score is discussed in a later section. The QSS_3 sums the contribution of recent, relevant interments in the vicinity of each of the sampled wells; it is plotted against the 19 wells previously identified (Figure 6.1).

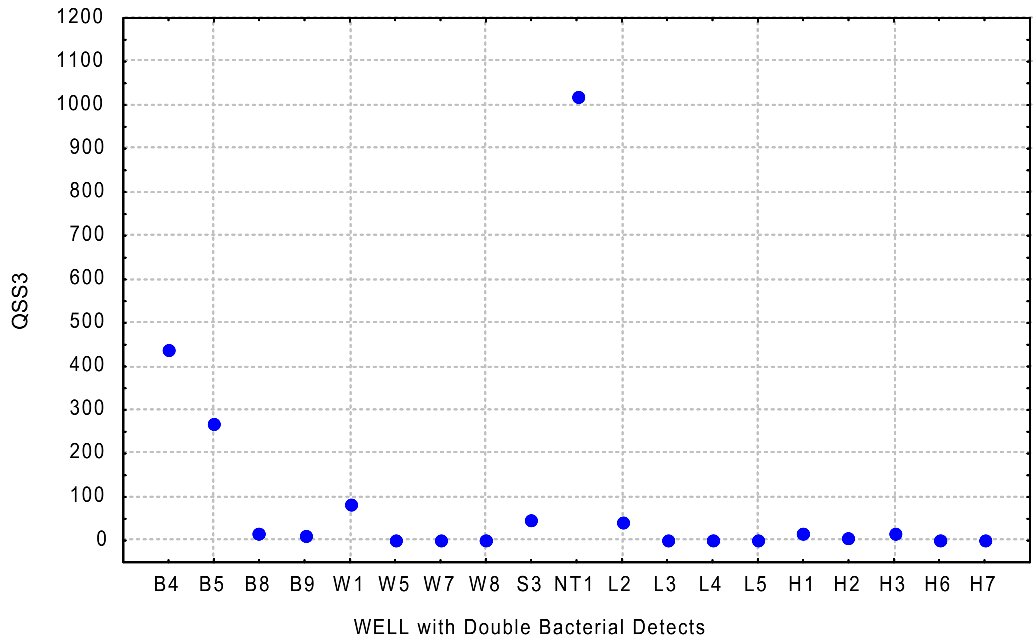


Figure 6.1 Bacteria Detection Related to QSS_3
All Acceptable In-Cemetery Wells

An analysis of the results (Figure 6.1) indicates that there are no significant patterns to the distributions of indicator bacteria in the cemeteries. This is a result wholly consistent with previous analyses in Chapter Five that characterised the nature of cemetery groundwaters. Within the results, there are only two sites – BOT and HEL, where the interred remains were into the unsaturated zone of an aquifer, and hence are sandy soils; whereas, WOR and LAU results are for clayey soils.

The NEW well (NT1) intercepts water at the fill-natural interface which is very close to the grave invert level. In this case the result may reflect inadequate attenuation before the decomposition products reach a groundwater pathway. However, the nearby well NT2 did not show the same pattern. Unfortunately the data are inadequate for determining travel-time patterns.

MERCURY FROM DENTAL AMALGAM

During the course of this Study a targeted effort was made to assess groundwater samples for their mercury content. The chemical analysis of dissolved mercury, particularly since concentrations are usually very small, requires careful techniques and QA support; samples are generally recovered in dedicated containers (see Chapter Four). It was considered that the cemeteries are likely to be repositories of increased mercury – a geochemical anomaly – because of the widespread use of this metal in dental amalgam for repair of dental carries. The sample data are summarised in Table 6.4.

Various historical sources report dental amalgam as known to the Chinese since the 7th Century where it was in use as a silver-mercury paste. It's widespread use, in clinical dentistry in England, France and then the USA started in the 1800s. The oldest cemetery in this Study (HEL) has been operational for 121 years, so that the metal is likely to have been present since the earliest interments.

Jonasson and Boyle (1972) have discussed the primary geochemical factors relating to the mobilisation or movement attenuation of mercury in soils and groundwater. The highest Hg concentrations occur in acidic soils and groundwaters; increased levels of bicarbonate and trace amounts of Cl favour solution and concentration of the metal, although not all researchers have agreed on the role of Cl (Karasik et al, 1965). Mercury ions, in either valence state +1 or +2, adsorb strongly onto surfaces of particluate materials at pH 4 – 7, and further as pH increases the adsorption to sediments and other surfaces appears to increase (Jonasson, 1972). Hg can move as vapour and ions at considerable depth through soil, snow and ice; whilst ionic complexes move by capillary movement and are also readily taken up by plants (Jonasson and Boyle, 1972, Rasmussen, 1995).

Table 6.4 Summary of all Mercury Data

(Separated by Cemetery, Hydrogeological Zone and Role)

Part (A) VADOSE ZONE values in mg/L

Well	Well Role*	No samples total	> dl ^	Min	Max	Median	Mean
W4	WVB	5	0	n>dl ^^	n>dl	n/a ^^	n/a
W1	WV	4	0	n>dl	n>dl	n/a	n/a
W2	WV	6	0	n>dl	n>dl	n/a	n/a
W3	WV	4	0	n>dl	n>dl	n/a	n/a
W5	WV	5	1	0.00050	0.00050	0.00050	0.00050
W6	WV	6	0	n>dl	n>dl	n/a	n/a
W7	WV	6	0	n>dl	n>dl	n/a	n/a
W8	WV	5	0	n>dl	n>dl	n/a	n/a
W9	WVE	4	0	n>dl	n>dl	n/a	n/a
M2	MV	6	3	0.00011	0.00023	0.00014	0.00016
M3	MV	1	1	0.00075	0.00075	0.00075	0.00075
M5	MV	1	1	0.00014	0.00014	0.00014	0.00014
M6	MV	2	1	0.00026	0.00026	0.00026	0.00026
M7	MV	1	0	n>dl	n>dl	n/a	n/a
S1	SV	3	0	n>dl	n>dl	n/a	n/a
S2	SV	4	0	n>dl	n>dl	n/a	n/a
S3	SV	3	0	n>dl	n>dl	n/a	n/a
S4	SV	5	2	0.00005	0.00006	0.00006	0.00006
S5	SV	4	0	n>dl	n>dl	n/a	n/a
NT1	NV	6	1	0.00008	0.00008	0.00008	0.00008
NT2	NV	5	2	0.00005	0.00006	0.00006	0.00006
NT4	NV	4	3	0.00005	0.00056	0.00023	0.00028
L2	LV	4	2	0.00010	0.00100	0.00014	0.00041
L3	LV	7	3	0.00018	0.00400	0.00050	0.00156
L4	LV	6	1	0.00009	0.00009	0.00009	0.00009
L5	LV	4	2	0.00005	0.00050	0.00028	0.00028
L6	LV	4	1	0.00005	0.00005	0.00005	0.00005
L7	LV	5	2	0.00009	0.00150	0.00080	0.00080
L13	LV	2	0	n>dl	n>dl	n/a	n/a
L15	LVE	1	0	n>dl	n>dl	n/a	n/a
L16	LVE	1	0	n>dl	n>dl	n/a	n/a
C7	CV	3	2	0.00020	0.00060	0.00040	0.00040
C8	CV	3	1	0.00010	0.00010	0.00010	0.00010

Notes:
* Well Role: site code letter plus V = vadose zone, S = saturated zone,
U = underlying aquifer, B = background well, E = boundary well (or a well at the lowest-most hydraulic position)
^ Number of samples greater than detection limit (dl)
^^ n>dl no samples with values greater than the detection limit
n/a not applicable

Table 6.4 continued

Part (B) SATURATED ZONE values in mg/L

Well	Well Role*	No samples total	> dl ^	Min	Max	Median	Mean
B1	BSB	5	1	0.00050	0.00050	0.00050	0.00050
B11	BSB	2	0	n>dl ^^	n>dl	n/a ^^	n/a
B12	BSB	1	0	n>dl	n>dl	n/a	n/a
B2	BS	1	0	n>dl	n>dl	n/a	n/a
B3	BS	6	0	n>dl	n>dl	n/a	n/a
B4	BS	5	0	n>dl	n>dl	n/a	n/a
B5	BS	5	0	n>dl	n>dl	n/a	n/a
B6	BS	3	0	n>dl	n>dl	n/a	n/a
B7	BS	6	0	n>dl	n>dl	n/a	n/a
B8	BS	6	0	n>dl	n>dl	n/a	n/a
B9	BSE	7	0	n>dl	n>dl	n/a	n/a
N1	NSB	5	3	0.00006	0.00017	0.00007	0.00010
N2	NSB	5	2	0.00015	0.00054	0.00035	0.00035
N3	NSBE	2	2	0.00006	0.00008	0.00007	0.00007
N7	NSE	5	3	0.00012	0.00050	0.00014	0.00025
N8	NSE	5	4	0.00005	0.00037	0.00025	0.00023
H6	HSB	5	2	0.00010	0.00090	0.00050	0.00050
H7	HSB	5	1	0.00480	0.00480	0.00480	0.00480
H1	HSE	5	4	0.00010	0.08800	0.00030	0.02218
H2	HS	4	1	0.00060	0.00060	0.00060	0.00060
H3	HS	6	2	0.00020	0.00110	0.00065	0.00065
H4	HS	2	1	0.00010	0.00010	0.00010	0.00010
H5	HS	5	2	0.00010	0.00010	0.00010	0.00010
G1	GSB	5	0	n>dl	n>dl	n/a	n/a
G2	GSB	2	0	n>dl	n>dl	n/a	n/a
G3	GSE	1	0	n>dl	n>dl	n/a	n/a
G4	GSE	4	0	n>dl	n>dl	n/a	n/a
G5	GSE	5	0	n>dl	n>dl	n/a	n/a
G6	GS	5	0	n>dl	n>dl	n/a	n/a
G7	GS	5	0	n>dl	n>dl	n/a	n/a
G8	GSE	6	0	n>dl	n>dl	n/a	n/a
S12	SSUB	3	1	0.00008	0.00010	0.00009	0.00009
S8	SSU	6	1	0.00008	0.00008	0.00008	0.00008
S9	SSUE	4	1	0.00009	0.00009	0.00009	0.00009
S10	SSUE	3	1	0.00014	0.00014	0.00014	0.00014
C1	CSU	3	0	n>dl	n>dl	n/a	n/a
C2	CSU	3	0	n>dl	n>dl	n/a	n/a
C3	CSU	4	0	n>dl	n>dl	n/a	n/a
C4	CSU	5	4	0.00010	0.00070	0.00040	0.00040
C5	CSU	5	3	0.00010	0.00490	0.00090	0.00197
LP	POND	6	2	0.00021	0.00500	0.00261	0.00261

The presence of increased Hg in the sites was conscientiously sought. The sample returns showed extremely low amounts of the metal present: in the samples of the unsaturated zone only 22% (29 of 130) had measurable Hg, whilst for the saturated zone the figure was 23% (41 of 176) with amounts above minimum detection level. The levels of Hg in the sites' soils were not evaluated.

The data of Table 6.4 are better viewed as box and whisper plots for the hydrogeological zones of each site (Figure 6.2). The diagrams also show reference ANZECC (1992a, 1992b) guideline values for mercury contamination action. In the case of groundwaters this is 1 µg/L, and for soils is 1 mg/kg. In only a few cases do the results return extreme values outside of these guideline values for groundwater and the pond at LAU.

Overall, the levels of mercury found, across all spectra of hydrogeological zonations and contrasting background to In-cemetery values, shows very low amounts. There is no consistent pattern and almost no indication of any accumulations. The notable exceptions are for HEL and LAU, which both have a few extreme values associated with them.

At HEL, the cemetery is an old site closely surrounded by former heavy metal fabrication industry (car manufacture) and associated plants. The possibility of an external influence on the cemetery groundwaters cannot be discounted and is considered to be highly likely. The soils at HEL are slightly alkaline and favour retention of the metal rather than its disbursement. The site is out of character to its general surroundings, and is known to have a watertable that seems to change its direction of gradient (see Appendix I) it is possible that the cemetery has acted as a sink in this area.

In the case of LAU, the site sits atop a hill and comprises much native bushland. It is not associated with industry but is associated with Tertiary sediments adjacent to plutonic features. It seems more than likely that any higher mercury results here are associated with the natural sediments, although this can't be verified from the present sampling. Further background water samples and soil analyses would be required.

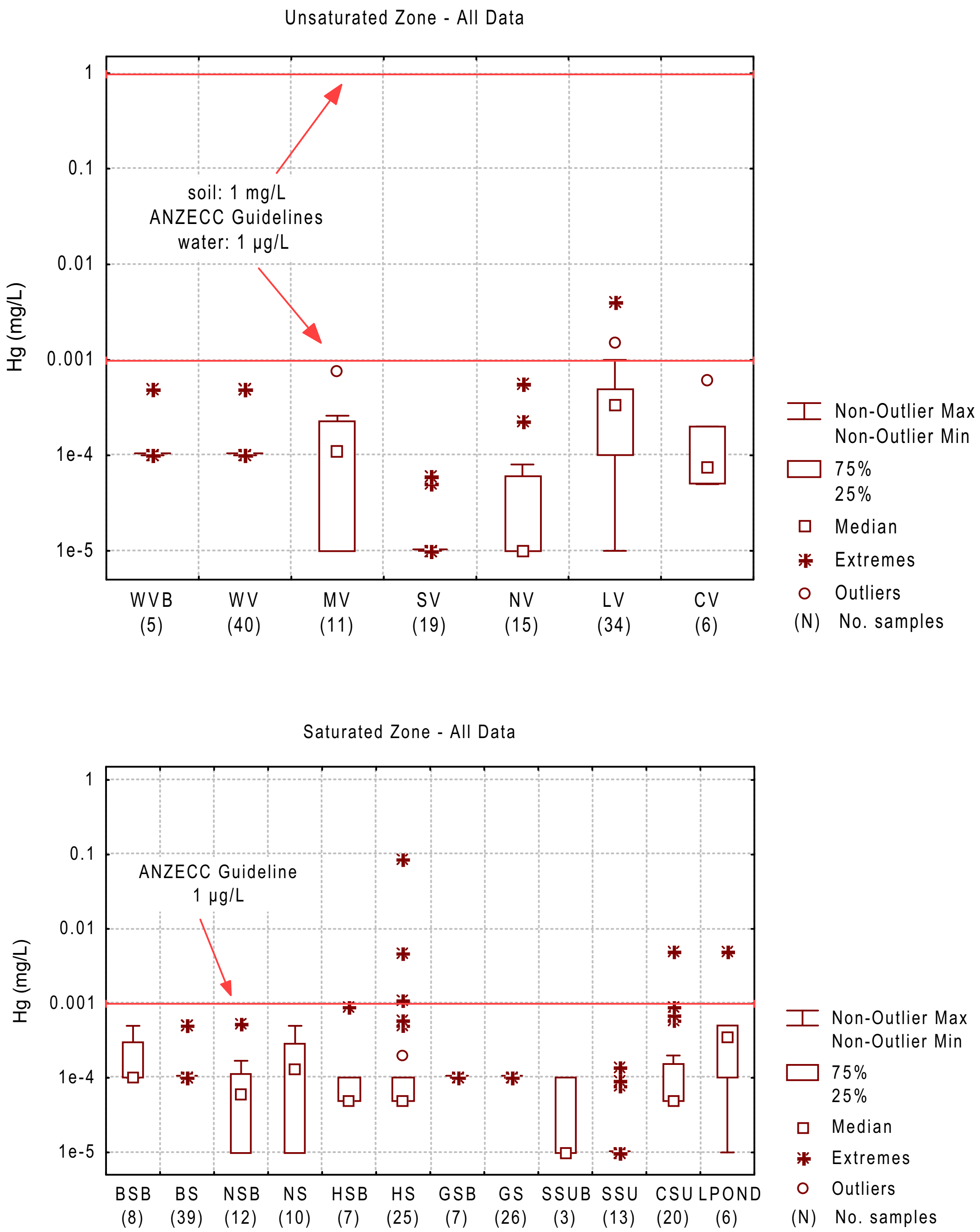


Figure 6.2 Mercury in Cemetery Groundwaters

(All acceptable data plotted by hydrogeological zones and categories:
sites identified by key letters - B, W, M, S, N, L, C, H, G;
hydrogeological zones as - vadose V, saturated S;
sampling site categorisation as – background B, underlying aquifer U)

The occurrence of some elevated mercury readings in the pond, which collects in-cemetery runoff, is supportive of this idea.

A non-parametric Correlation Analysis (Kendall *tau*) was re-run to further evaluate the effects of pH, TOC, SO_4, Cl and Br on the data for Hg. The data were separated by hydrogeological zone and then as to whether the site soils were acidic or alkaline. The analysis was repeated for matching against known soil chemistry as pH or CEC. There are no significant correlations between these analytes.

No special role for mercury could be established, it certainly isn't a pollutant of concern in any of the cemetery groundwaters in this Study. A future direction might be to examine the chemistry of the soils to ascertain whether Hg is accumulating.

MODELLING CONSIDERATIONS

In concert with common evaluation techniques in hydrogeology, it may be considered worthwhile to model the influence of the cemetery on the hydrogeological setting or on the environment, or upon some other relevant planning compartment or concept. This technique is certainly common practice in the evaluation of contaminated sites or landfills. Since this Study portrays the cemetery as a special kind of landfill - a conceptual model (Figure 6.3) first defined by Dent and Knight (1998), it might be argued that the next step of preparing a quantitative model is a completely reasonable approach.

However, this is not the case for cemeteries. Cemeteries have very unique characteristics when contrasted to landfills or other kinds of land-use. They can be visualised on an overall basis as a 'black box' – a lumped or composite site, possibly containing several hundred thousand interments in a well defined area of tens of hectares, which would make them a recognisable point source of contamination. On the other hand, at a micro level, they can be conceived of as so many individual graves; each is its own point source. The second approach is quite unworkable conceptually as explained below.

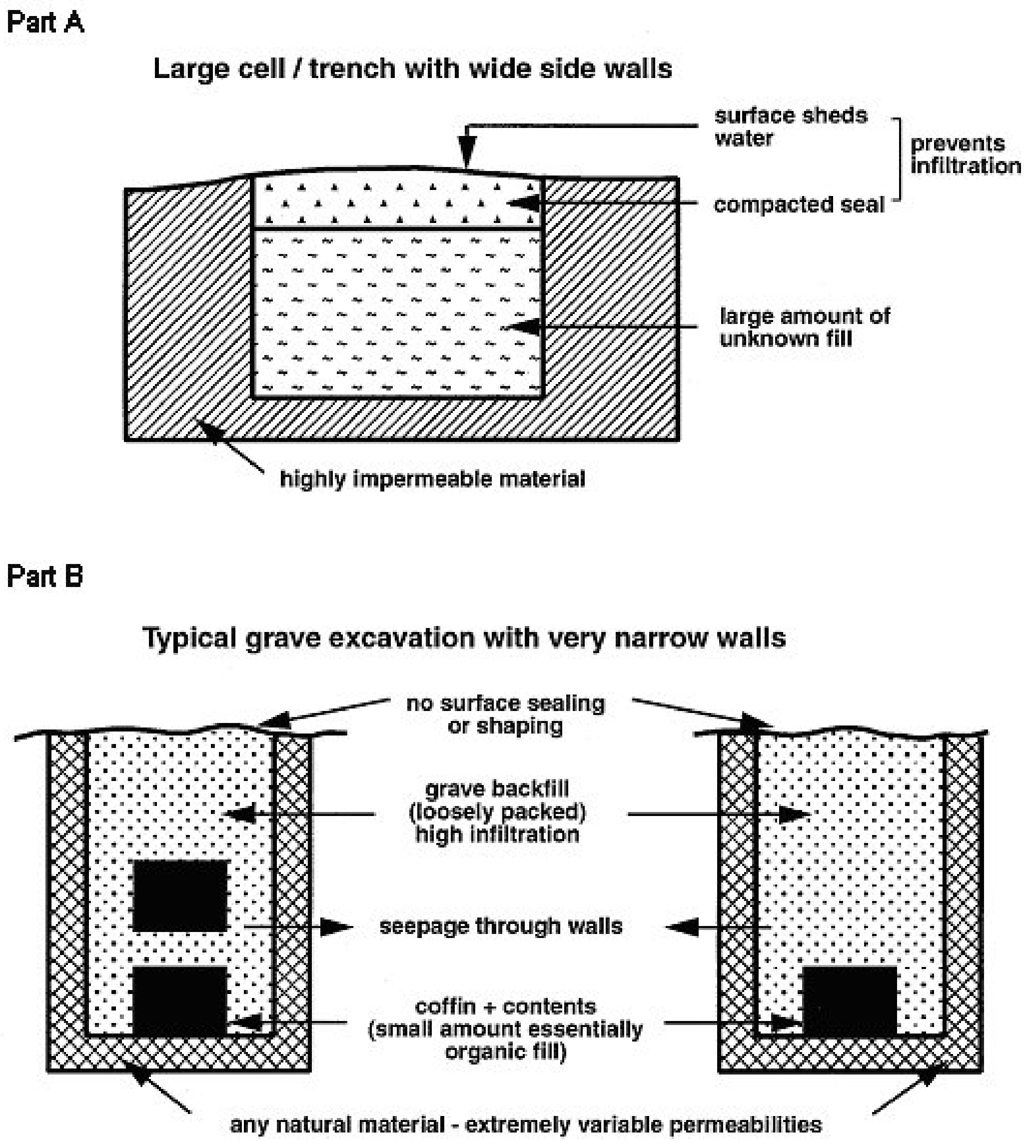


Figure 6.3 Diagrammatic Representation of the Comparison of Landfill Cells and Cemeteries. Part A – Idealised Landfill Cell, Part B – Typical Grave Completion

Small amounts of remains (see Chapter One and Figure 1.1) are interred at different times, at different levels and at different places in the cemetery. The remains themselves are also fundamentally different – different:- age, size, sex, build, amount of fat, body chemistry in that it may be different due to diet or hereditary factors, embalmed/preserved state (including absorbed antibiotics), and in different degrees of aerobic decomposition, they may also be partially dissected. In addition, the wide variances in elemental compositions (see Chapter Two) have an effect, as well as ratios like: females to males, children to adults.

The remains are treated differently:- they may be naked or clothed, partially clothed, clothed in wool, cotton or plastic; they may be in a body-bag; they may be embalmed, and when done – to different degrees. The coffin may be plastic- or metal- or un-lined; it may have cotton, plastic or other fabrics atop the liner; it may include saw-dust, shredded paper or absorbent fibre. The coffin may be made of wooden planks of pine or hardwoods, or of particleboard, fibreboard or cardboard.

The percolating groundwaters react with the remains and various materials directly associated with them in different ways and at different rates. The reactions in turn depend upon the amount of moisture, oxygen, carbon dioxide, methane and putrefactive gases present; the chemical nature of the soil, the hydrochemistry of any influent groundwater, and the presence of:- bacteria, necro-leachate, reactive funereal artefacts, the coffin construction materials and sealing, and the temperature.

Furthermore, in some selected cemetery areas it is more than usual that the interred have certain repetitious characteristics, for example:- all buried in a sequential time-span, all buried fully clothed, all in simple pine coffins, all non-coffinated, all in concrete vaults, all partially embalmed – as may happen for distinct ethnic, religious or cultural groups. After these aspects are considered, then in addition, the remains generally exhibit the very large range of variable characteristics previously noted.

Without extremely detailed knowledge of the relevant variables for the interred close to any sampling point, then it’s likely that an averaging effect must be considered for any compartmentalised examination of the hydrogeochemistry of the sampled groundwaters. Only in-soil interments can be properly considered because vaults and crypts introduce another considerable set of environmental variables, and remove soil- and many groundwater-related interactions.

Added to this is a plethora of natural or cemetery-induced or off-site induced characteristics of the groundwaters themselves. The factors of the underlying regional aquifer characteristics, or the nature of the soils in whatever way that they may be relevant, cannot be entirely discounted. The sampled waters do not necessarily reflect just the influences of the cemetery and the nearby interments. This is quite different to a well-established landfill cell site. In that case the landfill is sited so as to specifically exclude regional or localised groundwater influences. The majority of cemeteries utilise natural ground, which is frequently un-prepared, un-investigated and improperly understood. Only in those circumstances where the cemetery is so conceived and built that these natural influences are largely excluded, or local knowledge can satisfactorily exclude those influences, can the sampling be regarded as reflecting only necro-leachate.

Thus, when attempting to examine the chemical effects of the interred remains on any one sample location or set of samples, there are many effects to be taken into account; whatismore, the presence or absence of many of these is also unknown. This means that modelling of cemetery hydrogeochemistry at a local scale is, for the general case, an extremely difficult task, and is unreliable in almost all cases of an individual grave. Even when considering the whole cemetery – the 'black box' – averaging concepts can be misleading.

The general issue of modelling the behaviour of cemeteries overall needs to take into account both the inorganic and organic hydrogeochemistry, and microbiological attributes. Being so diverse in input, the cemetery and any risks it imposes may be better treated by uncertainty/risk analysis methods than by some stochastic methodology. The process is predicted to be very complicated, with many variables, and in the end of probably limited value; see for further discussion a paper relating to a different in landfills by Abbaspour et al. (1998).

Quantity Surveying Evaluation

With this context and an acute awareness of deriving ill-founded conclusions in *mind, the Researcher undertook the measurement of quantity data with respect to sampling points. Not all sampling points could be represented because:- they were either background sites; influenced by other known factors for example a shoestring aquifer in CEN or the floodplain of NEW; established for some particular purpose like attenuation studies at WOR or LAU; or, too broadly influenced by a large area of interments to be useful, like at WOR, SPR, LAU or BOT.*

As outlined in Chapter Four a zone of likely influence of the interred remains on samples was established where possible and the numbers of interments in these zones counted. The data were assembled against year of interment and are tabulated for each of the sites (Appendices B-J). Many graves are no longer effectively marked (or never were so) and this has a significant effect on the counting. If a date of interment could not be established the count was assigned to the "Unknown" category. The older the cemetery or interments, the greater the proportion of "Unknown" values in the total age/interment distribution.

To reduce the spread-out data to a meaningful state for comparative study, the age distribution was given various ratings relative to a perceived amount of body decomposition likely. *Length of interment* was the *only* variable weighted. The weighting scale used (Table 6.5) has been developed from considerations of international contextual reporting on decomposition rates (Chapter Three), other literature (Chapter Seven), knowledge of the decomposition of pigs in soils and the formation of adipocere (Forbes, pers. comm. 2002, and Forbes et al., 2002) and personal information gathered by the Researcher. However, it is at best somewhat unrefined and in the light of the preceding discussion must be viewed as an indicative guide only.

Even within the sampling period of this Study there are further variations in that the length of time interred has increased over the period of the Study: for simplification a 1998 sampling year has been assumed for all samples. Except for the period 1995 – 1998, the surveying did not count to an accuracy of 1 year but generally worked in 5 – 10 year classes. Again as a guide and a simplification, the weighting (Table 6.5) most applicable to the majority of the data class was applied.

Table 6.5 Weighting Scale for Interment Quantities Analysis
(for use with in-soil interments only)

Years of Interment	Representative relevance to state of remains	Weighting
<1	Body fluids escape remains but may be substantially trapped in coffin or taken-up in surroundings or fabrics - not leached far; some adipocere may form	2
1 - 3	Substantial decomposition, body fluids and fluids from decomposed tissue leached from the grave; most soft tissue now decomposed; adipocere if formed begins to inhibit decomposition	5
4 - 10	Completion of soft-tissue decomposition and mobilisation into grave surroundings; leaching has been substantial; adipocere may inhibit further decomposition	7
11 - 30	Complete skeletonisation most likely, skeleton considerably leached; bone organic fraction mostly removed; adipocere may start to breakdown	2
31 - 70	Skeletons substantially leached away by chemical weathering processes	1.5
>70	Inorganic bone fragments likely; rare cases of minor tissue remnants	1
>120?	Of very minor consequence	0.1
Unknown	Use an average – choose the median interment length from known data and apply that weighting to all the number recorded	

Analysis of Quantity Surveying Data

By multiplying together the number of age-classified interments and the weighting number, and then summing the subsets, a Quantity Surveying Score (QSS) was developed for each well considered. The QSS was then available for statistical analysis using the STATISTICA Ver 5.5 (StatSoft, 2000) computer software (see Chapter Five for further explanation of the computer statistical analyses).
Initially all applicable groundwater data (Appendix L) was analysed by graphical means. 50 variables (including all biologically related ones) were plotted against QSS in scatterplots and examined for patterns. These variables included the Factor score developed for analyses in Outcomes 1 – 3 in Chapter Five. The resultant was an indication of possibly correlated (significant) variables, subdivided by

hydrogeological zone: 16 variables overall for the vadose zone, and, 22 variables overall for the saturated zone.

Setting QSS as the dependant variable, a Multiple Linear Regression Analysis (Helsel and Hirsch, 1992, and StatSoft, 1995) was then performed on the data in respect of the significant variables. Although this kind of analysis does not have a separate form of treatment for non-parametric data, it was useful for eliciting the most important predictors of QSS performance from a simple set of numbers and conditions. This analysis was done in two passes; firstly with all significant variables which highlighted the key variables from the set, and secondly, the same data with all outliers eliminated from the key variables following an analysis of residuals.

Some further caution is needed in the interpretation of the results for these sample populations, that is, $N < 100$. With lower sample populations Regression Analysis estimates are unstable, and outlier values also exert a greater degree of influence (StatSoft, 1995). The results are presented in Table 6.6 which lists the top three or four predictors for each analytical category and stage.

Many of the correlated variables showed some degree of linearity so that the previous analysis was repeated in order to account for the use of non-parametric results and to attempt to refine the consideration of the near-linear correlates.

Now that the structure and behaviour of the data was generally understood it was further interpreted. All relevant data was analysed by Correlation Analysis and using a Spearman's $R \geq 0.8$, the key correlates were selected and re-assembled in a matrix. The respective matrices for either the vadose or saturated zones were then re-analysed by Multiple Linear Regression. The input data had now been refined to be of the highest quality. The results are given in Table 6.7.

Table 6.6 Results of Multiple Linear Regression Analysis
on Significant Variables for QSS in Main Hydrogeological Settings
(two passes of increasing complexity)

Pass	# Variables	# Cases	Most Important Predictors	p level (1)
Vadose Zone				
1	7	61	Factor 3 (2) Factor 2 Factor 1 EC	0.0007 0.0017 0.0269 0.0586
2	7	58	Factor 3 Factor 2 Factor 1	0.000008 0.00003 0.0027
Saturated Zone				
1	10	67	EC Factor 1 Factor 2 Factor 3	None signif.
2	6	65	Factor 2 EC Factor 1	0.0940 0.1211 0.2940

(1) a p level < 0.05 is regarded as statistically significant (StatSoft, 1995)
(2) Factor 1 is related to the inorganic forms of N; Factor 2 is related to the major cations – Na, Mg, Ca as well as Cl; Factor 3 is related to forms of P

Table 6.7 Repeated Multiple linear Regression Analysis
but Using a Non-parametric Correlated Matrix

Pass	# Variables	# Cases	Most Important Predictors	p level
Vadose Zone				
Correlated Matrix from 16 Variables and 61 Cases With Spearman's R ≥ 0.8 Factor 2, Factor 3, EC, Cl, Na, Mg, Cr				
3	7	61	Cl Na Factor 3	0.0085 0.2426 0.3587
Saturated Zone				
Correlated Matrix from 9 Variables and 68 Cases With Spearman's R ≥ 0.8 Factor 1, Factor 2, Factor 3, EC, Cl, NO_3-N, Tot Inorg. N, PO_4, Tot P				
3	9	68	NO_3-N Tot Inorg N EC	0.0017 0.0020 0.0022

The results from this third analytical run show that the Factors (which are groupings of analytes) are overall of lower importance than individual analytes. The most important predictors elicited from the analysis, however, are still consistent with the framework determined in the first two analytical runs (Table 6.6). The results suggest that the relationships found in the vadose zone are a little more regular than those in the saturated zone; but that overall there is no single conclusion.

The most consistent framework result was that the QSS reflects the composition inherent within Factors 1 and 2 – that is, the inorganic forms of nitrogen and the major cations and anions, within cemetery groundwaters. This outcome is totally consistent with previous analyses of the characterisation of cemetery groundwaters, but is not further enlightening in understanding cemetery function. Furthermore, the results are not always statistically significant ($p > 0.05$) making it difficult to justify any further conclusions.

From the data available and the considerations noted previously, this aspect of cemetery modelling seems unable to be refined. Cemetery decomposition product loadings – as measured by this survey methodology - are variable and inconstant, but are within the general hydrogeochemical range that has been identified for this landuse.

Maximal Loadings – Calculations by Others

In order to make sense of the potential for cemetery pollution some studies have referred to quantities of interred remains and proceeded to attempt calculations of chemical loadings. There are very few known to the Researcher and these are very restricted works which were primarily concerned with the effects of embalming fluids containing arsenic or formaldehyde (methanal). In all the published studies and the following calculations, the interment density is based upon a single level, that is, one body per grave.

It is also worth recording at this point that formaldehyde (methanal) is a gas at normal temperatures; it is a member of the alkanal group formed from the hydroxylation of alkanols (alcohols). It is used as a preservative in solution – up to about 40% in water, as the substance formalin (Hart and Shuetz, 1966). It can be further oxidised to formic (methanoic) acid and carbon dioxide.

The most often cited work in this context is Soo Chan et al. (1992) who derived potential loadings of formaldehyde and nitrogen for an acre of cemetery overlying a small, highly recharged, phreatic aquifer. They used a representative lean body mass of 58.4 kg containing 1.87 kg of nitrogen (as a protein component), decomposing at a steady rate over 10 – 15 years for an interment density of 500 bodies per acre. The nitrogen loading is consistent with the data in Chapter Two for body composition, however, the representative body mass is too low – 70 kg is more acceptable; and the interment density seems very conservative. Based on Australian experience and the model presented in Figure 1.1, wherein a typical grave space is 2.64 m^2; then an interment density of 1000 – 1200 per acre – or say 2500 per ha allowing for a path and road space allowance of about 3000 m^2 per ha, would be more likely.

In the work by Soo Chan et al. (1992) there is some, but limited, acknowledgement that there are difficulties in the theoretical development of decomposition product loading factors; however, their work seems to be too simplified from a hydrogeological perspective. For instance, there is a conceptual difficulty with the method of aquifer recharge in relation to the size of the aquifer (unspecified) and the proportion of the aquifer occupied by the cemetery (unspecified). Only the recharge directly through the cemetery is consequential in moving the freed-up decomposition products, and groundwaters upgradient of the cemetery are not affected by the incorporation of these products. Immediate incorporation of decomposition products even on an annualized presentation rate to the percolating waters is highly unlikely, and of course the intervening soil layer usually provides some adsorption and control. The situation for the product formaldehyde (methanal) is even more complicated since it needs to be assumed that the product will undergo fairly rapid decay due to the influence of soil and/or groundwater bacteria. The in-soil decay rates and intermediate decay products of formaldehyde are not yet fully understood. A re-working of their data (Soo Chan et al., 1992) suggests, that for their model, the potential loadings should be higher than they specify. The final outcome of their considerations and data was that actual measured results were well below any theoretical loading predicted.

In a discussion by Williams and Konefes (1992), the potential amount of arsenic interred with remains for a theoretical cemetery is considered. Using a working value of 6 oz (about 170 g) As per body, then over 30 years of burials of about 1000 bodies (total) x 6 oz = 380 lb (about 170 kg) accumulates in the cemetery. There is no doubt that such a phenomenon would constitute a geochemical anomaly; but these figures are too bald and are not accompanied by specification of interment density, soil density or any idea of typical background soil As values. The amount of interred As per body could also be quite variable.

If the model from this Study (Figure 1.1) is applied to the Williams and Konefes (1992) data, and using an interment density of 2500 per ha (from previous), then 170 kg of As is released into 1000/2500 ha in a grave soil environment of 5.54 m^3 at 2000 kg/m^3 soil density. For the individual grave this makes an As loading of 170 g/ 5.54 m^3 (30.7 g/m^3) or 170 g/ 11080 kg soil (15.3 mg/kg). However, on a cemetery-wide basis (the 'black box') this implies loadings of: 425 kg/ha, 10.2 mg/kg of grave soil equivalents.

Reimann and Caritat (1998) provide some limited data on global As soil values. They estimate a global median of 5 mg/kg but also list data from European and Canadian soils (tilled agricultural soils to C horizons) which in total have ranges from <0.5 to 83 mg/kg, with B and C horizons consistently being of higher values. Taylor and Eggleton (2001) cite other summaries for average soil As at between 8 to 11 g/t (mg/kg). The results from the present calculations suggest that the imposed limits of the hypothetical example would be within the typical natural ranges for soils found globally; however, the cemetery considerations are also subject to the variations of amount of As used, number of bodies affected and burial densities.

The problem with As, and with any heavy metal accompanying an interment whether from the body alone or imposed in the situation, is that its mobility in the site's soil and environmental conditions needs to be considered. Then the hydrogeological setting needs to be examined if the element is to be a consideration for affecting groundwater. For example, geochemically, As has an extremely strong affinity for ferric hydroxide (Taylor and Eggleton, 2001); and this may be important in accounting for the wide natural ranges of the element, and doubtlessly will reflect on its behaviour in some cemetery soils. This Study's results (Chapter Five) found little evidence of an impact from interred metals or environmentally concerning elements like As, in the cemeteries.

Wendling (1991) made the statement "Only about 50% of the cemetery surface soil mass is occupied by a body in a casket" in the context of a generalised discussion about the environmental risk imposed by cemeteries. However, this calculation is not further amplified and is quite unclear in meaning. It may refer to the areal distribution of actual coffin space compared to the grave space allocated ($0.855\ m^2/2.64\ m^2 = 32\ \%$ in this Study's model – Figure 1.1) or perhaps to the areal occupation of actual interments per hectare of cemetery – $2.64\ m^2$ x 2500 burials, that is 66% per ha (this Study's model). If on the other hand the figure of 50% relates to grave soil volume, then it is seriously in error. In Australia a typical coffin occupies 10.2% of the excavated grave space (Figure 1.1), and using a larger coffin (casket) and shallower level of interment would only alter this value to within the range of 15% to 25%. Consequently, this work does not aid further understanding of the situation.

van Haaren (1951) undertook a fairly comprehensive, chemically-based modelling of body decomposition and gas interactions in-soil, based on a contribution of 10 kg protein, 5 kg fat and 0.5 kg carbohydrate. Unfortunately van Haaren used the assumption that all body parts will be oxidised in the ground, even though he recognised the occurrence, and hence limitations, of anaerobic conditions. He concluded that under uniform conditions a body could be completely oxidised in a porous sandy soil, when buried at about 2.5 m – to leave a skeleton - in about 2100 days (or about 6 years) and in unfavourable soil conditions in about 12 years. Examples of the decomposition state of remains were given as: 13 years buried – completely skeletonised, and 2.5 years buried – little change (van Haaren 1951).

van Haaren (1951) also concluded that drug treatments in hospital, for example antibiotics, are likely to retard decomposition of cadavers; and noted that only about 35% of the typical churchyard cemetery space was utilised for burials.

In 1995, the Sydney office of AGC Woodward-Clyde Pty. Ltd., consultants, was commissioned to undertake a desk-top assessment of the environmental impact of Rookwood Necropolis (Sydney) which is within the catchment of Haslam's Creek, in relation to studies requested by the NSW EPA. The report prepared (Woodward-Clyde, 1995), includes a limited discussion on potential contaminant loadings to the soils and groundwater. The consultants had the benefit of earlier work by the Researcher in this endeavour.

At the time of modelling, the Rookwood Necropolis hosted about 600,000 interments within 238 ha and had been in operation for 128 years; the current interment rate was about 3000 per year, which at 70 kg each approximated to about 210 tonnes per annum of human organic waste (Woodward-Clyde, 1995). In raw terms, and on a dry weight basis, this was equivalent to a current period (1987 – 1990) loading of 63 tonnes per year, or for all of the operation since its commencement, to about 351 kg per ha per year. The consultants then concluded that, the interment process of a small amount of waste per cell (sic), where these are the point sources of contaminant loadings and are spread over a large area, are at a much lower density of mass loading compared to the situation in a landfill (Woodward-Clyde, 1995).

Environment Agency (1999) published "Draft Guidance" in respect of the pollution from cemeteries. Within that report is a section which assesses loadings of inorganic nitrogen and Cl in two different lawn, and one woodland, cemetery. The models are developed using standardised body decomposition figures based on Forbes (1987), and standardised infiltration rates for three different groundcovers, viz. grass, shrubs and trees, and chippings; the latter is taken to mean diced hard vegetation (mulch or bark) or wood chips. The author of that report (C.P.Young, Principal Hydrogeologist employed by WRC plc, UK) had the advantage of this Researcher's work before preparing his models and has used similar grave size and volume calculations to the present. Young's evaluation of similar parts of the present model (Figure 1.1) yielded results concurring with those in this Study.

In the three models evaluated, Environment Agency (1999) have attempted to show the maximum loadings and groundwater concentrations developed from the regular decay (50% reduction steps on remainders) of single corpses over a 10 year period. These were then extrapolated to representative loadings for a small cemetery (10 interments per year), municipal cemetery (350 interments per year) and a woodland burial site (30 interments per year). The calculations include a number of assumptions about regularity of decay rate, the conversion of 75% of all available N to NH4 and its immediate percolation to groundwater: the reporting of concentrations has a minor error in that it should be labelled NH4-N, not simply "NH4". Individual graves are assumed to be influenced by an effective seepage area of about 5 times the grave space; there is no consideration of differing soil types; and only single layer interments are assumed. The calculations were repeated for Cl which was assumed to be 100% contributed at the same decay rate. The results are presented in Table 6.8.

Table 6.8 Results of Environment Agency (1999) Modelling.
Potential decomposition loadings of N and Cl over a rolling 10 year period.

Year	Small burial ground 10 interments/yr		Municipal cemetery 350 interments/yr		Woodland cemetery 30 interments/yr	
	N (mg/L)	Cl (mg/L)	N (mg/L)	Cl (mg/L)	N (mg/L)	Cl (mg/L)
1	348	19	331	18	305	16
5	135	7.4	129	7.1	119	6.5
10	69	3.8	66	3.6	61	3.3

Although the modelling is the most advanced known outside the discussions of this Study, it includes a number of necessary simplifications and is unable to properly account for real hydrogeological conditions. In particular, it is assumed that the decomposition products are immediately removed from the grave and are available to groundwater at an even, annualised rate; there is no retardation, no delay before loads are applied to the regional groundwater table, and no losses, for example to nitrogen gas. As the results of various studies show, the assumption of conversion of available N to NH_4 is not correct, some is lost as N_2, other incorporated in organic modules and oxides and other gases. It may be quite reasonable in many cases to accept the uniformity of soil conditions required by the models; but in a real cemetery there is likely to be some heterogeneity in (a) percolation rates at different depths and (b) soil properties over the site area; this introduces for consideration - variable flowpaths, mounding, perched conditions and the like.

It was shown in Chapter Two that the mere presence of carbohydrate in the grave environment for example, and its support for nitrate-reducing and ammonia-oxidising bacteria, is likely to lead to the alteration of forms of inorganic nitrogen leaving the gravesite. Consequently there is likely to be an additional loss of N as nitrogen gas, thus influencing any stoichiometric calculation of nitrogenous oxides or ammonia groundwater products.

It is simply *too* simplistic to scale-up the effects of individual graves to represent the cemetery 'black box'; apart from all the previously noted differences in the interment aspects, cemeteries are, more often than not, disordered in the development over all their space. Diffusion and advection processes must also be given credence as part of any flux calculation. Although the models use a constant infiltration rate for different surface coverings, these rate derivations have been incorrect because there was no allowance for loss due to runoff. Furthermore, cemetery topography is not usually even and the assumption of constant infiltration anyway, is yet another variable.

In a subsequent paper (Young, 1999/2000?), the previous models were re-considered with a view to illustrating the potential of decomposition product loadings with respect to cemetery size. Using the same calculations the potential loadings of N per hectare were considered. Unfortunately, the results (Table 7, Young 1999/2000?) are not properly expressed. It was the author's intent to demonstrate what would be the loadings of N seen in this space with time, if 1 ha of cemetery land was developed from a green/brownfield site. The rate of application of N has been confused with the conceptual application outlined preceding, so that the table of results improperly (and then inaccurately) mixes rates (kg N ha^{-1} yr^{-1}) with number of occurrences of interments producing N. So that apart from stating the obvious - that a municipal cemetery can put more N into the environment (because it buries more bodies per year) the work provides no new insight. The rate of N loading is only different between the standardised cemetery and the woodland burial.

The models have also been applied to the issue of formaldehyde (methanal). Environment Agency (1999) considers the case of 9 L of 2% formalin solution per body being 50% decomposed after burial, giving a potential release of about 0.1 L of formaldehyde (methanal). If this chemical remains in solution, then initial concentrations of up to 40 mg/L are possible, but longer term they are likely to be about 8 mg/L. This modelling, however, makes the major assumption that formaldehyde (methanal) can remain in the soil/groundwater environment unchanged for 10 years or more.

This effort by Environment Agency (1999) is a good reminder of just how difficult the task of postulating cemetery effects is. This modelling is quite a different situation to where relatively large masses of municipal waste, maybe at the rate of 50 -500 tonnes per day, are deposited in one place and compacted there, immediately adjacent to one or many more lots of the same kind with perhaps a thin layer of sandy clay soil separating the lots.

Representative Factor Loadings

The context of the cemetery as a special kind of landfill doesn't work for the single grave entity. A cemetery needs to be considered as a whole identity – a 'black box' – since internally its characteristics, operations and workings are very diverse. Furthermore, there is a great divergence in the way that the interred organic waste of cemeteries interacts with and affects the environment: there is a distinct relationship to the prevailing hydrogeological conditions of the sites, and some of this is to portions of very small area. But conditions of such variability are not sensibly dealt with at a 'micro' level: hence the understanding of the cemetery can only effectively be an overall concept.

There are some instances where a modification of some or all of this approach may be relevant. These are situations where the cemetery ground is relatively uniform over its entirety; for example, on near flat alluvial floodplain or other fluvial/coastal deposits, or uniformly gently sloping land underlain by a constant formation. However, as slopes increase, runoff patterns change, regional groundwater tables change, heterogeneous regolith conditions are more likely, and infiltration rates are altered. Furthermore, increased slopes bring alterations in cemetery road, path and garden layouts, control of surface (and sometimes sub-surface) drainage, and introduce the possibility of highly localised groundwater systems occurring.

Hence, the theme often repeated by the Researcher, and in accordance with some others (see Chapter Eight) that cemetery sites should be properly assessed from a geoscientific perspective. *The variability of hydrogeological conditions brought about by nature is at the essence of why certain aspects of cemetery operations, for example, the off-site migration of pathogenic organisms or decomposition product plumes need to be considered. The matters of cemetery location, operation and environmental interaction, are, for most situations, not clear-cut.*

Likewise, the understanding brought by looking at potential loadings of decomposition products is very limited. Typically these considerations force the modeller to adopt the concept of a constant flux into the groundwater system which is saddled with a large variety of hydrogeological assumptions about the site soils, geomorphology and regolith aspects. In the urban context, the predominant setting for our larger cemeteries, the issues of the surrounding (and sometimes previous) landuse impact heavily on the cemetery sites; any pollutant measurements must therefore be interpretted with this in mind (see for instance discussions about BOT and HEL).

The expected results for decomposition products emerging from cemetery sites are low. This is because their waste loadings are low. Within the cemetery it is certainly possible to conclusively detect the decomposition products in groundwaters and soils, and this has now been done in Brazil (Pacheco 1986, Martins et al. 1991, Matos 2001), Canada (Soo Chan et al., 1992), Germany (Matthes, 1903, Keller, 1966, Schraps, 1972), The Netherlands (van Haaren, 1951, van der Honing et al., 1986), United Kingdom (Environment Agency, 1999, Lelliott, 2001 and possibly Trick, 2000), and the United States of America (Sponberg and Becks, 2000). To measure the products off-site is much more problematic; the low concentrations when mixed with regional groundwater systems are unidentifiable at this stage (see Chapters Five and Eight); attempts in Canada (BEAK, 1992, Soo Chan et al., 1992), Germany (Braun, 1952) and The Netherlands (van Haaren, 1951, van der Honing et al., 1986) have been unsuccessful at this. The phenomenon of decomposition products leaving the cemetery boundary has been demonstrated in this Study for BOT, HEL and GUI, that is cemeteries with more porous, sandy types of soils underlain by phreatic aquifers.

Nonetheless, for the sake of completeness some modelling for the Australian experience has been considered. The original model of this Study – Figure 1.1, has been taken as the basis for a large cemetery in a major capital city which would carry out about 34 interments per week (about 1750 per year). The potential loadings in the allocated grave space have been derived from a consideration of the major decomposition Factor analytes (see Chapter Five) previously derived, together with a consideration of how these are likely to decompose with time – the model used previously (Table 6.5) in the understanding of Quantity – Decomposition loadings. The resultant model, extrapolated over a 20 year timeframe is presented in Table 6.9. Figure 6.4 has been derived from the model values and illustrates the general patterns of decomposition product loadings with time; but without losses as N_2 gas.

To further enhance the understanding of these loading figures – *which from any perspective related to contamination rates, landfill, waste disposal or effluents are small* – then some comparative data for landfills and septic systems (also representing smaller point load sources) are considered. There is now a very large body of literature, primarily dating from the mid 1970s, concerning the composition of typical municipal landfill waste, sewerage farming and infiltration beds, as well as septic system waste disposal in its raw forms and in contaminant plumes. The various forms of waste and disposal systems have been examined from points of view on the effects of system design and engineering function, soil attenuation, aquifer properties, recharge rates, hydrochemistry, isotope dating, characterisation or signature species, loadings, modelling and much more.

If cemeteries are regarded as just one more form of waste disposal in the totality of society functions, then it's certainly not a difficult conceptual step to envisage that the effects of cemeteries, and their decomposition products and their behaviour, will somehow relate to, or emulate parts of, the other waste disposal systems. It's the size of the loadings and potential loadings given the great range of hydrogeological settings, that distinguishes cemeteries. Thus, when the potential loadings are compared to those of landfills or septic systems, say, the values are likely to bear no obvious relationship. A significant difficulty occurs with trying to translate masses (cemetery loadings) into solution values, by flux calculations or in comparing to concentrations of solutions, where they are the typical medium sampled. Perhaps what is more critical, is the relative analyte proportions in the composition of the respective leachates.

Necro-leachate is almost instantly and intimately associated with the grave environment. It is not collected or farmed or controlled; and it is so spread out both spatially and temporally in a typical (or certainly, older) cemetery that it isn't necessarily detectable in any one place. Only recently established, or extensively modified cemeteries, where subsoil drainage is in-place to assist the control of off-site migration of decomposition products, would this collection be seen and examinable: for an example, see the discussions about Argentina in Chapter Three.

Table 6.9 Maximal Loadings Data for Idealised Cemetery
(large cemetery in major Australian city – 1750 interments per year)

Part (A) Model Data

Model aspect	Units	One interment	1750 interments
Total wet, lean body mass (1)	kg	70	122500
Body plus allowance for coffins and artefacts at 15 kg each	kg	85	148750
Volume of grave space consumed if 80% are new interments at 2.1 m invert & 20% are second internments at 0.5 of available volume	m^3	5.54 or 2.77	8725.5
Areal grave space for all interments but - not allowing for roads/paths etc (2)	m^2	2.64	4620
Equivalent mass of soil at 2000 kg/m3 for all including second interments - after allowance of 0.3 m3 per coffin (that is, not soil)	kg	10480	16401000
Human organic waste density in allocated grave space	kg/m^3	15.8	
Total waste disposal density in allocated grave space	kg/m^3	19.2	
Total waste disposal on an areal basis	kg/m^2	32.2	
Minimum landfill compaction results in NSW (3)	kg/m^3	> 1100	

Part (B) Human Body Contributions Relative to Decomposition Status – in g and % of total

Body Part	Nitrogen		Chloride		Sodium		Magnesium		Phosphorus		Sulfur		Strontium	
Total (4)	1800		95.0		100		19.0		500	(1)	140		0.320	(5)
whole blood & urine	161	8.9%	15.0	15.8%	0.4	0.4%	0.2	1.1%	2.0	0.4%	10.0	7.1%	0.000	0.1%
skin	120	6.7%	6.9	7.3%	0.2	0.2%	0.2	0.8%	0.9	0.2%	4.1	2.9%	0.000	0.1%
adipose	120	6.7%	18.0	18.9%	7.6	7.6%	0.3	1.6%	2.4	0.5%	11.0	7.9%	0.000	0.1%
muscle (skeletal)	770	42.8%	22.0	23.2%	21.0	21.0%	5.3	27.9%	32.0	6.4%	67.0	47.9%	0.000	0.1%
cartilage & connective	219	12.2%	11.5	12.1%	25.0	25.0%	n/a	n/a	n/a	n/a	26.6	19.0%	0.003	0.9%
skeleton - bone tissues	300	16.7%	14.0	14.7%	32.0	32.0%	11.0	57.9%	448	89.6%	17.0	12.1%	0.315	98.4%
hair	2.9	0.2%	0.0	0.0%	0.0	0.0%	0.0	0.0%	n/a	n/a	0.9	0.6%	0.000	0.0%
teeth	1.3	0.1%	n/a	n/a	n/a	n/a	0.3	1.7%	4.0	0.8%	n/a	n/a	n/a	n/a
other	106	5.9%	7.6	8.0%	13.8	13.8%	1.7	9.0%	10.8	2.2%	3.4	2.4%	0.001	0.3%

Table 6.9 continued

Part (C) Participation of Body Parts' Chemical Contributions at Differing Decomposition Rates #

Analyte release time	All N		Chlorine		Sodium		Magnesium		All P		All S		Strontium	
	*contrib.	ass. %	contrib.	ass. %	contrib.	ass. %	contrib.	ass. %	contrib.	ass. %	contrib.	ass. %	contrib.	ass. %
<1 year	some	10	some	10	minor	5	minor	5	minor	5	some	10	negligible	0
1 - 3 yr	major	50	major	50	significant	35	significant	35	minor	5	major	45	minor	5
4 - 10 yr	significant	35	significant	37	major	50	major	50	most	77	significant	35	most	75
11 - 30 yr residual ^	minor	5	minor	3	some	10	some	10	some	13	some	10	some	20

The level of participation assigned is based on an interpretation of the a rate at which different body parts are engaged in the decomposition processes – see Table 6.5 for a fuller explanation; for example, most hair, teeth and skeletal bone are last.
* contrib. = contribution assessed; Ass % = assigned percentage of all available decomposition analyte in Reference Man according to the following scheme: minor = <5%, some = about 10 - 20%, significant = about 30 - 40%, major = about 50 - 60%, most > 90%.
^ 30 years represents the time for complete skeletonisation to occur, and weathering of the skeleton to have been well established.

Part (D) Representative Loading Rates Relative to Allocated Grave Space

Aspect	Units	All N	Chlorine	Sodium	Magnesium	All P	All S	Strontium
grave area	g/m^2	681	0.04	0.04	0.01	0.19	0.05	0.00
raw volume	g/m^3	361	19.1	20.1	3.8	100.3	28.1	0.1
soil mass	g/kg	0.19	0.01	0.01	0.002	0.05	0.01	0.00 (5)

Table 6.9 continued

Part (E) 20 Year Loadings in kg (see also Figure 6.4) (6)

year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
all N	315	840	1365	1890	2048	2205	2363	2520	2678	2835	2985	3119	3237	3339	3426	3497	3552	3591	3615	3623
Cl	17	44	72	100	110	120	131	141	151	161	166	170	174	177	180	182	184	185	186	186
Na	9	29	50	70	85	99	114	128	143	158	174	189	202	214	223	231	237	242	244	245
Mg	2	6	9	13	16	19	22	24	27	30	33	36	38	41	42	44	45	46	46	47
all P	44	58	73	88	200	312	424	537	649	761	869	966	1051	1125	1188	1239	1279	1307	1324	1330
all S	25	61	98	135	149	163	178	192	206	221	329	425	511	585	647	698	738	767	784	789
Sr	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.4	0.6	0.6	0.7	0.8	0.9	0.9	1.0	1.0	1.0	1.0

Notes:

(1) All human body data used in these models has been derived for the "Reference Man" (ICRP, 1975), with the exception of P. Forbes (1987) presents newer data for P which is on average 280 g/human less than Reference Man. The values of skeletal muscles, bone and remainder fractions have been adjusted in the latter part of the modelling in accordance with the newer data.
(2) These loadings are based on the allocated space of one grave – without allowance for paths, roads, buffer zones or other infrastructure. Since these matters are highly variable between cemeteries, ultimate spatial loadings – which will be lower, would need to be calculated on a particular basis.
(3) Data from Waste Service NSW (2002) – reported minimum compaction obtained in municipal landfills; this finalised rate is 57 x cemetery disposal rate.
(4) n/a means that some data was not available for Reference Man.
(5) The most minor strontium values are only significant at the 4^{th} or 5^{th} decimal place; real value used in loadings calculations
(6) During the decomposition process some amounts of various elements are lost as gases, for example in CO_2, CH_4, mercaptans, and as N_2 due to denitrification. These amounts are very variable and are not allowed for in this model.

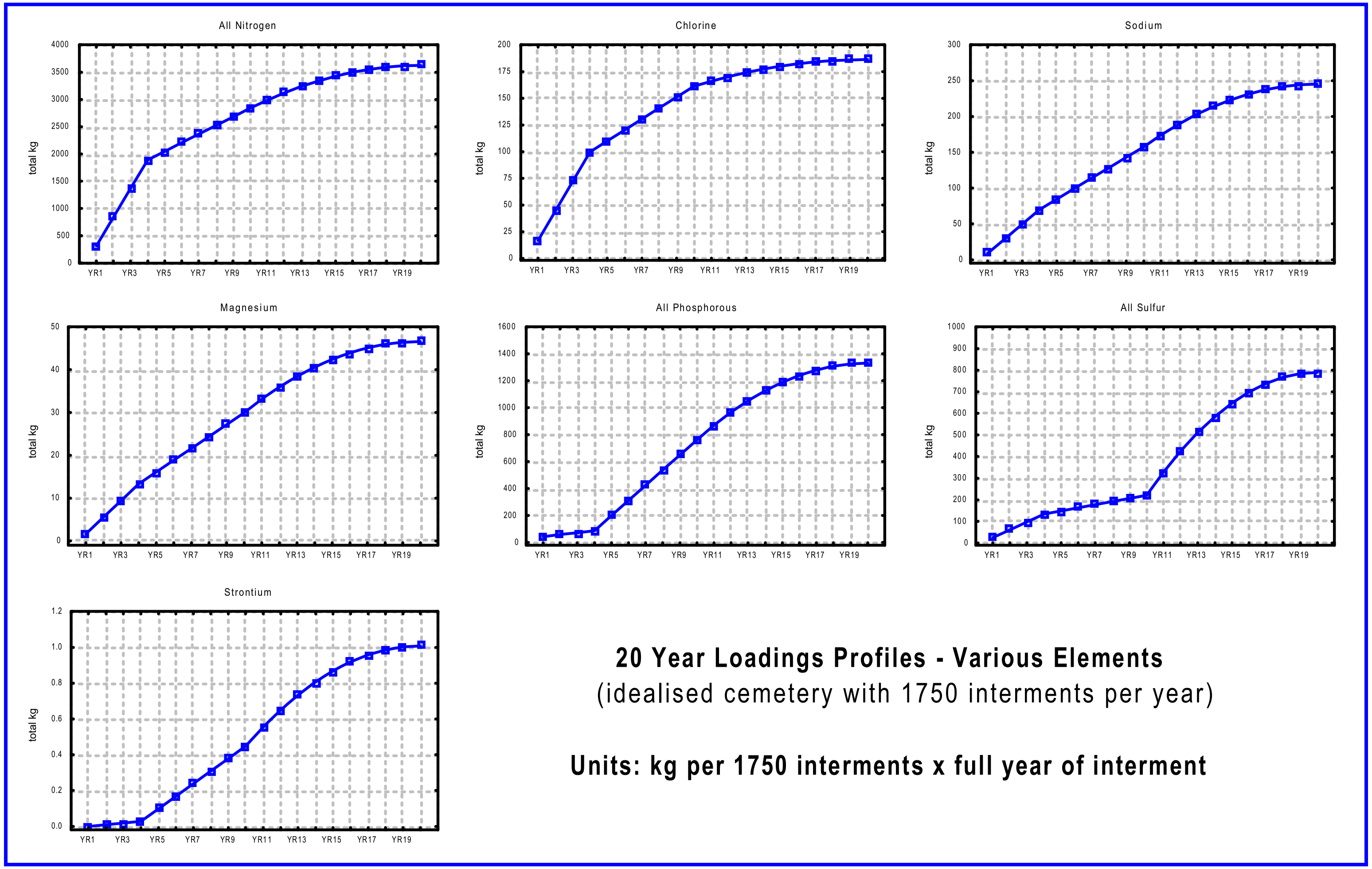


Figure 6.4 Factor-based Maximal Decomposition Product Loadings

It is much more difficult to make sensible comparisons from in-grave decomposition product loadings occurring over time and consisting of some initial fluids, some fluids resulting from the decomposition processes, and then the weathering of solids; all at different times and rates; with the results of clearly identifiable leachate or effluent solutions.

Comparison of vadose zone data with enhancements over background (see later) is perhaps one method by which this could be accomplished; or perhaps the same method for underlying aquifers might be used if the data is known. Primarily, however, the matter of decomposition product movement is all about attenuation in the vadose zone.

The comparison and discussion of studies concerning cemeteries and other waste disposal processes, is further complicated by the great range of sampling methodologies used, the media sampled, the statistical treatment of data and the range of analytes examined. Almost no two studies are alike. The analyses in Chapter Five for cemeteries in relation to regional and other aquifer systems, bear out the assertion that vadose zone data is more useful.

Black Box Comparisons

In an attempt to better understand the waste disposal context, the matter of total analyte presence in the environment can initially be approached from the methodology of considering enhancements of detectable amounts in plumes compared to say background values, or some other aspect.

This methodology treats the cemetery, the landfill, the septic system or effluent field as a 'black box' – the whole of the complex's area would normally be considered, unless a distinct portion can be separated for analysis.

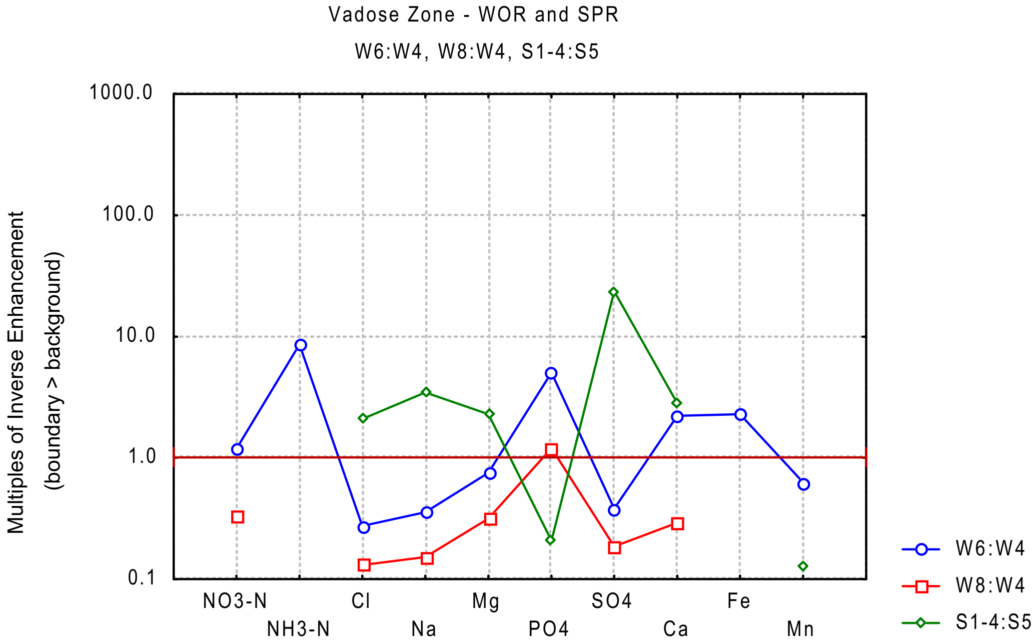
> *This methodology – when used in a general sense such as follows - lacks statistical rigour and it must be borne in mind that this approach is* ***indicative only,*** *when it is not accompanied by detailed site analyses.*

Strictly speaking inter-well comparative data, or off-site data, or data from unknown statistical populations cannot be combined or pitted one against another in detail. The Outcomes of statistical analyses 5, 7 and 8 in Chapter Five, further demonstrate this concern.

Figure 6.5 presents a graphical analysis of broad-brush enhancement studies for selected vadose zone sites at SPR and WOR, saturated zone sites at BOT (using the centrally located background well B1), HEL and GUI, small but young landfill sites in Illinois, USA and data from septic systems in Central Canada. This analysis shows the relative enhancement of end-product features – that is, the vadose zone soil groundwaters or aquifer groundwaters - compared to input leachates or background/upgradient groundwaters. If the 'Multiple of Inverse Enhancement" is less than 1.0, then the end-product groundwater is not as rich, in the analyte being considered, as the input leachate, effluent or waste. The smaller this value the greater the attenuation has been since release; and usually this attenuation has been in the vadose zone.

In the case of municipal landfills, the number of studies which provide comprehensive vadose zone hydrochemical data, is small; see Bagchi (1994) for a brief list of some studies. One of these few that may be considered (Figure 6.5) is Johnson et al. (1981), but even so it is not as useful as desired because the landfills studied were very young, small and the vadose zones were thick – 7 to 10 m of generally fine sandy formations for the Genesco and Crystal Lake Landfills. The data is for solutions but clearly shows the quite rapid attenuation of leachate decomposition products in sandy types of soils. The landfills examined were not properly completed to prevent surface recharge.

Nevertheless, the pattern of inverse enhancement of the landfills (Figure 6.5, Part B) has similarities to those for the cemetery vadose zones (Figure 6.5, Part A). Namely, there is an increase in oxidised inorganic nitrogen products (presented as NO3-N), a decrease in NH3-N, Cl and Na, but relatively greater Mg, PO4, and metals. The sites' and groundwaters' pH is another important variable to consider, however. For this Study, the SPR data compares median values of analytes for all samples from



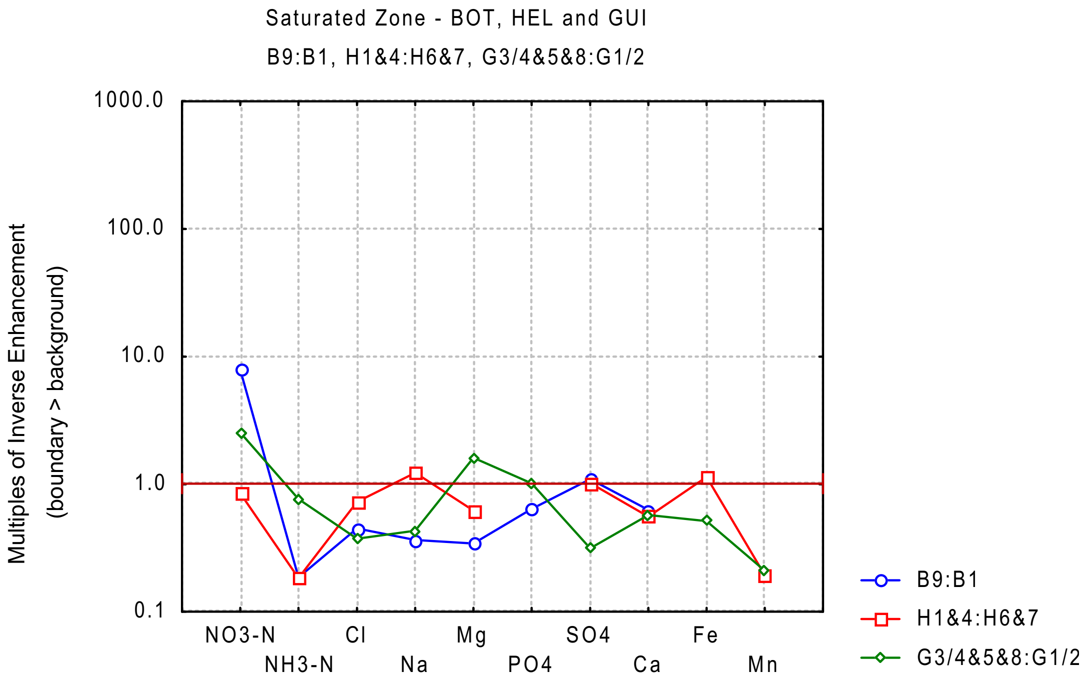
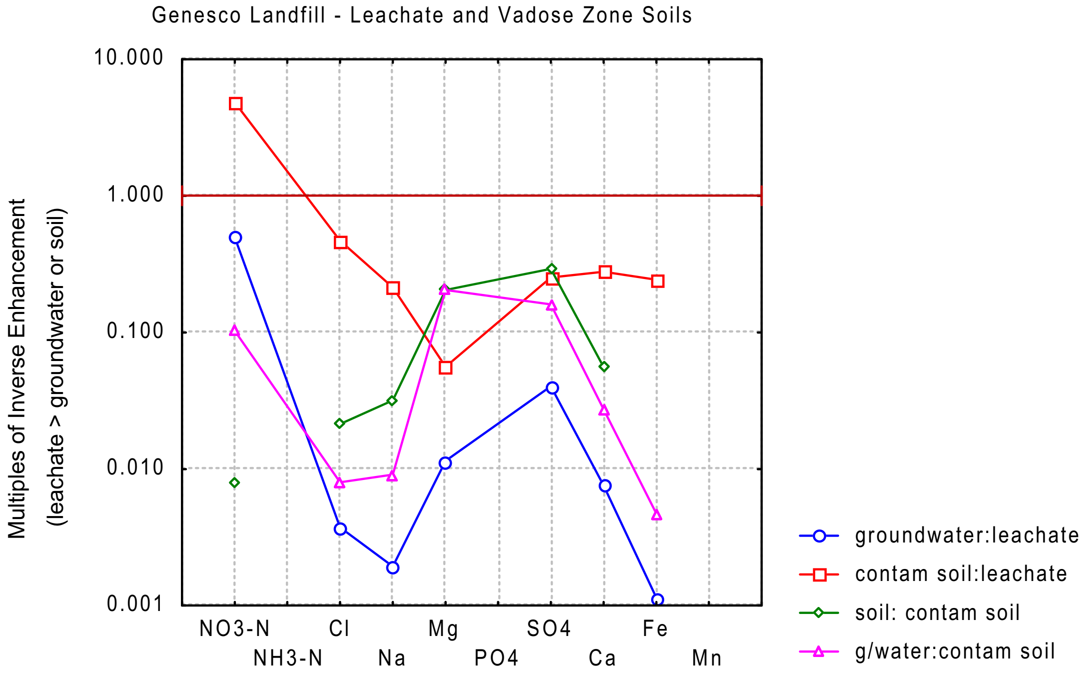


Figure 6.5 Enhancement Concept – Factor-based

Part (A) Cemetery Examples: Boundary > Background wells at BOT, HEL and GUI



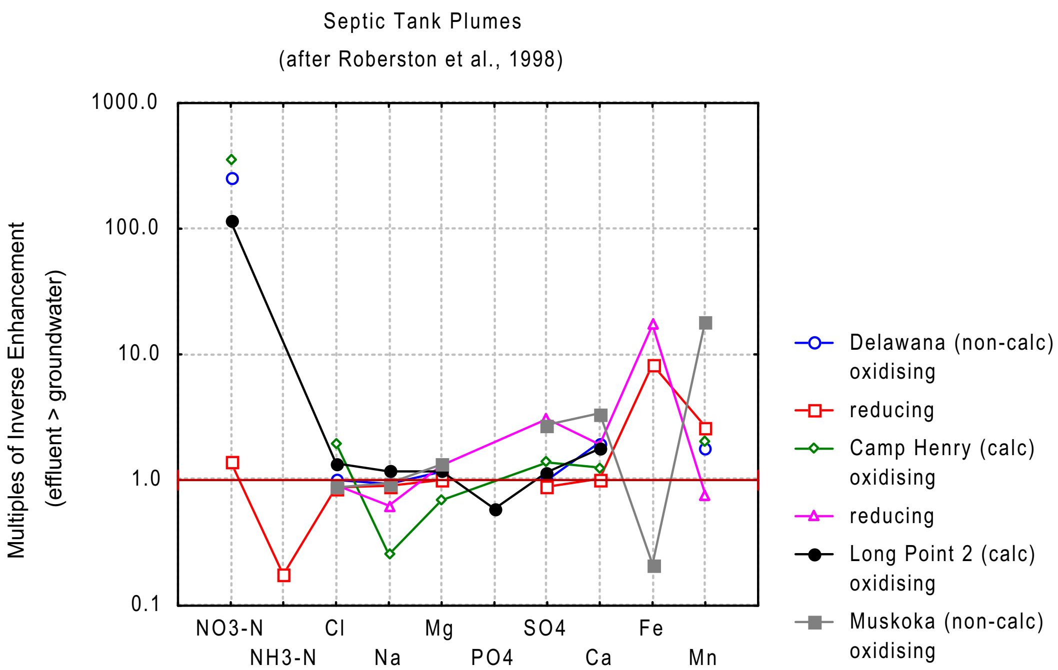


Figure 6.5 continued: Enhancement Concept – Factor-based

Part (B) Landfill and Septic Tank Examples: Leachate > Groundwater at Genesco Landfill (after Johnson et al., 1981) and Central Canada (after Robertson et al., 1998).

wells S1 to S4 to that of the background well S5; whilst the WOR data compares the same type of results for boundary wells W6 and W8 to background well W4.

Table 6.10 Typical Municipal Waste Leachate Concentrations

analyte	data from Bagchi (1994), mg/L	data from Qasim and Chiang (1994), ppm
pH (units)	3.7 – 8.9	
TOC	nd * - 40000	
BOD	nd - 195000	
NO_3-N NO_2- N	nd – 250 nd – 1.46	1.88 (38) #^
Total Kjeldahl N	2 - 3320	
NH_4 - N	nd - 1200	
Cl	2 - 11375	
Na	12 - 6010	
Mg	4.0 - 780	
Total P	nd - 234	
SO_4	nd - 1850	
K	nd - 3200	
Ca	3.0 - 2500	
Hg	nd - 3.0	0.002 (19)
Fe	nd - 4000	221 (120)
Ni	nd - 7.5	0.326 (98)
Zn	1.7 – 8.63	8.32 (114)
Pb	0.22 – 2.13	0.162 (73)
Cd	0.02 – 0.03	0.022 (46)
Se	nd - 1.85	0.012 (18)
As	nd – 70.2	0.042 (72)
CN^^	<0.10	0.063 (21)

* nd – non detectable minimum
# number of studies considered, in brackets
^ reported as “nitrate”
^^ CN – cyanide, is not otherwise reported in this Study – but should be considered as a possible metabolite product during decomposition

In more mature, and larger landfills, a great variety of leachate compositions is to be expected. These waste disposal facilities have very variable inputs, inconstant compositions, which have changed markedly over the last 30 years with increased community recycling schemes, and have variable amounts of recharge depending on their construction and management. In respect of this context, Bagchi (1994) has listed the wide range of concentrations in municipal waste leachate reported from summaries by others, whilst the USA EPA, reported in Qasim and Chiang (1994) have reported median leachate concentrations from a large number of studies. These data are partially reproduced in Table 6.10 for comparative purposes. The emphasis of the USA EPA data (Qasim and Chiang, 1994) is toxicity to humans.

Data for the saturated zone are more readily considered. Table 6.11 sets out the results for data from sites at BOT, HEL and GUI for boundary wells in soil formations that are somewhat similar to the landfill sites of Johnson et al. (1981). The septic system studies used for comparison (Robertson et al., 1998) were also in a variety of sandy and silty sediments.

In a previous study, Dent (1995), boundary well samples were also taken at BOT. Sample 2 is from an observation well downgradient of an older, essentially fully developed part of the cemetery, and sample 72 is from a new water supply well established about 3m downgradient of B9 used in this Study and comparison. These results are re-presented in Part (B) of Table 6.11: they show considerable variation - generally lower concentrations - to the present data. They serve to document how variable results can be in similar hydrogeological situations, as well as re-enforcing the viewpoint that decomposition products leaving cemetery boundaries are frequently in small concentrations.

In Figure 6.5 the results for the saturated zones' Inverse Enhancements suggest that with the general exception of inorganic N, the necro-leachate effects are diminishing substantially downgradient. The effects in the alkaline environment of HEL are less marked that in the other acidic environments (BOT and GUI). The graphical result is a marked improvement over the results for the vadose zone, and is considerably less variable than for the landfill example.

Finally, some of the septic system plumes' data from Robertson et al. (1998) is considered (Figure 6.5). That comparative study presented a great deal of data from

Table 6.11 Boundary Well Data for Comparative Analysis

Part (A) SATURATED ZONE – values in mg/L unless indicated
(3 sites with silty sand/sandy formations)

analyte	BOT				HEL				GUI			
	n	min	max	median	n	min	max	median	n	min	max	median
EC (µS/cm)	5	364	607	523	5	3090	4310	3780	12	300	777	400
pH (units)	5	6.2	6.7	6.4	5	7.5	7.8	7.6	12	5.7	6.5	5.9
total NOx	5	1.55	18.71	2.90	5	19.10	20.50	19.70	12	1.61	36.90	15.12
NH3 - N	5	0.16	0.63	0.27	5	0.01	0.59	0.03	12	0.00	0.33	0.19
kjeldahl N	1	1.55	1.55	1.55	5	0.14	0.81	0.50	n/a	n/a	n/a	n/a
total N	5	3.73	18.98	5.00	5	19.85	21.13	20.25	12	1.82	47.00	18.82
PO4(3-)	5	0.63	3.16	2.70	5	0.00	0.20	0.00	10	0.00	5.50	1.35
total P	5	0.21	1.03	0.88	5	0.03	0.33	0.07	12	0.01	1.80	0.35
BOD	1	3	3	3	5	4	18	13	1	5	5	5
TOC	5	4.7	9.7	8.8	5	1.7	28.0	2.7	12	4.0	33.0	11.5
Cl	5	41.0	76.0	68.0	5	428.0	622.0	555.0	12	10.0	110.0	32.5
SO4	5	23.0	61.0	43.2	5	169.0	193.0	184.0	11	9.0	46.0	13.1
Hg	5	1 x <0.001, 4 x <0.0005			4	1.00E-04	8.80E-02	3.00E-04	11	all <0.0005		
B	5	0.1	0.9	0.3	5	2.9	3.9	3.1	12	0.0	2.1	0.1
Na	5	29.8	56.0	47.3	5	505.7	924.2	817.5	12	14.2	69.2	31.8
Mg	5	6.9	12.2	10.2	5	59.6	75.5	68.3	12	9.3	47.9	18.7
K	5	7.0	10.7	9.7	5	9.7	16.0	13.4	12	2.8	17.8	6.4
Ca	5	30.3	52.5	48.5	5	26.4	36.8	33.4	12	5.0	26.7	14.0
Cr	5	8.97E-04	2.09E-03	1.50E-03	5	7.80E-03	1.60E-02	1.21E-02	12	3.14E-04	4.19E-03	8.89E-04
Mn	5	4.31E-03	1.66E-02	1.04E-02	5	2.90E-03	1.76E-02	4.77E-03	12	3.38E-04	1.88E-02	4.23E-03
Fe	5	8.82E-02	1.79E-01	1.25E-01	5	1.80E-01	5.00E-01	2.12E-01	12	1.11E-02	5.36E+00	8.20E-02

Ni	5	6.03E-04	1.50E-03	1.14E-03	5	6.28E-04	1.59E-03	1.14E-03	12	4.77E-04	2.26E-03	9.01E-04
Zn	5	1.79E-03	1.82E-02	2.44E-03	5	3.50E-03	3.31E-02	1.54E-02	12	3.99E-03	3.64E-02	1.54E-02
Cu	4	6.14E-04	1.64E-02	1.34E-03	3	1.55E-03	7.69E-03	1.81E-03	8	1.12E-03	8.09E-03	2.84E-03
As	5	6.62E-05	1.56E-04	6.94E-05	5	1.68E-04	3.29E-04	2.04E-04	12	0.00E+00	2.15E-04	5.08E-05
Se	5	0.00E+00	4.94E-03	3.09E-04	5	1.01E-02	2.64E-02	2.46E-02	12	0.00E+00	9.53E-03	0.00E+00
Sr	5	1.07E-01	2.23E-01	1.91E-01	5	4.50E-01	5.92E-01	4.88E-01	12	2.11E-02	2.70E-01	6.85E-02
Mo	5	6.68E-04	2.13E-03	1.14E-03	5	3.29E-03	5.21E-03	3.69E-03	12	9.84E-06	1.58E-03	2.33E-04
Cd	5	5.84E-05	2.04E-04	7.48E-05	5	1.20E-04	8.22E-04	2.10E-04	12	1.11E-04	1.26E-03	2.50E-04
Pb	5	5.29E-04	1.63E-03	9.59E-04	5	6.78E-04	6.98E-03	1.53E-03	12	3.80E-04	2.61E-03	8.11E-04

Part (B) EARLIER RESULTS FROM BOT; Boundary Wells (after Dent, 1995) – values in mg/L unless indicated

analyte	**sample 2 6-Sept-94**	**sample 72 23-Nov-94**	**analyte**	**sample 2 6-Sept-94**	**sample 72 23-Nov-94**	**analyte**	**sample 2 6-Sept-94**	**sample 72 23-Nov-94**
EC (µS/cm)	200	298	Hg	<5E-04	<5E-04	Zn	0.17	0.2
pH (units)	6.3	6.4	B	<0.1	<0.1	Cu	<5E-03	0.015
tot NOx -N	6.05	6.8	Na	14	25	As	<5E-03	<5E-03
NH3 - N	0.13	0.03	Mg	2.8	4.5	Se	<5E-03	<5E-03
EC (µS/cm)	200	298	K	3.2	4.1	Cd	<1E-03	<1E-03
total N	6.55	5.4	Ca	15	20	Pb	<5E-03	<5E-03
total P	0.065	0.050	Cr	<5E-03	<5E-03	F		0.2
BOD	4	<1	Mn	<2E-02	<2E-02	Faecal coliforms ^	nil	<2
Cl	27	37	Fe	0.27	0.1	Faecal streptococci ^	nil	10
SO4	15	25	Ni	<5E-03	<5E-03			

Notes:
n/a not available; this most likely comes about because the chemical analyses have been rejected (see Chapter Four for criteria
^ Bacterial measurements in CFU/100 mL; Faecal streptococci now called *Enterococcus faecalis*.

oxidising and reducing portions of plumes from septic systems 6 – 44 years old, and in calcareous and non-calcareous soils. In that the septic plumes are essentially wholly derived from human wastes, they are also usefully considered for comparative effects. Their composition is likely to be fairly regular but that composition is narrower than for that of necro-leachate which derives from a whole-of-body decomposition.

The graphical analysis (Figure 6.5) for the septic systems shows a considerable variability in behaviour, generally lower degrees of Inverse Enhancement and marked variations depending on the oxidative state. The analysis is useful because it again puts into perspective the generally lower, and more uniform, downgradient concentrations found in relation to cemeteries.

It is worth re-iterating that in all cases, however, the spatial variability of the sampling system, even the nature of the watertable, the context of the sampling setting, and the nature of the vadose and aquifer soils and sediments will have an effect. This area of understanding is a fruitful one for further research which would better elicit understandings of cemetery functions, if satisfactory comparative sites can be found.

MOUNDING – THE BUCKET AND SPONGE EFFECT

The soil above the interred remains is disturbed; it has a lower bulk density than that of the surrounding grave space; it is frequently mixed, that is, no longer in the natural order of the soil/sediment profile, and as a result of this is generally more oxygenated and wetter than the surrounding. The re-filled grave typically presents relatively easy pathways for water and gases from the surface to the grave invert level, and gases to exit from the grave; however, see Chapter Two for a discussion about grave oxygen levels.

There are a number of commonly variable parts in the above situation. The typical

Australian situation is to complete the grave immediately after the interment with a heap of excess grave soil (spoil) above the grave space. This practice is to provide for replenishment of the grave fill as it almost invariably settles, to variable extents, in a short time. Usually the grave fill is emplaced with machine (backhoe or similar) and during this process a degree of compaction in the lowest-most parts is usually induced with the machine's bucket. In parts of BOT and other confined cemeteries, for example part of MEL, the grave fill is emplaced using hand-tools.

For graves that are to be later completed with some monumental masonry, the heaped spoil normally remains, to the extent that it has settled or not. Graves to be completed with lawns or similar are typically topped-up with topsoil, as at CEN, or additional sandy spoil as at GUI. In some cases, manicured lawn pieces are used for surface completion. Generally, however, it is unusual for the surface to be completed so as to shed precipitation and encourage water runoff. Surface completion is usually done in some manner compatible with the surrounding surface.

Whether or not the surface completion is by spoil heaping or other, the surface finish provides or screens a discontinuity to the natural formation of the cemetery. It is therefore a preferential pathway for water ingress. When the grave fill has settled there is frequently a depression left in the surface. This depression can act as temporary storage for runoff or precipitation.

Within the grave at depth, a similar situation pertains. The grave walls are discontinuities to the natural formation and work independently of the backfill to permit water percolation into the grave space. Only in the most homogeneous of sandy formations does the backfilling allow some relatively quick, near-restitution of the *a priori* state. As a consequence the typical grave receives more infiltrated water than the surrounding grave space or other land of the cemetery. Add to this body fluids and fluids of decomposition. The grave works like a sponge for extra water.

With the variable percolation rates and variable permeabilities of the grave environment, it would be expected that some groundwater mounding would occur. This is likely to be a highly variable, ephemeral phenomenon, overlaid with spatial and compositional variabilities of the groundwaters (Figure 6.6). Well drained sites, or those with sandy or open, porous vadose zones are expected to be least effected. On the other hand, such sites can be influenced by fluctuating watertables, or watertables that respond rapidly to recharge events. The former matter is a significant issue in several irrigation districts of Australia.

The presence of water in graves is a very common experience in certain parts of most of the cemeteries of this Study: at CEN and MEL the clayey soil frequently works as a bucket, at BOT rapid recharge is a problem, at GUI fluctuating watertables are a problem, at WOR and LAU grave-to-grave seepage is an issue, whilst at NEW seepage along the constructed fill-natural interface is an issue. In-ground vaults are notorious water storage devices, and are typically pumped out before multiple interments at CEN and MEL (Figure 6.7).

In many cases individual coffins also act as a water storage (Figure 6.8) – a bucket. This comes about because the plastic liner remains intact for a long time after burial and frequently remains in a position which permits it to fill with water. The latter effect occurs because the in-filled grave soils pack around the coffin and continue to pack as time goes on. If the soils are competent clays they take on the shape of the coffin and the plastic liner moves to flatten itself against this shape as the coffin wood decomposes.

Coffin ‘buckets’ are likely to disappear in the much longer term as the sides of the grave, and the overlying in-fill collapse into the coffin void. Furthermore, the plastic liner begins to slowly degrade with time, developing tears and holes through which entrapped groundwater is then free to move and soil to ingress. The timeframe for these matters is unquantified at present, but the example in Figure 6.8 is over 20 years old. Plastic coffin liners – mostly as PVC, have been used since the 1960s so that the incidence of such ‘buckets’ will be widespread in the cemeteries. In more recent times there have been developments of plastic liners which breakdown relatively rapidly when buried.

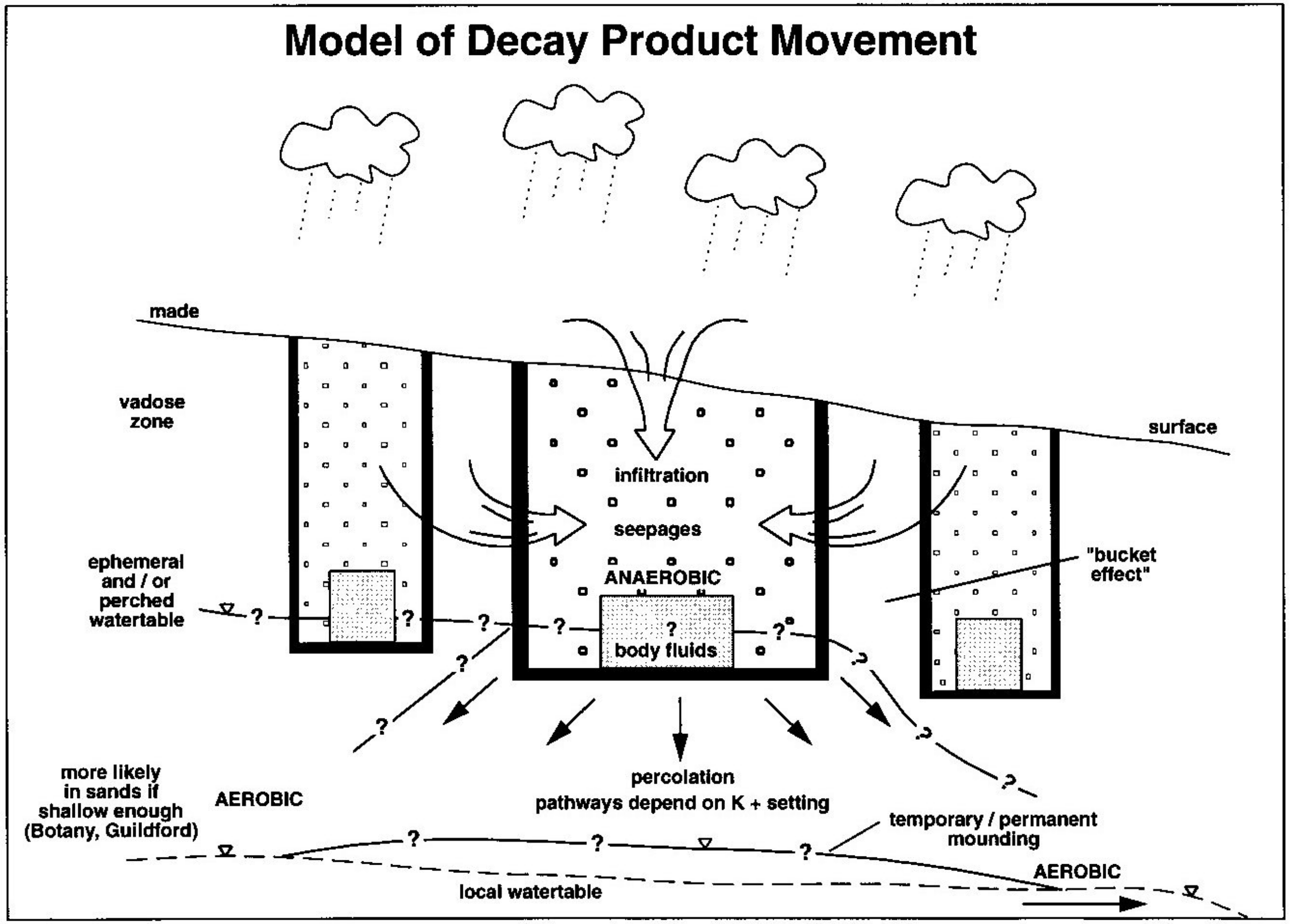


Figure 6.6 Model of In-grave Groundwater Disposition

Figure 6.7 Water-Filled Concrete Vault at CEN
(photo courtesy of G.Hodgson, 2000)

Figure 6.8 Coffin Filled with Water – Excavated for Lift and Deepen at CEN
(photo courtesy of G. Hodgson, 2000)

In sandy, or less competent, and/or wetter soils, the plastic liners don't maintain the coffin shape and initially collapse vertically to the sides of the cadaver. The remains and decomposition products are then freer to act with the grave environment, although there is some retention and retardation at the invert.

Generally speaking, the plastic liner retards the decay processes by storing the decomposition fluids and tissues; this is also likely to assist the maintenance of microbial populations. Furthermore, the plastic remains as a relatively inert landfill component for many years, and whilst intact it influences the hydrogeological system at the micro scale; including mounding of groundwaters on an effective aquitard.

Other kinds of coffins can also act as buckets. For example, those that are metal lined or constructed of timbers which slowly decay in certain in-grave situations. It is not uncommon for older coffins, if relatively intact, to issue up black water when opened or struck by an excavator. For example, during the installation of seepage wells at LAU, this was observed for a wooden coffin estimated to be at least 70 years old, buried at 1.8 m in an area hosting springlines. The water illustrated in Figure 6.8 is also black.

*

CHAPTER SEVEN

MANAGEMENT ISSUES, OPERATIONS AND PLANNING POLICIES

Contents

LONGEVITY OF REMAINS

Body decomposition relative to any timeframe is a problematic issue and it needs to be considered in respect of resolving a number of planning and management issues. These issues primarily relate to grave re-use and cemetery site location. As shown in the preceding Chapters, body decomposition continues at different rates in different hydrogeological conditions, and is attended by many factors relating to the site, the remains themselves, funereal aspects and so on. Conventional European wisdom (van Haaren, 1951 and van der Honing et al., 1988, Mitchell, 1998, Environment Agency, 1999) suggests that 10 - 12 years is a minimum timeframe for a hygienic decomposition – skeletonisation – to occur, whereas Schraps (1970) reports that 50 years may be insufficient in Germany. In Brazil, remains are disinterred after 3 to 5 years, a very unsatisfactory situation.

It needs to be accepted as a fact, that parts of remains have been recovered from widely different, hydrogeological settings on a worldwide basis. Many tissue remains, other than mummified ones, are found well after generational time-frames, see for instance Mant (1987) and Janaway (1997). Bone as well as mummified skin and tissues, survive for thousands of years in some settings, however, the survival time of the organic part of bone is not fully documented. In the lift and deepen practices at CEN and HEL considerable quantities of bone, to the extent of in-tact skeletons, still in their coffin base, more than 50 years old have been recovered (Figure 7.1). At BOT where the remains of original settlers had been re-interred after being relocated (see Zelinka, 1991), pieces of bone and coffin are still occasionally recovered more than 100 years after re-interment in this sandy soil (Jacobs, pers. comm. 1997).

The studies of exhumations in England, see for instance the work on the Spitalfields Project (Janaway, 1993) and the International Centre for Life and Dance City (Mott MacDonald, 1996, data are still to be published) recovered recognisable tissue after long burial times; between 150 and 260 years (mostly coffinated, mostly in-crypt) at the first, and more than 150 years at the second (earthen burials, coffinated and non-coffinated). Janaway (1997) records other examples of identifiable, quite intact soft tissue from thousands of years, 1600, 1400, 500 and 150 years ago. Most of these cases are associated with freezing, desiccation or freeze-drying and are usually recovered from ice or frozen ground; although peat bogs and extremely dry environments also apply. Grupe (1988) reports well preserved bones, tissue (including some brain tissue) and coffin woods in soils of pH 6.5 – 7.0 dating from the 11^{th} and 12^{th} centuries, for 250 individuals exhumed at Schleswg (Northern

Germany): no other site or soil details are available.

Figure 7.1 Skeleton more than 50 years buried for retrieval at CEN
during the 'Lift and Deepen" process. (Photo courtesy of G.Hodgson)

An associated issue is that of the survival of pathogenic organisms within graves or crypts/vaults. This area of information is desperately short of detail and has largely been ignored by archaeologists, forensic practitioners and others who practise in the field of exhumation or remains recovery. The collective wisdom seems to be that pathogenic organisms quickly die with the body – within a few days to weeks of death, and is often stated so (see for instance, Healing et al., 1995, Mitchell, 1998 or Environment Agency, 1999). Mitchell (1998), who made specific enquiries on this matter, stated that organisms associated with plague, cholera or typhus – in pits and mass burial sites, and with tuberculosis, syphilis, HIV and hepatitis, die out within weeks of burials. Zuckerman (1984) raised the matter of whether smallpox survived over archaeological timeframes: this has been criticised by Anand (1985) and is considered unlikely by Fenner et al. (1988), but there is no conclusive evidence one way or the other. Other authors have considered the matter from a different perspective: they reason that because certain tissues survive, therefore destructive micro-organisms have died out (see for instance, Mant, 1987, Henderson, 1997, Smith and Allen, 1998).

Generally, it seems that because much soft tissue has been preserved in a wide range of situations, but mostly dried-out or frozen, then it is assumed that any native microbial activity has either been starved, desiccated or frozen to the point of being non-viable. **But the organisms are rarely sought**. In the Spitalfields Project morphologically intact smallpox virus was found in tissue more than 150 years old, but the virus could not be grown and was thought to be non-infective (Mitchell, 1998). Anthrax spores have also been considered for their viability, but need to be interpreted in context, for example old tanneries and abattoirs are places of higher expected occurrence; see below.

Haagsma (1991) has documented a number of bacterial diseases and their environmental relationships associated with farm animals, particulary in relation to anaerobic bacteria. Haagsma (1991) states that *Clostridia botulinum* (the botulism-causing organism) may persist as infectious, highly resistant spores in soil for at least 20 years, and *Clostridia tetani* (the tetanus-causing organism) as highly resistant spores in soil protected from light and heat, for "very many" years.

At the International Centre for Life and Dance City Project, Newcastle upon Tyne, UK, a thorough risk evaluation and management plan, including for micro-organisms was undertaken prior to excavation (Mott MacDonald, 1996, Smith and Allen, 1998). Accordingly, some very limited soil testing for anthrax was conducted but the bacterium (*Bacillus anthracis*) was not found. Testing of soils from cadaver chest cavities (30 tests) and grave surrounds (4 tests) for lipids specific to the tuberculosis bacterium (*Mycobacterium tuberculosis*) was also conducted there, but this pathogen was also not found.

Turnbull (1996b) reports, one of the few studies of longevity of anthrax spores in soils. In the case reported, an anthrax infected bullock was buried in a field near

Landkey, England, around 1938. Subsequently the land was tilled and thereafter two ponies grazing in the field died, at least one of these from anthrax. Soil testing in 1991 and 1992 confirmed the presence of viable spore; so *Bacillus anthracis* spore had survived at least 50 years and at least in topsoil. Full site conditions are not reported except that the soil is referred to as a “thick clay soil” (Turnbull, 1996b). In another paper Turnbull (1996a) suggests that sampling the top 25 cm of soil is generally sufficient unless there have been known burials of anthrax infected livestock, whence 2 m is more appropriate.

The papers by Turnbull (1990, 1996b) are also interesting because they report other relevant cases of the survival of anthrax spores: in bone, believed to be at least 200 ± 50 years old in South Africa; within roof insulation for 110 years at Kings Cross Station (UK); 68 years from the original work by Louis Pasteur; and 60 years in dry laboratory soil. In each of these cases, detail of relevant soil/moisture/humidity conditions and other factors are not known or given. At Gruinard Island, Scotland, anthrax survived in field peat bog about 0.5 m depth above sandstone bedrock for 40 years (Manchee et al., 1994).

In the absence of site-specific information, a simple distillation of the above scant data suggests that the time of decomposition for regularly interred human remains is too variable to be allowed to be considered as ‘*short*’ in most circumstances. A minimum working time-frame is at least 50 years; but it is proposed that a time-frame of at least 100 years should be a guiding one for the re-designation or development of cemetery land involving dis-interment in a temperate climate. At the same time it seems reasonable that 50 years is a satisfactory time-frame for the dealing of remains in a lift and deepen process, but that 25 years is too short. It is also clear that remains of some sort should be reasonably expected at most sites up to 100 years old; sites with acidic soils are less likely to have substantial preserved bone than others.

In the case of risks posed by dormant, but viable, pathogenic organisms, there is simply too little information available to provide reliable guidelines. If remains, likely to have been associated with some infectious diseases are to be exhumed, then clearly 50 years may represent a possible risk time-frame, but 100 years (undisturbed) is less likely to be a problem.

CREMATED REMAINS – FURTHER CONSIDERATIONS NEEDED

Where very large concentrations of cremation ashes exist there is the possibility of a metallic geochemical anomaly being created: the data on human body composition suggest that cremated remains may be rich in metals within a calcium and phosphate base (see Chapter Two). The In-cemetery storage and/or scattering of cremation ashes needs to be considered in the context of whether the concentrated metals or phosphorus could leave the cemetery boundary and thus become a pollutant.

Where the ashes are interred they are frequently contained within a box or other receptacle of plastic or metal construction. Since they are buried they are then comparable to latter stage intact remains after about 10 to 30 years (see Table 6.5). That is the continued decomposition or effect is essentially about inorganic weathering and transmission of solutes. Just like the case of any burial, the metals and other inorganic chemicals interact with the soil and groundwater and will have about the same influence. Small differences might arise, on the micro scale because the ashes are concentrated in a small volume (say several litres) compared to that of coffinated remains, and that being tightly contained in a receptacle of generally different construction to a coffin, they won't be released as steadily as in the case of the interred body: that is, when the container bursts all the inorganic products become more or less instantly available.

Frequently, the cremated ashes are congregated into designated parts of the cemetery with the resultant that the density of interments is considerably greater than it would have been if the same space had been used for burials in the standard way. This creates a geochemical anomaly within the cemetery with the potential to release more metals and/or phosphorus than would normally be released. If the ashes interment occurs well within the cemetery then it really need not be considered to be any different to the rest of the cemetery and the whole is still treated as a 'black box'.

Only if the concentration of interred ashes is high close to the cemetery boundary is there likely to be the potential for off-site migration of decomposition products in higher than usual amounts. At this point the other usual aspects of the discussion come into play: that is, the type of soil, depth of burial, types of receptacles, flux of percolating water, manner of burial and backfilling, together with the areal density, presence and size of a buffer zone, will affect the propensity for off-site migration.

The likelihood of a problem should be highest in open, porous soils, and be the lowest in clayey soils. Therefore, if the interred cremated ashes emplaced in high concentrations – that is say at the rate of 5 – 8 per standard grave space, are kept remote from the outer parts of the cemetery, this would be desirable. Interment of these remains at a density of about 8 per standard grave space is unlikely to cause a problem. For this reason the presence of remembrance gardens, occasional tree or shrub plantings of cremated ashes, adjacent to and even impinging upon buffer zones to a very low extent are unlikely to create problems.

The interment of ashes should take place below the subsoil – at about a depth of 1m, and needs to be at least 1 m above any level to which a watertable can rise, and be in soil not affected by ephemeral or perched watertables. The interments should not take place into unlined chambers constructed in fractured rock.

In general terms, the same kinds of concepts as in the foregoing also apply to scattered cremated ashes. When ashes are scattered the concentration of decomposition products obviously decreases, with the exception of designated areas like remembrance gardens where routine scattering is practised. The major concern with scattered ashes is that they be prevented from entering waterways and drains *en-mass*, that is they should not be allowed to wash from gardens or lawns.

High density scattering, at a rate say of about 25 times the standard burial space density ought to be possible without leading to an extreme accumulation of metals in the near surface. For example, using the data from Table 2.1 and Figure 1.2 for chemical composition and grave space, and a collective of the equivalent of 10 normal interment spaces (that is 26.4 m^2 total) then this would lead to potential surface deposits, for some critical heavy metals, as shown in Table 7.1. In addition the extra loads of calcium and phosphorus, possible if all of these elements from the average set of remains are included, are shown.

It is difficult to completely judge how acceptable these sorts of potential metals concentrations are. Various planning and environmental protection instruments will operate in different legislative dominions. In some cases potential land contamination is regulated by Guideline Values or Clean-up Standards, whilst in others it is by evaluation of Risk in the light of overarching standards. In Australia, for example, the second type of regime is emerging after some interim timeframe wherein the first applied; see documents -ANZECC (1992b). In many jurisdictions The Netherlands' soil contamination standards were used for a long time; the "probably uncontaminated' A values are shown in Table 7.1 (Cairney, 1995). Nowadays the trend in Europe is to larger 'trigger values' similar to the former Netherlands' C levels, for example, some values for dry soil of parks and open space in mg/kg are: Cd – 3, Cr total – 1000, Pb – 2000, Hg – 20, Se – 6 (Cairney, 1995).

In Table 7.1, the Australian Background Values "A" (ANZECC, 1992b) are listed as a guide. Generally speaking, these were indicative values, and it was considered that no further action was necessarily required if soil elemental values were in the ranges given. The results of Table 7.1 at the modeled level (about 250 sets of remains per 25 m^2) do not suggest a significant problem. However, at higher densities of scattering the elements zinc and cadmium begin to be of concern.

In Chapter Two the potential radioactive content of the remains, particularly following treatment in hospital, was discussed. One of the isotopes of concern here is ^{89}Sr which is used to treat bone cancer; it has a half life of 50.5 days. In a study for the UK National Radiological Protection Board, Cooper et al. (1989) concluded that although it was difficult to estimate completely: "The maximum doses [of radiation] to an adult member of the public scattering contaminated ashes …. are extremely unlikely to exceed the dose calculated for an individual crematorium worker per cremation" and these were a pessimistic maximum of 0.3 μSv compared to an annual average dose in the UK received by all persons of 2500 μSv. Given the potential distribution of such events in areas designated for the scattering of remains, there is unlikely to be an additive radiation exposure hazard.

Table 7.1 Potential Surface Loadings of Cremated Remains
(based on 250 sets of reference remains per 25 m^2 incorporated
into topsoil of density 1700 kg/m^3)

Metal and (weight per reference 70 kg human)	250 sets of ashes per 25 m^2 based approximately on Table 2.1 and Figure 1.2. g/m^2	**Additional -** by weight for top 100 mm of topsoil with density 1700 kg/m^3 mg/kg	ANZECC (1992) Background Values for contaminated sites mg/kg	The Netherlands A values (1983) probably uncontaminated mg/kg (dry soil)
Zn (2.3 g)	21.78	128.1	2 -180	200
Cu (0.07 g)	0.66	3.9	1 - 190	50
Pb (0.045 g)	0.43	2.5	<2 - 200	50
Cd (0.019g)	0.18	1.1	0.04 - 2	1
Ni (0.01 g)	0.09	0.6	2 - 400	50
Cr(<0.002g)	0.02	0.1	0.5 - 110	100
Ca (1000 g)	9.47E+03	9.47E+04	n/a	n/a
P (180 g)	1.70E+03	1.70E+04	n/a	n/a

The composition of cremated remains is a matter in need of urgent, dedicated investigation. As discussed in Chapter Two, only a very limited number of analyses are publicly available. This is insufficient data to allow for reliable considerations to be made about the pollution potential of ashes, which may end up be disposed of in concentrated assemblages in gardens or underground vaults, or by being scattered.

Another related matter is the likely effect of the collective disposal of ashes in ash pits. These pits are usually adjacent to crematoria and contain collections of mixed residues and fly ash from the cremators. The pits can be quite considerable in size and in addition to human ashes contain metal residues from coffins and funereal artefacts. Since the pits, almost unavoidably, contain cremated remains, it seems consistent with the ideas of disposing of the deceased, that they be within the cemetery. Accordingly, the siting of the pits needs to be as carefully done as any other aspect of cemetery management.

Consistent with the considerations so far developed, pits of cremated ashes also need to satisfy the following disposal criteria. They need to be:-

- well away from cemetery boundaries and not located in the buffer zone;
- not located so as to aid the scattering of the ashes beyond the cemetery boundary;
- not near watercourses, lakes or swamps;
- constructed with inverts at least 1 m above any watertable;
- designed so that the uppermost level to which the ashes are deposited is at least 1 m below the surface, and then the pit should be over-filled with site soils; and
- finished off to prevent rainwater infiltration or animal burrowing or wind or water scour; hence, ideally they would not be in a gully.

GRAVE RE-USE

The majority of the cemeteries in our major urban areas are now well demarked by other land uses, and their boundaries well defined by historic land dedications. There is little room for expansion of existing sites and most included space is either full or being rapidly consumed. Most of our capital cities are now seeking land for cemetery dedication in the urban fringe areas, which to some extent goes with expanding populations and urban sprawl. However, in only a few known cases, notably in Melbourne (at NEW and a cemetery at Fawkner), and at LAU, GUI** and to a lesser extent at WOR, is there sufficient free land to accommodate such activities. Concomitantly, the city dwellers show a low inclination to bury their dead great distances from their homes, with the consequence that older, closer-in cemeteries are facing disproportionate pressures for burial space.

> ** In the case of GUI, emerging environmental issues are having a significant effect on shaping the future development of that cemetery (McLean, 2000, pers. comm.), and community-driven environmental issues have also impacted to a lesser degree at LAU.

In Adelaide, South Australia, these pressures can be clearly seen at work in a large outer, but confined, and a small, old, inner-city, cemetery – CEN and HEL respectively. By a fortuitous combination of the right-of-burial legislation in that State, and the geography of the Adelaide urban area, these cemeteries are widely invoking the management practices of grave re-tenure and re-use.

Throughout this Study the concept of multiple interments in a single grave has often been referred to; the following is a more formal explanation of the practice. Grave re-use essentially comprises two forms; firstly where a relative to a previously deceased is interred in the same grave, but at a shallower depth than the original interment. This practice is widely used at most cemeteries; non participation in this practice usually results from various religious or cultural bases. Secondly, the South Australian practice of "lift and deepen" is used. In this situation, previously interred remains that are no longer licensed for exclusive burial, say by the expiration of a 50 or 100 year lease, are gathered together in to an ossuary box or bag which is then re-interred below the original grave invert, and the grave space then becomes available for standard burials (up to three per grave) again. In Western Australia a system of 25 year licences has been introduced.

The Australian industry is keen to develop and extend the re-use/re-tenure concept to answer the problems of inadequate grave space into the future. This is a common practice for varying lengths of interment in many overseas countries, and seems to be gaining acceptance where it is being used today.

The analyses of this Study suggest that there is no geoscientific difficulty in the concept of grave re-use in either of the explained formats. Every indicator and situation considered return the same understanding. Essentially, if graves are properly sited, and cemeteries managed so as to attenuate any movement of off-site decomposition products, then in-earth burial is a sustainable land use. The burdens imposed on the land are relatively small, and from all the evidence considered, these burdens seem to be handled very well by natural processes. Where the hydrogeological setting, or management/interment practices are, or have been, less than optimum then certain difficulties can arise. These aspects, together with prudent rules for the relationship of cemeteries to natural and anthropogenic features (for example water wells), are considered independently throughout the Study.

SOIL PROPERTIES AND THEIR INTERPRETATION

The sites' soils were classified in terms of the USCS System (Bureau of Reclamation, 1960) (Chapter Four, Appendix K). This system was chosen because it is extremely practical, easily understood and has immediate application to the soils' use. It is based on visual assessment and limited physical testing, thus allowing for relatively quick initial evaluation if required; but more importantly: in the context of international cemetery applications it allows a sufficient but simple means of comparing the soil properties anywhere. For greater understanding of cemetery responses and effects, limited other testing and evaluation was undertaken (pH, EC, CEC, mineralogy), and this information provides a second level of soil assessment for potential cemetery sites.

The approach to soil classification and evaluation cannot deal totally with all the likely soil types to be met, and is clearly deficient in chemical understanding, climate influences, soil structure and direct understanding of hydrogeological properties. It would form part of any geoscientific site evaluation. However, there seems no merit in constructing a comprehensive, all-inclusive pedologically based system when the primary issues confronting the cemetery operator or developer follow from other, higher-level site assessments. If the site can be ruled 'in', so it can be developed, the remaining problems turn to ‘how’.

Operating sites have the advantage that the cemetery staff usually understand the site’s soils quite well; they can identify which parts of the site wet-up after rain, remain unworkable after rainfall, have springs, or develop instabilities during the excavation process. For others involved in broader-scale planning and assessment, or even planning interment and development patterns at the site level, and wanting a more numerical information, then soil classification is a more useful basis.

As an indicator, Table 7.2 sets out the engineering understanding of general soil properties and behaviour based on the USCS. The table concentrates on a range of soil groups but generally embraces those identified for this Study.

Certain soils are fundamentally unsuitable for cemetery usage because their properties usually inhibit the free movement of groundwater, or encourage rapid groundwater movement, or they are compressible or friable, or they are highly unworkable. To a limited extent these criteria may be modified by locally prevailing climatic conditions. For example, the frozen soils (permafrost) or peaty soils of the Northern Hemisphere have at times been somewhat workable, and/or have preserved human remains, for example “bog people”; see Janaway (1997) for illustrations of cold and organic preservations.

The issue of which soils are suitable for cemetery development is not new. Various authors mention gravelly (usually easily drained, although a vast range is encountered in clayey gravels) soils and those which are boggy underfoot as likely to be not suitable. However, there are many examples of cemeteries then inappropriately located in such soils. Today, researchers like Pacheco (pers. comm., 2000) are concerned about this issue and are able to link cemetery practices, for example the dis-interment of remains after 3-5 years with soils fundamentally unsuitable for the purpose of a cemetery.

Table 7.2 Properties and Usage Aspects of USCS Classified Soils
(after Bureau of Reclamation, 1960* and Charman and Murray, 1993)

Typical description	USCS symbol **	Permeability (1) when compacted	Shearing strength when compacted and saturated; # piping resistance (4)	Compress-ibility when compacted and saturated; # cracking resistance (5)	Workability as a construction material
clayey gravels, poorly graded (2) gravel-sand mixtures	GC (3)	pervious to semipervious to impervious	good to fair 1	very low 4	good
well-graded sands, gravelly sands, little or no fines	SW	pervious	excellent 3	negligible -	excellent
poorly graded sands gravelly sands, little or no fines	SP	pervious	good 5	very low -	fair
silty sands, poorly graded sand-silt mixtures	SM	semipervious to impervious	good 4	low 3	fair
clayey sands, poorly graded sand-clay mixtures	SC	impervious	good to fair 2	low 4	good
inorganic silts and very fine sands, silty or clayey fine sands with slight plasticity	ML	semipervious to impervious	fair 5	medium 6	fair
inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	CL	impervious	fair 2	medium 2 to 5	good to fair
inorganic clays of high plasticity, fat clays	CH (3)	impervious	poor 1	high 1	poor

Notes to Table 7.2

* The scheme was developed for using earthen materials for construction.
** Soils with dual symbols have a combination of properties of the two classes.
(1) permeability refers here to the ease of transmission of water. This could be different in natural deposits where it varies with internal structure, texture and the presence of macropores.
(2) a poorly graded material shows an irregular (including constant) range of sizes throughout, such that all particles don't pack closely together.
(3) GC and CH (or MH – inorganic plastic silts) soils on their own are unsuitable, however if part of a soil with dual classification they may well be acceptable.
(4) Value of 1 represents highest resistance to piping in a non-tunnelling situation.
(5) Value of 1 represents highest resistance to differential settlement.

Keller (1966) probably made the first comprehensive evaluation of this and classified soils with respect to their primary particle sizes, drainage and air circulation aspects; and went on to make recommendations about suitable depth of burial relative to soil type. Keller was concerned primarily with soils favouring decomposition of the interred remains and concluded that soils predominantly with particle sizes between 0.02 and 2.0 mm diam. (fine/medium – coarse sands) were optimal.

These understandings are borne out by this Study – see data and discussions for BOT and GUI – but need to be evaluated in the light of additional information about decomposition product/s movements. Whatismore, they are likely to reflect an ideal situation which is not always achievable in the light of city planning, available natural settings and the demands of any particular community. Accordingly, Keller (1966) developed a five-fold classification system for soil suitability (Table 7.3); where a value of '5' is very poor, and '1' is very good. This was applied to some example sites where the grading was calculated as a weighted average relative to area, yielding possible results like 4.8 or 1.9 which are then used to classify the *whole* potential site for suitability.

Table 7.3 Soil Suitability for Cemeteries – Summary of Keller's (1963) Scheme

Soil type	Typical particle size (mm)	Grading	Evaluation
clay	<0.002	5	very poor
silt	0.002-0.06	4	poor
fine sand	0.06-0.2	3	sufficient
medium sand	0.2-0.6	2	good
coarse sand	0.6-2.0	1	very good
fine gravel	2.0-6.0	2	good
medium gravel	6.0-10.0	3	sufficient
coarse sand	10.0-60.0	4	poor
fissured rock, rocky soils	>60.0	5	very poor

The USCS scheme relatively easily allows for the identification of these soils; Table 7.4 records such relevant soil classes and sets out the essential unsatisfactory aspects, derived from a consideration of Bureau of Reclamation (1960) criteria, re-consideration of Keller (1966) and hydrogeological considerations.

Table 7.4 Unsuitable Soils – USCS Classified Soils

Soil description	USCS	Unsatisfactory aspects
gravels – well or poorly graded, silty, gravel-sand mixtures with little or no fines	GW, GP, GM, GC	drainage too rapid, excavation stability poor, permits free escape of gases, no or little attenuative properties
organic silts and clays and organic silt-clays of low plasticity	OL or OH	organic composition, workability and excavation problems, poor drainage
inorganic silts or clays of medium to high plasticity, micaceous or diatomaceous fine sandy or silty soils	MH or CH	poor drainage, ponding, swelling, workability , reduced gas circulation
peat and other highly organic soils	PT	workability, unsatisfactory drainage, wet, anaerobic, organic composition

Grave Invert – Watertable Separation Zone

An issue which has not been satisfactorily resolved elsewhere is the separation distance of the grave invert (bottom of grave) relative to any permanent or ephemeral or fluctuating watertable. This matter only appears to have been assessed by Keller (1966), Schraps (1972), Environment Agency (1999, reporting the MAFF code) and Inspectorate for the Environment (2001, The Netherlands), see Chapter Two. With the exception of The Netherlands' proposals which seem to be too thin, a separation distance of about 1 m is generally well regarded.

The grave invert – watertable separation distance is important because it comprises the first media that can provide:- retardation of solutes; filtering and adsorption of viruses, bacteria and salts; a delay distance for the die-off of microorganisms;

dispersion of fluids; and permeation of decomposition products like adipocere. In this zone, the flux of percolating groundwaters substantially controls the movement of the decomposition products to the watertable, and the degree of mounding or temporary saturation that will occur within the grave. This flux can be 'slug-like' or more or less continuous in higher rainfall areas or where soils have high infiltration rates. Crane and Moore (1984) and Fredrickson and Fletcher (2001) provide good reviews of the issues and processes involved for general microbial movement in the unsaturated zone.

In a preliminary proposal by the US EPA with regard to protecting groundwater supplies from microbial contamination, Jorgenson et al. (1998) have suggested that a vertical two-year time-of-travel of groundwater through the vadose zone (from surface to watertable) is likely to provide a high degree of protection. However, the suggestions made do not appear to have been proceeded with; see Berger (1994) for a suitable discussion. Considerations like this accompany others related to groundwater travel-times in aquifers (see later). For the former considerations it may be useful in the case of say land-spreading of sewerage effluent, but these considerations are unlikely to be directly applicable to a cemetery: Crane and Moore (1984) report a study that concluded that bacteria generally move less than 1 m in unsaturated flow conditions from soil-applied effluents.

Lewis et al. (1982) have also stated some relevant information from their considerations of microbial transmission in the unsaturated zone with respect to domestic sanitation. They point out how important the volumetric water percentage of the unsaturated zone is in the transmission process, and how in coarse soils as water infiltrates after a storm that the vertical hydraulic conductivity can change dramatically. The work by Bouma et al. on Wisconsin soils is extensively cited: in one case of a sandy loam till, it was shown that as soil moisture potential decreases (from 0.8 to 0.2 mH_20, that is, soil gets wetter) and hence moisture content increases (from 19 to 33 %), then vertical hydraulic conductivity rapidly increases (from 7E-3 to 8E-2 m/day), so that under a unity (1:1) flow gradient, water travel times fall by 98.5% (from 26.7 to 0.4 day/m). This has implications for all waste management in the unsaturated zone, and of itself is enough to make sure that suitable separation from the watertable is maintained.

Lewis et al. (1982) also report a study that sampled beside and below a septic tank drain in an adsorption field, wherein it was shown how there is a dramatic decrease of *Enterococcus faecalis* and faecal coliforms after 0.3 – 0.35 m travel in a loamy sand. In another example, they cite a study of virus movement in columns of Wisconsin (USA) soils and which was related to pore saturation level: the 60 cm columns effectively removed Polio virus type I added at a constant 50 mm/d over one year (effluent concentration of 10^5 PFU/L), but that at rates 10 times this (reflecting storm behaviour) the columns did not achieve the attenuation (Lewis et al., 1982). Thus, large hydraulic surges need to be avoided since they hinder virus removal: this could also be the situation for flooded graves.

From a study of water supply to a small community in Posen, Michigan, USA, Vogt (1961) reported on the transmission of infectious hepatitis virus through glacial till (to about 3 ft – 0.9 m) and then through about 30 ft to 90 ft (9.1 m to 27.4 m) of fractured limestone. The septic source of the contamination was easily identified and this event primarily occurred under the influence of increased fluxes due to melting snow. Although the hydrogeological details aren't precise, this case is another example of poor attenuation of virus in the vadose zone, and particularly where associated with fractured limestone.

In the study by Bouma et al. (1972), for one septic drainfield studied, a dramatic decrease in total bacterial count (primarily considered to represent enteric bacteria), was found at 4 ft (1.2 m) below the adsorption bed in medium sand (with occasional fine and coarse layers). At another site (Adams #1) they found significant total coliform bacteria in groundwater within sand under loamy sand at 2 m depth underlying the septic drainfield. Unfortunately, the results and testing were very qualitative and generalised, so that these results are only indicative of possibilities. In other tests of seepage water downgradient from various septic drainfields, Bouma et al. (1972) found significant numbers of transported enteric bacteria. They also sounded a warning that the separation of sources and watertables must take into account the upper level to which watertables fluctuate.

The cemetery is considerably different to the general cases because the loadings of microbial (and all) decomposition products occur at depth – likely to be at least 1.2 m (coffin 0.3 m plus a minimum 0.9 m soil cover). The amount shed in the decomposition fluids of an individual, infected cadaver may be very large, but the temporal and spatial patterns of the typical cemetery ensure that overall loading rates are low. In addition, the immediate decompositional environment is likely to be anaerobic, which will be at least antagonistic to some microbes. In a relevant study using subsurface filtration beds to measure *Salmonella typhimurium* sorption and movement from septic effluent, Duchinski (1970) found that 1 m of anaerobic, medium-grained sand was sufficient after the system had stabilised, at a flux rate of up to 30 L/lineal m of absorption trench.

Nevertheless, public health and groundwater protection considerations necessitate that due regard be given to the potential escape of pathogenic organisms from the interred, their survival and transmission beyond the cemetery boundary. Accordingly, the grave invert – watertable separation zone must be prominently featured in the regulation, management and siting of cemeteries. It cannot be too thin lest no attenuative assistance is provided.

Unfortunately the flow of water in the unsaturated zone is complex. Mathematically it is controlled by complex and variable, non-linear equations: "the hydraulic conductivity and water capacity are functions of the dependent variable (water content or potential)" (Campbell, 1985). Consequently the solution of such equations is highly site-specific and primarily depends upon the volumetric water content of the soil, its composition and texture. "… at low-moisture potentials (high volumetric water content), … sandy soil [can have a] greater hydraulic conductivity; however, at high (more negative) moisture potential (low water content), … clay [soil] can have a greater hydraulic conductivity" (Fetter, 2001).

In order to determine a suitable travel-time at the grave invert level, site specific information is required and then specific modelling (computer-based) would be required. Generally, it would be expected that wet sand would drain to the watertable more quickly than clay; Darcy's Law for flow holds in this zone (Freeze and Cherry, 1979, Fetter, 2001). Mounding is driven by the different permeabilities of the grave fill and formation soils, the creation of temporary sub-surface 'ponds' – the bucket effect, and then the advance of the percolating water front according to normal infiltration theory. As a result, only general guidance is likely for the specification of the thickness of the grave invert – watertable separation zone.

The other important issue in this context is the survival and hence transportability of micro-organisms. As discussed in Chapter Six, this is a matter not richly supported by relevant field studies. However, there is some evidence of the viability of organisms having been percolated through the unsaturated zone; for example, Lance (1984) reports the survival of faecal coliforms (*E. coli*) at 9.1 m in loamy sand beneath recharge basins intermittently flooded with secondary treated sewerage. In a similar, or perhaps the same case, Gilbert et al. (1976) report on studies for the Flushing Meadows sewage recharge basins. Here renovated seepage waters from wells at 6.1 m and 9.1 m deep within sandy gravel and gravelly sand beneath a 0.9 m loamy sand infiltration layer, in and about the recharge basins, regularly returned samples containing "Faecal coliforms" (*E. coli*) and *Enterococcus faecalis* over a one year period. In the same testing it was found that a range of Polio and Coxsackie and echo- viruses did not survive this percolation.

Bitton and Harvey (1992) discuss the likely survival of *E. coli* from 3 to >100 m depth and Polio virus type I has survived for at least 6.1 m (Gerba et al., 1975). Jean (2000) reports the contamination of a well about 100 m deep in coarse-grained fluvial deposits by the near-by (about 30 m) burial of infected pigs due to FMDVs (also called aphthovirus which cause foot and mouth disease and is pathogenic to humans when ingested): the land burial invert was at about 15 m depth which was 2 – 5 m above the watertable in the dry period, and 0 – 5m below the watertable in the wet period; initial decomposition products likely entered the unsaturated zone and were later flushed into the saturated zone with monsoon rains.

Lewis et al. (1982) report other studies of sewage treatment systems where vertical percolation was monitored; *Enterococcus faecalis* was still quite plentiful after 18.3

m of silty sand, but that 6m of fine loamy sand removed faecal coliforms. In another reported study: Polio virus and probably other enteric viruses penetrated 2.5 m of clay overlying a limestone formation and were detected at 35 m depth. In another case transmission has been obvious through 18 m of soil overlying fractured limestone. Similarly, Edworthy et al. (1978) reported a near 100-fold decrease in virus (type unknown) concentrations, from 5500 to 63.4 PFU/L after effluent from a sewage treatment works had percolated through 10 – 15 m of unsaturated chalk formations to the watertable in The Middle Chalk aquifer system of the UK. At the same time, bacteria as *E. coli* were attenuated from 20000 to 1300 CFU/L (?); and it was also found that, boreholes 200 m and 900 m downgradient of the infiltration system, showed no viruses.

As a general rule, thicker grave invert-watertable separation zones are required in sandy soils than in clayey ones. It is more likely that clayey soils have perched and ephemeral watertable situations than sandy sites, so that separation allowances need to take these phenomena into account. A comprehensive geotechnical investigation should, and needs to, resolve these matters. The general rule of at least 1 m thickness for this zone should apply in all cases. Wet, fine, quartz sand should have a thicker zone than its dry equivalent; similarly wet clayey areas should be thicker than dry ones; if a watertable as such exists in this material.

Soil Suitability Grid

The considerations of this Study, together with an evaluation of the previous information, has led to the construction of a grid of soil properties that allows for satisfactory cemetery development in a range of soil conditions. The important aspects are deemed to be:

- prevention of contamination of groundwater systems (including ephemeral and transient flows) by bacteria and viruses or excessive loads of nutrients; attenuation of nutrient decomposition products
- sufficient workability of sites – soils should be easily excavated by hand (most sands) or light excavator, site surfaces should be lightly trafficable

(not including roads)

- ❖ sufficient subsurface drainage (unsaturated hydraulic conductivity) so as to reduce mounding in individual graves, to encourage the within-ground percolation of decomposition gases and potential reduction of anaerobic conditions

The grid employs both the USCS and a consideration of chemical properties which, if not necessarily favouring decomposition, do not hinder decomposition. The coarser soils encourage gas diffusion and aerobic conditions. The CEC, which reflects the presence of clay/silt particles and organic matter, influences virus and heavy metal retardation. Clay type alone can provide the same effect (for example smectite clays) but can have the adverse impact of workability constraints. Smectites swell and are highly plastic, they affect trafficability, workability and excavation stability, as well as retaining too much water; they reduce soil hydraulic conductivity generally. Soil CEC is more favourable if lower - say less than 40 from most methods of determination.

The soil pH, as indeed the groundwater pH, is of reduced influence. Acid conditions generally seem to favour the destruction of deleterious, in-soil bacterial populations (see for example results for HEL where *Pseudomonas aeruginosa* survived), but the issue isn't clear-cut from the current analyses. Significantly acidic ($pH < 4.5$) or significantly alkaline ($pH > 9.0$) soils have other implications on workability and longevity of cemetery infrastructure. Soil pH is most satisfactory if within the range $5.0 < pH < 9.0$.

The soils' electrical conductivity reflects the ready detachment of ions. Many of these are implicated in salinity issues (again with implications for cemetery infrastructure) and include, Na, Cl, and SO_4, and other exchangeable bases. For cemeteries, soils with highly mobile ion complements may affect both the survival of bacteria and viruses, the hydraulic conductivity (hence drainage and mounding) and may have, as yet, unquantified effects on remains' survival. Soils with many free bases like Na, K, Ca and Mg can exhibit variable effects in clay components, particularly in wetter areas. This might extend to difficulties in workability and excavation stability. Soil EC less than 1000 µS/cm is likely to be indicative of a suitable soil.

Soils which have any of the mineralogical or lithological aspects listed below are likely to be generally unsuitable:

- high contents of swelling clays, like illites >40%, smectites or montmorillonites >5%, chlorites >10%, vermiculite >5% (weight percentage of clays present);
- rich in gypsum or anhydrite ($CaSO_4$), or halite (NaCl);
- rich in sulfur, or sulfides of iron, copper, arsenic or zinc (including Acid Sulfate Soils and Potentially Acid Sulfate Soils); arsenic may work as a bacteriacide;
- mineral salts of arsenic, mercury, uranium or cadmium generally; radon gas and the presence of transuranic elements; preservative issues as well as considerations for cemetery staff health apply;
- coal, charcoal or graphite more than 5% by weight: tar sands.

Table 7.5 - a Soil Suitability Grid has been devised to try and encapsulate the aspects of soil types against their effects on the decomposition of interred remains and cemetery operational matters. The Table is not completely comprehensive but can be used to indicate likely suitable soil situations for establishment of a cemetery. It also summarises other aspects of grave and/or cemetery planning and location, for example widths of buffer zones: some of these aspects are discussed elsewhere in this Chapter.

Table 7.5 Soil Grid – Suitability of Soils for Interments

(together with conditions for depth of burial, separation from permanent watertables, conditions relevant to springs and ephemeral watertables, buffer zones, well-head protection limits; indicative examples used)

USCS*	**GC**	**SW**	**SP**	**SM**	**SC**	**ML**	**CL**	**CH**
encourages decomposition	fair - good	good	good	good	fair-good	some	no	no
encourages drainage	good	good	good	fair	fair	slight	no	no
general workability	poor	good to poor		good	good	fair, check for mass movement	fair, check for mass movement	poor, check for mass movement
pH > 8 special precautions in karst	decomposition fair	fair – poor, enables soft tissue decomposition, preserves bone				poor, retards decomposition		
pH 4 - 8	good	good	good	good	good	good	good	good
pH < 4	generally poor, enables excess mobilisation of metals, significant loss of bone, variable negative effects on decomposition							
CEC < 40 meq/100g	poor	good - fair			poor, value is too low			
CEC > 40 meq/100g	good	fair	fair	fair	good - poor	poor, does not aid decomposition, possible swelling problem		
encourages bacterial/viral Transmission (T) survival (S)	high T low S	high T	high T	mod T fair S	low T mod S	low T high S	no T high S	no T high S
grave invert separation from watertable	1.2	1.2	1.2	1.2	1.0	1.0	1.0	1.0

buffer zone downgradient or topographically low	20	20	20	20	10	10	10	10
buffer zone upgradient or topographically high	10	10	10	10	5	5	5	5
distance to downgradient water well	100 days 200 m	100 days 200 m	100 days 200m	100 days 200 m	200m unlikely	200m unlikely	n/a	n/a

Notes to Table 7.5

* USCS (Unified Soil Classification System) - designation symbols 1st : G = gravel, S = sand, M = silt, C = clay; 2nd : W = well graded, P = poorly graded, L = low plasticity, H = high plasticity, C = clayey; (Bureau of Reclamation, 1960)

General:

A. any number of interments may be made in the one grave space: emplacement is only limited by safe working and excavation conditions;
B. there is no impediment to emplacing remains vertically orientated;
C. interred remains need not be coffinated;
D. the grave invert level (lowest-most base of grave) should be at least 1 m above any permanent, ephemeral or fluctuating watertable, and at least 1.2 m in sandy soils (Figure 7.4, notation C);
E. the minimum thickness of soil cover entirely above the last interment should generally be not less than 0.9 m of clayey soils and at least 1 m of sandy soils (Figure 7.4, notation B);
F. the finished backfill above all grave spaces should be permanently sloped to shed water away from the present and adjacent grave/s and in the direction of natural site drainage;
G. the nearest horizontal distance of any interment part to the cemetery boundary (the buffer zone) should be not less than 10 m in clayey soils and not less than 20 m in sandy soils if topographically downhill or hydraulically downgradient; and half these values if topographically uphill or hydraulically upgradient (Figure 7.4, notation D).

CEMETERY LOCATION

Floodplains and Coastal Sites

The matter of siting cemeteries on floodplains has two major aspects to it. Firstly, the issue of scour of the site, and secondly, the effects of inundation of graves and vaults. This second aspect in turn has sub-issues related to the spread of disease, hydrostatic uplift of the coffin and compaction of grave fill. Beyond this, other matters relate to the maintenance and repair of the site and its infrastructure, destruction of drainage networks, clogging of subsoil drains, damage to monuments and grave property, and relocation and possibly scattering of interred cremated remains.

From many viewpoints, the location of a cemetery on a floodplain subject to near-term inundation is undesirable. The greatest difficulty is to decide what constitutes 'near-term' exposure. It certainly doesn't mean consideration of eustatic sea level rise, except if the location is coastal or estuarine and global sea levels have a high likelihood of inundation within the time-frame otherwise adopted. If this were the situation then parts of BOT, all of NEW and HEL would be unsatisfactorily located.

In Australia during the 1990s a great deal of planning attention was given to floodplain delineation with consequent reservation of areas from development and application of development restrictions. Much of this effort was devolved to local government who have had to implement policies restrictive to community activities and commercialisation. Cemeteries are not immune form these considerations; the Researcher has consulted on two sites in different states where these matters were exactly the ones being considered. The developers' desires to maximize their site usage need to be considered from all aspects.

Scour occurs when the velocity of the moving water is sufficient to either force soil particles into suspension or is so turbulent that the particles move along the bed of the flowpath. Many floodwaters are sluggish and/or very slowly invade or retreat from the land and consequently scour is not a serious issue. In such cases the inundating waters are liable to deposit silts and clays as their velocity falls. The situation is exacerbated by evaporation with the likely consequences of clay coatings on monuments and structures, and fresh soil blankets elsewhere. The more sloping the site, the greater the chance of scour, so that low-lying, sloped ground, for example a stream bank, *if somehow utilised*, should be designed to direct waters gently away from it.

A concomitant concern is for sites that are located in coastal areas subject to scour as wave erosion due to storm surge or tsunami. If standard geoscientific conditions relating to cemetery location have been satisfied, then further special attention needs to be given to these sites.

Because of the likely strength of tsunamis and their instantaneous and unstoppable nature, the potential location of cemeteries in tsunami-prone land has to be carefully considered. The major concerns relate to exposure of graves by scour, and monument and infrastructure destruction. The likelihood of inundation and disease spread is lower than for other floodplain situations because the invading waters should rapidly retreat. The speed of the retreating waters needs to be managed.

The retreating waters might be managed by ensuring that the cemetery is designed around shallowly sloping land, all sloping towards the ocean/estuary with no physical restrictions between highest and lowest points and perhaps with purposeful, shallow swales aligned along maximum gradient in order to funnel the drainage. These swales should not be developed in their central area in case of scour. Areas or artefacts that could encourage ponding should be prohibited. Such sites also need to be in non-friable soil, for example clayey sand or sandy clays, and should be well vegetated with deep-rooting grasses. A cemetery in this kind of location would be well-suited to a lawn-type: interments should never be shallow – probably always with at least 1.2 m of soil cover. The need to allow free downgradient surface drainage inhibits the kind of plantings in the buffer zone in the lowermost portions; deep-rooting shrubs are likely to be better than trees for such a task.

Storm surge occurs where unusually large storms force water – usually seawater –

onto the land; often the event is associated with high tide. This is usually a sudden occurrence, however, it may be sustained for a number of hours, and repeated over several days in very extreme conditions. The erosive force of the driven water is usually high and is responsible for considerable structural damage, scour and shifting of soils where this is facilitated. Friable soils are more susceptible than well planted ones to removal. In 1972 a major storm event in Sydney resulted in erosion by this process in the southeastern corner of BOT; a coffin was exposed.

Where storm surge is judged to be a possibility, then either defensive construction should be undertaken to protect the area, or burial should be prohibited in this land.

Sites which will only ever be subject to very low velocity floodwaters in inundation and retreat are primarily of concern from the other major matter – spread of disease.

The spread of disease, related to micro-organisms interred in the remains, occurs as a result of the normal processes of the hydrologic cycle; this is discussed previously. The likelihood of the presence and spread of the micro-organisms will vary for each different hydrogeological context. The difficulty with flooding is two-fold. Firstly, the event causes an ephemeral mounding condition in one or more graves that will likely in turn cause an abnormal recharge to the groundwater table, in a less-than-usual timeframe (because of the column of saturation), with the capacity of taking with it any opportunistic or viable pathogenic micro-organisms; or, it may create an in-grave, sustaining pond (bucket). Secondly, the super-saturated condition, in-grave, could lead to the spread of the same types of micro-organisms onto the surface.

In both instances the longer time viability, or even the innate survival, of the micro-organisms may be challenged. However, the major unknowns are:–

- which micro-organisms are present,
- were they engaged,
- did they prosper,
- did they transmit.

In short, is there a risk of disease spread? The logical end-position is "yes". Accordingly the risk needs to be managed by aversion

As discussed earlier, the nature of cemetery operations is such that at any time the location or age of interment activities is substantially uncontrolled and/or unknown; albeit this may have been confined to certain 'new' areas or stages in the cemetery. The argument then turns on what is the correct timing for developing any new area or stage with respect to the likelihood of inundation. The answer, from any perspective, is that it is unknown; accordingly, the whole site – subject to inundation - must be treated under one set of rules.

At the same time an impinging argument relates to the longevity of the cemetery. In the case of a recent development this is quite obvious, but what about more established sites and closed sites? The issue is to define a suitable time-frame of concern.

An approach that has been used for planning purposes relied most heavily on the concept of the 100 year flood (NSW Government, 1986, Hall et al., 1993). This approach has for various reasons been discarded in some local development planning, for example in NSW – "Flood Development Manual, 1986" (NSW Govt.), however, it has some merit in the cemetery context. 100 years is a long time for a structure to stand or for unchanged societal activities in one place. In the context of family succession and possible interests in burial grounds/places, 100 years is also a suitably long time (4 generations) such that specific interest has usually waned; see for instance the analyses by Davies and Shaw (1995) and Bachelor (1996). As shown above, 100 years is also a reasonable time for the disintegration of large amounts of remains, although some parts of remains are likely to be present in most hydrogeological settings even after 100 years; the matter may then be considered to be one of ethics and social context.

Since 1998 when design concepts in the context of cemetery function were first promulgated (Dent and Knight, 1998) there should be no situation where any cemetery development would proceed without correct geoscientific evaluation. So the whole matter of time-frame is only of concern to still-operating, poorly sited cemeteries on land subject to inundation. The matter of closed cemeteries probably turns on economic factors; the relocation of a cemetery is very costly, and probably an unacceptable cost for any community to consider. It is not possible to predict when, in any 100 year interval, a cemetery will be inundated; merely to predict that it is likely – in any rolling 100 year period – that the land will be inundated. Consequently, only a general rule on relevant cemetery siting can be developed; individual sites may be able to be reassessed on their merits, in some cases a 50 year interval (absolute minimum) may be appropriate, and flood mitigation works or design can be used to reduce any of the effects discussed above.

In the general case then: **no operating cemetery should be located on any land likely to be subject to inundation within 100 years; the 1 in 100 year (or 1 %) flood level. Thus any existent cemetery, which although well developed and/or supposedly 'closed', located on any identified lands, should not receive any further interments.**

Swampland and Waterways

The previous assessment of the survival and transmission of potential pathogenic organisms, and the likely off-site migration of some nutrient substances, has reinforced the need to keep cemeteries away from swampland or other natural groundwater phenomena or waterways and lakes. This includes ephemeral lakes and areas where there are seasonally high watertables, unless in the latter case the grave invert – watertable separation distance, as herein, can be maintained. Waterways in cemeteries are usually small, often intermittent, streams; however, the same concepts need to be applied to the situation where a cemetery might have a river or lake frontage not otherwise protected by planning laws.

The potential risk is that products of decomposition will spread from the swampland and contaminate the groundwater system and/or have detrimental effects on the swampland ecosystems. In the latter matter, the effects will be very varied depending on the size, type and inter-relationships of the swampland.

In some cases such sites may only be known to cemetery staff (generally small sites), or local residents or visitors to newer areas. For this reason, potential cemetery sites must be correctly evaluated from a geoscientific perspective, before, and sometimes during development.

Historically, swampland has often been regarded as 'useless to society', a breeding ground for pests (for example mosquitoes), unattractive, or as land unsuitable to 'development' for other reasons. As a result, cemeteries have been located adjacent to and over such lands with concomitant effects on the environment and difficulties in operation of the cemetery. This is evident at BOT in the vicinity of the central water feature and GUI in respect of the cemetery dedication of ephemeral swampland. Fortunately at both these cemeteries, management and design practices have been instituted to mitigate any effects; however, it would have been better had they not been located there in the first place.

Generally speaking, society no longer accepts that it is satisfactory to degrade, drain or fill-in swamps; accordingly, future cemetery developments should be saved from being considered in this situation.

As for cemeteries adjacent to swampland or waterways (outside cemetery boundaries), then normal buffer zones must apply together with any other special considerations; it is not satisfactory for shallow groundwater systems to leave cemeteries and re-emerge in swampland after only a short distance. Some generalised planning rules should be applied: for example, a 50-day isochron derived by Uniform Flow Model (see later discussions) from the cemetery boundary, or 20 m plus 50-day isochron from the nearest interment.

For In-cemetery swampland or areas of high watertable, 20 m setbacks should be generally sufficient if they are fully within the normal buffer zone, or otherwise a 50-day isochron. Applying these criteria to GUI and BOT and using data from Appendices B, J and K; then at GUI setbacks of between 14 to 22 m (so minimum

20m) would be required. At BOT, the micro-topography around the main swampland is quite variable and consequently watertable gradients are variable and often quite steep; however, generalised modelling indicates that variable setbacks from 17 m (so minimum 20 m) to 83 m to173 m would be needed.

The limited scattering or interment of cremated remains (ashes) in and about In-cemetery swampland should not present a major problem provided that the practice accords with the guidelines already established previously (see above); with special attention being given to the likelihood of any overland flow removing ashes to the waterway/swampland, or any flood scour possible on the same land doing the same thing. Protection by bunds or levees is likely to provide some satisfactory solutions.

Cliffline/Cliff-top, Seepage Areas and Drainage

Clifflines are frequently used to demark landuse boundaries, and accordingly can be applied to cemetery location. If the cliffline is the cemetery boundary then normal provisions for buffer zones should apply with additional attention to the fact that groundwater often emerges at these places because of the lowered hydraulic head. Often this is seen as seepage at the soil – rock interface. In these cases, the protection and attenuation of groundwater otherwise conferred by continuous in-ground percolation is absent. Hydrogeologically, such situations are springs or seepage areas, and are akin to any emergence of shallow groundwater systems in swampland, lakes or waterways.

The management and planning concepts developed for swampland should be applied where groundwater seepage is evident, or occurs at any time, at clifflines. Where the cliffline hosts small In-cemetery waterways or drainage lines then the setback concepts for those features should also be applied. Generally these rules are the 50-day isochron and 20 m minimum. Generally speaking, drainage/seepage waters from In-cemetery situations should not simply be collected and led away off-site; they should be allowed to flow across the site or collected in holding ponds, or artificial wetland situations before being discharged to natural systems.

A related but slightly different situation occurs in the matter of sub-soil drainage. Generally speaking, such drainage systems are installed to aid the development or usage of areas that wet-up seasonally or which permanently have high watertables, or mounded groundwater. Some of this may be due to significant transient unsaturated zone flow, for example at WOR, MEL and LAU, associated with the soil – rock interface or shallowly dipping, thinly bedded strata, or fractured regolith. It is not satisfactory to simply collect this water and lead it off-site. Doing this may circumvent the attenuative roles of groundwater percolation and residence time.

Often the drainage is in less satisfactory, generally clayey soils (for example at CEN and LAU), and the groundwater has taken 50 days or more to reach it. In soils designated: SM - MH, ML - MH, or ML - CL, and with hydraulic conductivities of 1.00E-6 or lower, this is likely to happen in less than 1.5 m to 6m (the latter only at very steep gradients). In such cases, provided the nearest interment is at least 1.5 m from any drain then this should be satisfactory for the general situation. If the drain is a simple tile-drain or sand in-fill without basal pipes then this would afford better protection. Disposal or release of the drain water on-site is preferable. Much of the sampling at WOR examined this situation: well W9 was located in such a drain, well W5 trapped transient unsaturated zone flow, and well W7 was adjacent to, but didn't intersect, a sub-soil drain. See Appendix C and discussion in Chapter Five (Outcome 9) for detail of these results, which showed some variability.

Water in sub-soil drains which has not benefited by 50 days of subsoil percolation is more problematic. This water really needs to be collected and held or treated prior to release from the cemetery boundaries. One suitable method of doing this is by on-site ponds where eventually the water will leak away or be evaporated. This is done effectively at LAU in the in-filled gully area; the LAU pond was sampled regularly - see Chapter Five and Appendix G. Another method is to discharge the drains into an artificial wetland or similar where final residence time and 'polishing' of the water is provided. This is partially practised at WOR; however, these systems require regular maintenance.

If drainage, waterways or wetlands from cemeteries immediately feed into drinking water storages then a more rigorous protection and planning regime should apply. In such cases, all protective and location conditions should be directed toward a 100-day isochron for all possible groundwater before it leaves the cemetery boundary. Thus, the water crossing the cemetery boundary in such situations should generally comply with the requirements for drinking water abstracted from wells (see later discussions).

Aspects of drainage, typically disrupted ones above cemeteries, or diversions due to cemeteries, have been significant parts of litigation in the USA caselaw (Appendix M). The issues raise mainly relate to a claim for nuisance, and appear to have been settled on matters relating to landholders' obligations to permit free and natural drainage to continue.

In-cemetery Artificial Ponds, Lakes and Dams

Many cemeteries host constructed ponds, lakes and water features. Some of these like at BOT, SPR and LAU incorporate natural drainage lines, whilst others like at NEW and CEN are created In-cemetery. Wherever these features are constructed without impermeable linings they will impact on the natural groundwater system; in the first instance by localised raising of watertables and wetting-up of the vadose zone. Other effects may be by mounding with slow percolation, flow to watertables via fractures and macro-pores or a faster level of seepage into the unsaturated zone – an artificial recharge. Most features also serve as sinks for stormwater runoff, and when full, contribute overland flow into the cemetery.

These features are most likely to be problematic where they are effluent of the local groundwater system, and/or in any case are unlined and not independent of the cemetery soils. In such cases some of the rules already established for waterways need to apply; with the aim of preventing a buildup of potentially pathogenic organisms and nutrients. If the nearest interment is located at a distance of at least 20 m or the 50-day isochron away, then this should represent a generally satisfactory situation.

As per the situation of swampland, if these features are fully In-cemetery, they need to be wholly within buffer zones: if permitting infiltration to the unsaturated zone or coupled with the watertable directly, then they need, in addition, to be at least as far as the 50-day isochron (Uniform Flow Model) from the cemetery boundary.

Cold and Tropical Areas

Decomposition processes will be retarded in cold ground and enhanced in warm ground (see Chapter Two) . Moreover, since some sites in colder climatic areas also experience some seasonal warming, then it might be expected that shallow interments may exhibit short periods of faster decomposition. On a gross scale, and for a body on the surface, this was one of the effects observed in the Iceman, an approximately 5300 year old mummy located in a former glacial region (Bereuter et al., 1999). It might be expected that interred remains will exhibit aspects of natural mummification, except if contained in non-biodegradable body-bags; adipocere formation is measurably retarded in cold conditions (Forbes, pers. comm., 2002).

The present Study focused on sites generally in temperate areas (Chapter Four) and it is to be expected that there will be some difference to sites in other climatic regions.

Sites in colder areas should release their decomposition products more slowly, and hence this should be of significance over a longer timeframe, meaning that there is the propensity for environmental impact for longer. Bacteria and viruses are likely to survive longer in such settings (Chapter Six) and where transported are more likely to be done so in a viable state. Accordingly, setback and buffer zone distances, as developed elsewhere herein, need to be strictly applied. Some extra, special consideration may be warranted for cemetery - well separation distances; but these should certainly not be less than the 100-day isochron (see following discussions).

In tropical areas, the enhancement of decomposition, particularly for shallow interments implies the opposite of the foregoing. An enhancement may include the likely rapid increase of potentially pathogenic bacteria as they build-up under favourable conditions: they may then be distributed in greater quantities than for the temperate zone, and possibly further under the influence of greater percolation rates. This requires that careful attention needs to be given to aspects of bacterial and viral subsurface distribution.

Gases from the decomposition processes are likely to be released more quickly in warmer areas so that the amount of cover on interred remains should likely be greater than that for the typical temperate setting. A related matter is that the in-filling soil of the grave is likely to wet-up and remain saturated or at field-capacity for long periods of time, and mounding within graves is more likely because of increased precipitation. Probably a minimum 1.2 m of well-compacted grave in-fill with heaping of spoil above grade, is required to ensure good interment conditions.

Shallowly interred remains are subject to contributing substantial amounts of necro-leachate to shallow groundwater systems or to overland flow because the grave works as a ‘bucket’ and the stored water is rapidly disgorged. This is exacerbated in clayey soils and is illustrated in Figures 7.2 and 7.3 for the situation in the cemetery Vila Nova Cachoeirinha, São Paulo, Brazil, where cemetery operational practices are poor.

In many tropical areas a problem is encountered in aquifers with rapidly changing watertable levels. For example, Jean (2000) reported that for a study in Taiwan the watertable fluctuated between 2 and 10 m seasonally, and in the case reported this was a factor contributing to the spread of pathogens. Consequently, cemetery management practices in tropical areas must take account of the full variations in sites’ hydrogeology.

Karst and Areas Prone to Mass Movements

Areas exhibiting, or known to be underlain by, karst, pose a special problem for the siting of cemeteries. Two main issues arise; firstly, the depth of the soil, and secondly, the possibility of large scale bacterial and viral transmissions from the site.

Figure 7.2 Shallow burial (0.6 m) at cemetery Vila Nova Cachoeirinha,
São Paulo, Brazil (photo B. Dent, 2000)

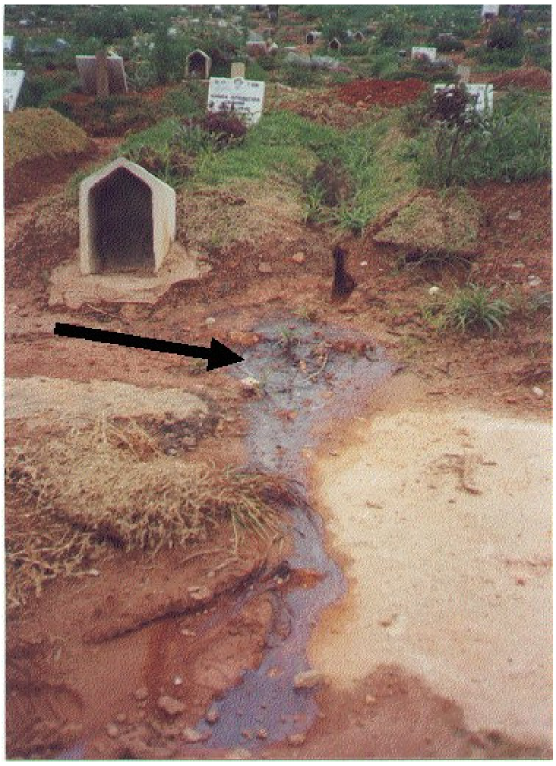


Figure 7.3 Necro-leachate (arrowed) at cemetery Vila Nova Cachoeirinha,
São Paulo, Brazil (photo courtesy of B. Antunes, 1999)

Where soils are thin, there is likely to be the tendency to inter remains directly on or within bedrock – a carbonate rich material (usually limestone, but including chalk and dolomite); and, in some cases - calcareous alluvial deposits. This means that percolating groundwaters and hence necro-leachates are in rapid contact with fracture and/or solution systems with high hydraulic conductivities, and hence they easily migrate off-site with little or no attenuation. The interment of remains in dolines, caves, or solution structures of any kind should be prohibited.

A suitable approach is to require that cemetery soils in karst, or similarly suspect terranes, be thicker than usual, and that there be at least 1.2 m soil thickness beneath grave invert level. This may be a somewhat onerous requirement in general terms, so that a comprehensive geoscientific site investigation for any proposed extensions or new cemeteries is required; and the outcome may rule out any difficulties and allow a variation to this proposal.

There are a number of well documented cases where groundwaters polluted with bacteria and viruses have travelled great distances in karst terrane or in fractured chalk. The distances reported vary from 900 m to at least 9 km, and include instances of percolation through unsaturated zones. Relevant discussions and reviews on this matter are to be found in:- Vogt (1961), Kudryavtseva (1972), Edworthy et al. (1978), Lewis et al. (1982), and Hunter and McDonald (1991). A report by Hötzl et al. (1991) reports the tracking of phage tracers for at least 10 to 14 km, and 39 km.

The relative location of drinking water wells to cemeteries in these terranes requires special consideration; and the 100-day travel-time isochron setback distance, should be properly instituted. Again, in many cases, diligent geoscientific investigation is likely to rule many sites in. At these sites, proper cemetery practices and enforced standards should ensure a relatively low impact from the landuse.

Areas subject to soil creep, slumping or earthflow movements are not suitable for cemeteries. In these terrane types there is at some point an excess of soil moisture; this is a significant factor in the land instability. With land instability comes the propensity for:- disruption of graves - lateral, down-slope, or twisting movements; exposure of graves and remains; excessive infiltration of precipitation into disturbed soils; and escape of fluids from the grave “bucket” (see Chapter Six).

Other impacts in slip-prone land relate to general damage and disruption to infrastructure and monumental masonry. Underground drainage, water and sewerage service lines are also subject to greater leakage with the possibility of decomposition products being encouraged to migrate off-site; possibly via natural drainage courses.

In many cemeteries the management often has to contend with monumental masonry, including lines of headstones or plaques, being disrupted due to vertical soil movements. At CEN, swelling soils and possibly gilgai, have a noticeable effect in some parts of the cemetery; however, large scale disruption of graves has not been reported. Any initial geoscientific investigation of a proposed cemetery site should include assessment of clayey soils for mineralogy and CEC. Soils rich in swelling clays like mixed illites or montmorillonite should be carefully evaluated for their potential impact. Shallowly interred remains should be avoided; but other matters with the heaving soils above graves essentially become a maintenance concern.

In colder climates, the surface phenomenon of solifluction may produce a small operational hazard in cemeteries and is also likely to impact on their general infrastructure. It is also likely that in such terranes that infiltration of groundwater will be increased, at least during the melting phase. The permanent heaping of soil above the grave after backfilling should help to mitigate this matter.

Landfill Sites

The Researcher has been asked by several Australian cemetery operators to consider the concept of developing large municipal domestic waste landfill areas for the purposes of a cemetery. The argument advanced by the proponents is that the land has already been used for waste disposal once, it is now reserved from development, yet comprises an often large areal extent, and therefore could host another surface activity without significant additional impact. Such a concept is known in the literature in only one paper by Stournaras (1994), for a site in Greece.

The idea seems instantly attractive but its deeper consideration raises a number of issues in hydrogeology and geotechnical practice. A properly completed landfill is designed to prevent the ingress of water, to shed surface runoff and to prevent the escape of landfill gases. Typically the sites suffer significant, irregularly spaced, on-going settlement accompanied by loss of integrity of the surface finish.

If the site is covered by cemetery infrastructure and graves the extent of the surface alteration will be largely unknown. Furthermore, it is not feasible to safely, hygienically or easily excavate into the landfill wastes to create a grave, so that any grave system must essentially be above the landfill finished level. There is a risk to the landfill integrity if the surface cover is re-opened, and there are also issues of creating mass movement in lifts and batters if the surface loadings are disturbed, possibly by extra loading of burial soils.

This is not to say that such sites cannot be re-developed or additionally developed to accommodate cemeteries above them. They generally have some suitable primary aspects, for example; provision of substantial buffer zones, already reserved land, propensity to become a more usable public resource, possibly drainage and/or leachate management systems, and road systems. Each site would require careful geoscientific evaluation and design elements consistent with the general approaches herein. Sites should not be excavated for development, and drainage and sub-surface water management considerations are paramount.

Some of the issues involved in the recycling of landfill space for other purposes have been reviewed by Qasim and Chiang (1994); the examples cited by them have relied on the near-completion of degradation of the fill – as measured by methane production. Other examples of re-use of landfill sites have involved the complete removal of the fill: however, in these situations the land acquires a considerably increased value and this is quite different to locating a cemetery on top. Locating a cemetery atop a landfill essentially reserves the land in perpetuity.

DRINKING WATER WELLS AND WELL-HEAD PROTECTION

One of the most vexed issues in geoscientific considerations and legal wrangling noted to date (see Chapter Three) concerns the relative placement of drinking water wells – whether municipal or domestic – to any interred remains or cemetery. Principally the issues relate to cemeteries located above, or contiguous with, unconsolidated aquifers. There are few discussions in the literature, other than perhaps for legislation; however, when the matter has been codified the separation required is of the order of 250 m or more (see Environment Agency, 1999 and 2000, WHO, 1998, Arche et al., 1982). The matters also extend to farm animal remains, and have become particularly important, indeed somewhat prominent in the 1990s with respect to diseases like anthrax, foot and mouth, 'mad cow' (TSE) and Newcastle; but, these are not specifically considered here.

Since the unsaturated soil at depth is where infiltration of decomposition products first occurs, then the vadose zone must be considered first. The concepts of vertical distance-travel times for microbial contamination in the vadose zone have been discussed in a previous section, but the matters need to be further clarified. This is a complex issue, and not the same as the situation where a broken sewer line or a septic tank drainfield or effluent recharge basin is used to provide large, and/or continuous fluxes of percolating, contaminated water. However, there is some synergy with the disposal of human excreta on a household level, in pit toilets or similar: these matters which have been canvassed by Lewis et al. (1982), can be drawn upon in the present considerations.

Percolation rates for decomposition products in the cemetery situation need to be considered in respect of the soil's volumetric moisture content below grave invert level. This is highly variable, and could include instances of mounded watertables, slugs of body fluid-induced wetness, and could be below or about field capacity of the soil, or be very dry.

Suitable separations can be determined on a site-specific basis, but they are not amenable to general guidance in a tabular form. **In general, the vertical separation zone between grave invert level and any watertable** (permanent, perched, ephemeral or fluctuating) **should be at least 1 m**; it should be greater in wet, fine, clean sands, and thicker in wet clays than dry ones (Figure 7.4, notation C). No interred remains should lie in, at, or be inundated by the watertable.

In respect of cemetery - well separations, it is difficult to source the relevant information generally regarding codified distances, and a comprehensive study of most countries' legislation would be required to adequately report this data. For example, in recent discussions De Natale (pers. comm., 2002) has conveyed the information that in the state of New Hampshire, USA, cemetery - well separations are controlled by 1950's legislation requiring sanitary set-backs for sewer and septic tanks from wells of 400 ft (122 m). On the other hand, Yanggen (1984) reports that in Wisconsin, USA, only 100 ft (30 m) separation is required of a domestic well from a cemetery grave site: it is not known whether this law still applies. This situation is likely to be indicative of the wide variation that might be found in just one country, let alone the World; another overview of the issues with reference to the USA is provided by Macler and Merckle (2000).

Goodman and Beckett (1977) provide a useful summary of early public health legislation in the UK. In their paper they state that in 1879 houses (and hence the houses' wells, since many had wells) were required to be 200 yards (183 m) from a burial ground, and that in 1906, the distance of a dwelling was reduced to 100 yards (91 m). The matter was apparently under continual review till at least about 1958 when a hydrogeologically-based discussion paper pointed out that "the risk to which wells are exposed from the proximity of a properly managed burial ground is in ordinary cases [not] great … [and] … is probably less than that to which [people] in unsewered villages … are exposed by soakage into the subsoil from cess pools and privies"; consequently the matter was not included in the *1961 Public Health Bill* (Goodman and Beckett, 1977).

In the UK, the Southern Water Authority's Aquifer Protection policy introduced the concept of a 50 day travel-time set-back distance (50-day isochron) in 1985

(Environment Authority, 1999); this has since become a common conceptual style applied to various well-head protection issues in the UK, USA and elsewhere. The US EPA in its initial considerations for the microbial protection of groundwater proposed a two year vertical travel-time for water infiltrating the vadose zone before it reaches the watertable (Jorgenson et al., 1998). In California, USA, land-spread, microbially contaminated, aquifer recharge water is required to be a minimum 500 ft (152 m) horizontally from any abstraction well (Karimi et al., 1998). The requirements of various groundwater protection matters are quite variable from place to place and water type to water type.

Adams and Foster (1991) of the British Geological Survey, comprehensively reviewed the matter of zonation around wells for sanitary and chemical protection on behalf of the National Rivers Authority (UK) who recognised the need for an inclusive consideration of groundwater protection. They reviewed the situation for many European countries and also presented indicative models as to how the process works for various levels of abstraction and aquifer properties. Most jurisdictions examined used a model of: a courtyard protection (that is, Zone I - no development immediately adjacent to the well for 10 – 100 m); then a Zone II (Inner Zone) defined by 50 – 60-day isochrons (or 100 – 400 days USSR, ≥ 200 m Italy); then a Zone III (Outer Zone) of extremely variable size or travel times. Finally they made recommendations which revolved around a general acceptance of the 50-day isochron as being the principal discriminator for immediate sanitary protection (Adams and Foster, 1991).

Soulsby (1999) has further discussed the zonation distances developed by the British Geological Survey in a variety of applications and enumerates the currently accepted practice as being: the concept of an inner courtyard (Zone I) of between 10 and 100 m, an Inner Protection Zone (Zone II) from 100m to 2 km being at least the 50-day isochron, followed by an Outer Protection Zone (Zone III) set at the 400-day isochron. Similar techniques have been developed in some USA jurisdictions: for example, Shair and Ahmed (1997) report a case in Florida where the zones are respectively set at the 10-day, 30-day, and 210-day isochrons, or the 30-day zone plus 0.3 m drawdown, whichever is greater. In another case, Carpenter and Mize

(1997) report on the Utah (USA) strategy which sets zones respectively at: 100 ft (30.5 m), 250-day, and 15 year isochrons. In NSW the State Government has adopted a zonation model based upon the 50-day isochron with minimum 50 m for Zone I, and 400-day isochron for Zone II (NSW Government, 1998).

Codified set-back requirements, or zoned protection travel times, are introduced as a general planning measure. They necessarily aggregate a number of relevant matters like the soil type and hydrogeological setting or cemetery operations, which might be important on an individual basis, into an easily understood and enforceable (usually) rule. These rules serve the general situation very satisfactorily, but it is possible that a comprehensive geoscientific study relying on considerable field data might determine that the "safe" location distance (cemetery – well) could be reduced for a particular site. For example, Adams and Foster (1991) point out that in some places of higher urban density and maybe lower socio-economic status, that it maybe difficult to have the desirable protection model in effect. In those cases the protective benefit conferred by the unsaturated zone should be taken into account, whereas this aspect is normally a 'safety bonus' and is not considered in the specification of zones or distances.

The concept of the cemetery being involved in a well-head protection zone close to the actual well (for example a Zone I or Zone II – courtyard plus inner zone - however defined) is considered to be generally unsatisfactory; but such an outcome is likely only be avoided in new establishments. Cemeteries have often been intimately incorporated into village and town life, so that now, with established land-use patterns and settlements, the situation is almost completely impractical to avoid. In such cases, there is the obvious proximity of the two features, and in addition, the effect can be brought about because in high demand wells, the capture zone theoretically continues to extend with continuous constant-rate pumping so that it eventually extends beneath any nearby cemetery. Fortunately, with time, the likelihood of micro-organism contamination from older cemeteries significantly reduces; but not necessarily for embalming metals like arsenic or mercury.

Rather than mandated distances (or travel times) a method of greater merit is the precise evaluation of travel-time distances for percolating groundwater. By doing this a sufficient standard is then applied so that any bacterial or viral transmissions will be dead or at least be reduced to extremely low dose possibilities, provided the absence of highly conductive soil or rock pathways is confirmed. Such evaluations are, however, very costly and require the detailed, field- and laboratory-supported testing by a hydrogeologist. The extent of the evaluation can range from very simple and general – the approach taken herein, to very sophisticated numerical modelling using projected decay rates for bacteria or viruses, and known site parameters.

This latter approach, based on modelling of worst-case viral transmissions, is one of the means indicated for groundwater suppliers in the USA in accordance with the US EPA's Groundwater Disinfection Rule (Berger, 1994). There are, however, difficulties in applying such advanced techniques in the case of cemeteries. These include:- an unknown source term (that is, how many virus particles to commence); which viruses to model for (most can be buried – over 100 enteric viruses are known to survive in adverse environmental conditions and water, see Armon and Kott, 1994); unknown decay rates for most viruses (Berger, 1994); unknown spatial and temporal starting points. Yates et al. (1986) attempted such modelling for septic tank set-backs in various hydrogeological conditions, and showed that these varied considerably from 15 m to > 150 m in the one small area. This matter is also discussed for bacteria by Gerba et al. (1991) in Hurst's book about modeling for micro-organisms in the environment. Modelling does not eliminate the need for site evaluation to provide real site hydrogeological data. A better approach, in this instance is likely to be generalised set-back/separation zone mandating.

From the review of micro-organism survival and transmission in soils and groundwaters in Chapter Six, it was proposed that a 100-day survival/travel-time concept was probably the safest approach. This is also the easiest general model to apply based on the concept of a well abstracting at some constant or design rate. In an unconsolidated aquifer, the effects of distortion of the watertable caused by pumping, within the cone of depression, and under the influence of a regional groundwater gradient have to be provided for. The work reviewed above, and most codified well-head protection schemes are, however, founded on the primary concept of the 50-day isochron. Adams and Foster (1991) briefly mention this matter and point out the difficulty in promulgating *any* arbitrary figure. A 100-day iscochron setback for cemeteries appears to be relatable to potential groundwater travel-times in a static sense, and hence is more likely to be effective in a dynamic sense (that is, during abstraction).

Ideally, cemetery - well separation distances would be developed on the basis of the intersection of the steady-state pumping well'/s' cone/s of depression and the cemetery boundary, or other nearby position, such that the effective hydraulic gradient induced during pumping was related to appropriate travel-time distances for bacteria and viruses (being at least 100 days); also see Berger (1994). But this is not practicable for the guidance in the myriad of hydrogeological settings likely to be involved. As the amount of water abstracted for any one well increases the size of the travel-time protection zone (isochron) grows. In addition, the area is subject to some recharge during the pumping phase and this has the effect of reducing the growth pattern, but only slightly. The final situation must therefore be fixed in terms of the maximum or sustained abstraction rate. Recharge is frequently ignored in primary calculations, just like any attention to the unsaturated zone.

There are three methods of arriving at the generalised setback distances required.; each has different merits. Firstly, the static regional flow ("Uniform Flow Method", Ontario, 2002) is the easiest to evaluate and provides a likely maximum distance – it is conservative. Secondly, the conditions represented by a pumping well ("Calculated Fixed Radius Method", Ontario, 2002) can be evaluated within the exact aquifer context; however, this is conservative on the down-gradient side but under-estimates the up hydraulic gradient setback because it makes no allowance for regional flow. Thirdly, are advanced numerical pumping and flow models which can estimate the isochron size quite accurately depending upon the input variables, although there is no exact mathematical solution to the equations of flow required. The third method is technically superior, and accounts for recharge, but requires detailed field information and is likely to produce a solution intermediate between the other two approaches, and should give a solution which saves some setback distance (Figure 7.4, note E).

Representative 100-day travel-times are presented in Table 7.6 for various values of hydraulic conductivity (K) and effective porosity of the aquifer using the Uniform Flow Model, a static (non-pumping) model. Representative values of K for various soil types classified in accordance with the USCS are also included (Table 7.6), but noting the difficulties of this concept (Fogg et al., 1998). The data of this table demonstrate how the 100-day travel distance can be quite substantial in some gently sloping coarse sandy or gravelly aquifers; for example, in a clean sand formation (K = 1E-3 m/sec) with a gradient of 1 m in 100 m, this could easily be 250 m. This time-distance requirement is, however, relatively conservative, because many aquifers, for example under floodplains, would have somewhat lower gradients and be comprised of more heterogeneous, or finer, media. At the other end of the scale, aquifers in aeolian dune deposits or alluvial fans, could easily exhibit features permitting groundwater flows with high linear velocities. Indicative maximum time-distance separations (r) generated by the Calculated Fixed Radius Method (Ontario, 2002) are shown in Table 7.7; these under-estimate the up-gradient separations.

A default cemetery - well separation of 200 m is proposed. It is likely to be quite acceptable for the general location of a correctly sited and managed cemetery. This separation is aided by the requirements for buffer zones and grave invert separations above watertables. Table 7.8 is presented using the 250 m separation concept, in order to illustrate the currently promulgated positions. Figure 7.4 (and note E thereto) presents an overview of all the concepts relevant in this matter.

The type of study required for the idea of overcoming the general rules must include a comprehensive field and laboratory investigation of the hydrogeological conditions surrounding the site, and which specifically includes the ruling-out of the presence of highly conductive zones along potential groundwater travel paths to the well. In addition, the location solution should be one that places the well with its maximum likely induced drawn-down hydraulic gradient **at least 100 travel days** from the cemetery boundary; any evaluation of K should reflect the typical local, uncontaminated, background groundwater found at 1m below the deepest invert of any proposed interment.

Table 7.6 100-day Travel Distance Tables for Various Unconsolidated Deposits

(Makes no allowance for dispersion. Tables should not be used to predict solute fronts. Use with cemeteries should consider the cemetery "black box" as a continuously producing source at the boundary across all at-boundary flowlines. Blank fields in table indicate unlikely natural condition. Not all variations are evaluated for all parameter combinations.)

values in metres
(m /100 days; highlighted values < 200 m)

typical K (1) m/sec	gradient m/m	Effective Porosity							
		15%	20%	26% (2)	30%	35%	40%	45%	48% (3)
1.00E+00	0.01			332308	288000	246857	216000		
	0.005			166154	144000	123429	108000		
	0.001			33231	28800	24686	21600		
1.00E-01	0.05			166154	144000	123429	108000		
	0.01			33231	28800	24686	21600		
	0.005			16615	14400	12343	10800		
	0.001			3323	2880	2469	2160		
1.00E-02	0.1			33231	28800	24686	21600		
	0.05			16615	14400	12343	10800		
	0.01			3323	2880	2469	2160	1920	1800
	0.005			1662	1440	1234	1080	960	900
	0.001			332	288	247	216	192	180
	0.0005			166	144	123	108	96	90
1.00E-03	1	57600	43200	33231	28800	24686	21600	19200	18000
	0.5	28800	21600	16615	14400	12343	10800	9600	9000
	0.1	5760	4320	3323	2880	2469	2160	1920	1800
	0.05	2880	2160	1662	1440	1234	1080	960	900
	0.01	576	432	332	288	247	216	192	180
	0.005	288	216	166	144	123	108	96	90
	0.001	58	43	33	29	25	22	19	18
	0.0005	29	22	17	14	12	11	10	9
	0.0001	5.8	4.3	3.3	2.9	2.5	2.2	1.9	1.8
1.00E-04	1	5760	4320	3323	2880	2469	2160	1920	1800
	0.5	2880	2160	1662	1440	1234	1080	960	900
	0.1	576	432	332	288	247	216	192	180
	0.05	288	216	166	144	123	108	96	90
	0.01	58	43	33	29	25	22	19	18
	0.005	29	22	17	14	12	11	10	9
	0.001	5.8	4.3	3.3	2.9	2.5	2.2	1.9	1.8
	0.0005	2.9	2.2	1.7	1.4	1.2	1.1	1.0	0.9
1.00E-05	1	576	432	332	288	247	216		
	0.5	288	216	166	144	123	108		
	0.1	58	43	33	29	25	22		
	0.05	29	22	17	14	12	11		
	0.01	5.8	4.3	3.3	2.9	2.5	2.2		
	0.005	2.9	2.2	1.7	1.4	1.2	1.1		
	0.001	0.58	0.43	0.33	0.29	0.25	0.22		
	0.0005	0.29	0.22	0.17	0.14	0.12	0.11		

Continued

1.00E-06	1	58	43	33	29	25			
	0.5	29	22	17	14	12			
	0.1	5.8	4.3	3.3	2.9	2.5			
	0.05	2.9	2.2	1.7	1.4	1.2			
	0.01	0.6	0.43	0.33	0.29	0.25			
	0.005	0.3	0.22	0.17	0.14	0.12			
1.00E-07	1	5.8	4.3	3.3	2.9	2.5			
	0.5	2.9	2.2	1.7	1.4	1.2			
	0.1	0.58	0.43	0.33	0.29	0.25			
	0.05	0.29	0.22	0.17	0.14	0.12			
1.00E-08	Unlikely to be an Aquifer								
1.00E-09	Unlikely to be an Aquifer								
1.00E-10	Unlikely to be an Aquifer								
1.00E-11	Unlikely to be an Aquifer								
1.00E-12	Unlikely to be an Aquifer								

(1) Representative Values of Hydraulic Conductivity (K); unconsolidated deposits USCS descritpor; * (Freeze and Cherry, 1979)
[a half-order change in value of K has a large effect on travel distance]

Descriptor	K range m/sec	Descriptor	K range m/sec
GP	1E-1 to 1	SP-SC	1E-7.5 to 1E-3.5
GW	1E-3 to 1E-1	SW-SM	1E-7 to 1E-4
GP- GM	1E-4 to 1E-2	SW-SC	1E-7.5 to1E-5
GW-GM	1E-4 to 1E-2	ML	1E-8 to1E-4.5
GW-GC	1E-4.5 to 1E-2	MH	1E-8.5 to 1E-5
GW-SP	1E-5 to 1E-2	ML-MH	1E-8.5 to 1E-5.5
SP	1E-4.5 to 1E-2	CL	1E-10 to 1E-8
SW	1E-5.5 to 1E-2	CH	1E-12 to 1E-8.5
SP -SW	1E-5.5 to 1E-2	CL-CH	1E-12 to 1E-9
SM	1E-7 to 1E-3	clean sand*	1E-5.5 to 1E-2
SC	1E-8 to 1E-4	silty sand*	1E-7 to 1E-3
SM-SC	1E-8 to 1E-4	silt, loess*	1E-8.5 to 1E-4.5
SP - SM	1E-6 to 1E-3	glacial till*	1E-12 to 1E-8.5

(2) A porosity of 25.95 % is attained when equal sized spheres are packed with rhombohedral packing
(3) A porosity of 47.65% is attained when equal sized spheres are packed with cubic packing (Fetter, 2001)

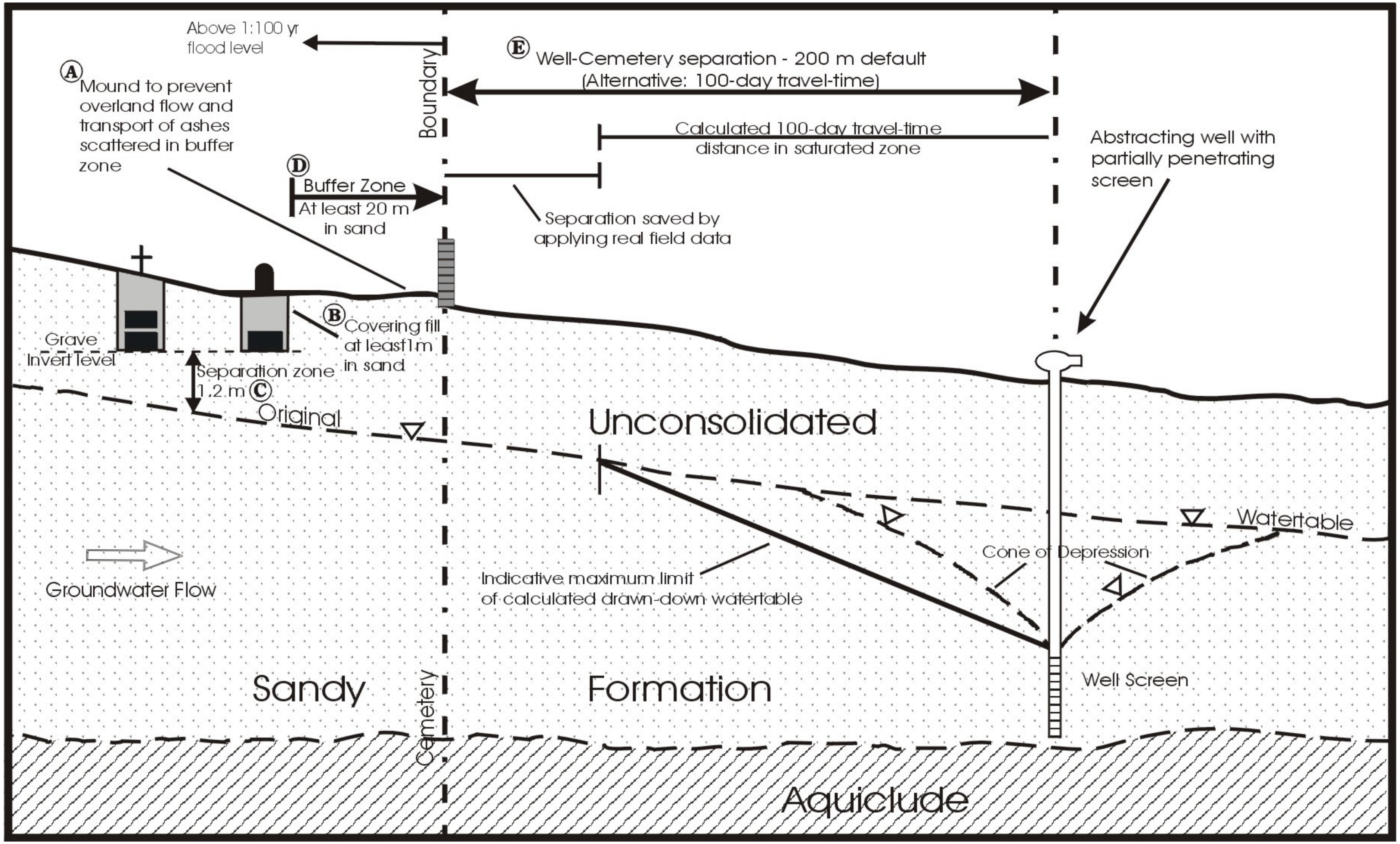


Figure 7.4 Diagrammatic Representation of Cemetery – Well Separation (notations A – E, see text)

Table 7.7 Indicative Upgradient Set-back Distances For The Fixed Radius Method

(Various values of abstraction Q (m^3/day), Transmissivity T (m^2/day), Hydraulic Gradient K (m/sec) and Effective Porosity n)^

100-day Isochron Radial Distances (r) in metres #

Q	**1 m^3/day**			**10 m^3/day**			**100 m^3/day**			**1000 m^3/day**			**10000 m^3/day**		
n	**0.1**	**0.2**	**0.35**	**0.1**	**0.2**	**0.35**	**0.1**	**0.2**	**0.35**	**0.1**	**0.2**	**0.35**	**0.1**	**0.2**	**0.35**
T*	**K = 1.00 E -2 m/sec**														
2000	11.7	8.3	6.3	37.1	26.2	19.8	117.3	82.9	62.7	370.8	262.2	198.2	1172.6	829.2	626.8
2500	10.5	7.4	5.6	33.2	23.5	17.7	104.9	74.2	56.1	331.7	234.5	177.3	1048.8	741.6	560.6
T*	**K = 1.00 E -3 m/sec**														
200	11.7	8.3	6.3	37.1	26.2	19.8	117.3	82.9	62.7	370.8	262.2	198.2	1172.6	829.2	626.8
500	7.4	5.2	4.0	23.5	16.6	12.5	74.2	52.4	39.6	234.5	165.8	125.4	741.6	524.4	396.4
1000	5.2	3.7	2.8	16.6	11.7	8.9	52.4	37.1	28.0	165.8	117.3	88.6	524.4	370.8	280.3
1500	4.3	3.0	2.3	13.5	9.6	7.2	42.8	30.3	22.9	135.4	95.7	72.4	428.2	302.8	228.9
2000	3.7	2.6	2.0	11.7	8.3	6.3	37.1	26.2	19.8	117.3	82.9	62.7	370.8	262.2	198.2
2500	3.3	2.3	1.8	10.5	7.4	5.6	33.2	23.5	17.7	104.9	74.2	56.1	331.7	234.5	177.3

Table 7.7 continued

T*	K = 1.00 E -4 m/sec														
50	7.4	5.2	4.0	23.5	16.6	12.5	74.2	52.4	39.6	234.5	165.8	125.4	741.6	524.4	396.4
100	5.2	3.7	2.8	16.6	11.7	8.9	52.4	37.1	28.0	165.8	117.3	88.6	524.4	370.8	280.3
200	3.7	2.6	2.0	11.7	8.3	6.3	37.1	26.2	19.8	117.3	82.9	62.7	370.8	262.2	198.2
500	2.3	1.7	1.3	7.4	5.2	4.0	23.5	16.6	12.5	74.2	52.4	39.6	234.5	165.8	125.4
T*	**K = 1.00 E -5 m/sec**														
50	2.3	1.7	1.3	7.4	5.2	4.0	23.5	16.6	12.5	74.2	52.4	39.6	234.5	165.8	125.4
100	1.7	1.2	0.9	5.2	3.7	2.8	16.6	11.7	8.9	52.4	37.1	28.0	165.8	117.3	88.6
	K = 1.00 E -6 m/sec, unlikely to be a water supply aquifer														
	K = 1.00 E -7 m/sec, unlikely to be a water supply aquifer														

In real field situations where a regional groundwater gradient is present, the Fixed Radius Method or 'Cylindrical Method' underestimates isochron positions up hydraulic gradient and over-estimates them in a down-gradient direction. This is not a desirable method for assessing well-head protection zones (Ontario, 2002) but serves only as the most basic indicator. Both methods ignore recharge. Further distortions occur in real situations because of the uneven nature of the thickness of unconfined aquifers, their frequent heterogeneity of properties and composition (Ontario, 2002, Haitjema, 1996). Sediments/soils with a low hydraulic conductivity are unlikely to provide sufficient extractable resources for water supply wells.

^ r (in metres) = $\sqrt{\frac{QtK.86400}{\pi T\phi}}$ where: Q is amount abstracted (m^3/day), t is travel time (days), K is hydraulic conductivity (m/sec), ø is effective porosity;

* T is transmissivity (m^2/day, where T = Kb and b is saturated aquifer thickness in metres)

Another way of considering the matter would be to examine the idea of a default maximum drawn down gradient of 1:1 within the likely cone of depression (if less than 200 m from the cemetery boundary); this could be used to set a minimum distance (Figure 7.4, note E). This is a variation of the Uniform Flow Model; any derived value should be compared to this one, and evaluated for its safety conferred. Table 7.8 illustrates the range of the effect of this concept for two distances - 100 m and 250 m (for 200 m simply double the 100 m values), and two effective porosities (20% and 35%) over a range of hydraulic conductivity (K) values. The results indicate, that if site-specific information is available, then the default of 200 m separation is only likely to apply in productive aquifers when the groundwater gradients are very steep.

Table 7.8 Illustrative Travel-Distance Ranges for Hydraulic Gradients of 1:1 Within the Cone of Depression – Well Located Near Cemetery Boundary (various values of K, and two effective porosities)

Gradient 1:1; Travel-Time (days)

K (m/sec)	**1.00E-3**	**1.00E-4**	**1.00E-5**	**1.00E-6**	**1.00E-7**
	gradient distance 100 m, effective porosity 20%				
TIME in days	0.2	2.3	23.1	231.5	2314.8
	gradient distance 100 m, effective porosity 35%				
TIME in days	0.4	4.1	40.5	405.1	4050.9
	gradient distance 250 m, effective porosity 20%				
TIME in days	0.6	5.8	57.9	578.7	5787.0
	gradient distance 250 m, effective porosity 35%				
TIME in days	1.0	10.1	101.3	1012.7	10127.3

Tables 7.6, 7.7 and 7.8 make use of values of effective porosity. In using the tabulated data it needs to be borne in mind that there are a number of well-known difficulties with using this parameter. Effective porosity is a function of the inter-

connectedness of the pore spaces. It is less than total porosity, is usually estimated, but it is better to be measured in the field (Yeh et al., 2000, or see Stephens et al., 1998, for a comprehensive review). In sandy or sandy and gravelly materials which are likely to represent aquifers, effective porosities are typically overestimated and are likely to be 50 – 70% of total porosity values (Stephens et al., 1998).

In summary: there are three alternative ways for evaluating the cemetery - well separation distance:-

1) 200 m horizontal distance from the cemetery boundary; or
2) 100-day travel-time separation at natural, long-term watertable gradient, after comprehensive hydrogeological site investigation along potential flowlines, eliminating (or taking into account) high conductivity zones, using K values evaluated for local groundwater upgradient of the cemetery at 1 m depth below grave invert level but ignoring the unsaturated zone (Uniform Flow Model); or perhaps by specifying travel-time distances using the distance generated by a default 1:1 gradient for the drawn-down watertable; or
3) location based on the long-term position of the proposed well's/s' cone/s of depression at the maximum design <u>operating</u> Q, where the upgradient watertable of the cone of depression or beyond places the well wholly 100 travel-time days from the cemetery boundary using the individual drawn-down watertable for calculation (where Q = rate of abstraction).

Method 3, generated by numerical modelling, should allow for closer location of the well in most hydrogeological conditions, and also accounts for recharge. Method 2 is more likely to represent the non-default, general case, and is likely to mostly be less conservative than Method 1. Overall, the central question addressed was –

> "how far must a drinking water well be located from interred remains?"

The answer depends on the consideration of the interaction of the following matters:

- ❖ cemetery decomposition product microbial loadings are likely to be very small (see Chapters Five and Six);

- as time elapsed since burial increases, the likelihood of pathogen survival considerably decreases (see Chapter Six);
- percolating groundwaters are attenuated by adsorption and filtering in the vadose zone, and by dispersion and adsorption in the saturated zone.

To re-iterate from above and Chapter Six, on balance, the potential microbial pollution from well-sited, correctly managed cemeteries, suitably separated from the watertable, in homogeneous aquifer materials is likely to be very low.

The potential may increase due to the:

- inclusion of more permeable heterogeneity in the aquifer (higher K conduits or beds that aid faster water movement), and *vice versa;*
- decreased proximity of any burial to the watertable (good separation required);
- decreased depth of burial or flooding (increased oxidation enhances microbial survival with appropriate organic substrate; spread of pathogens and new-site infection);
- presence of mass burials or significantly increased interment densities (decreased vadose attenuation);
- growth of an abstracting well's cone of depression (avoid over-production).

Thus, any cemetery - well separation proposal should be allowed after an appropriate hydrogeological evaluation shows that minimal conditions will always be met. The key criteria to be satisfied are the minimal separation of grave inverts above the watertable (at least 1m), the cemetery not to be within the 1:100 year flood zone, and the 100 day travel time from the cemetery boundary – taking into account the hydraulic gradient created by the steady-state cone of depression of the proposed abstracting well. The default cemetery - well separation is 200 m horizontally.

Another issue to be considered is how to site a well upgradient of the cemetery boundary. This issue is rarely discussed in considerations of source or well-head protection. It seems to be generally assumed that if the abstraction point is above the point source, or area of contamination, and that the immediate well-head (Zone I) separation is observed, then the matter is unimportant; but this is not necessarily true; see for instance the discussions by Berger, 1994 and Soulsby et al., 1999.

In the case of cemetery-well separation distances, the key point to consider is whether the cone of depression generated by abstraction at the well will cross the cemetery boundary. Typically, cones of depression are elongated up-gradient, but sometimes for an individual well, or when several cones of depression combine, the effect is more concentric (Freeze and Cherry, 1979, Fetter, 2001). If the Calculated Fixed Radius Model is used (Ontario, 2002) then the separation distance is over-estimated.

If the abstraction causes considerable distortion, and the watertable gradient is stable and correctly characterised, then the separation distance should be less than needed for a downgradient well. It is not appropriate to insist on the default 200 m horizontal separation distance. The matter can be resolved by requiring that the cone of depression under maximal, long-term operating conditions does not intersect the cemetery boundary, or that the 100 day travel-time distance at a hydraulic gradient of 1:1 within the area comprised of the cone of depression, be satisfied.

Does a single grave, row of graves, family cemetery, closed or historic cemetery, have the same requirements for well-head protection?

No. The issue of cemetery - well separation primarily relates to large, active cemeteries where the usual landfill model with all its internal operational variables applies. There are many instances where interred remains are located in small quantities or are very old; like a cemetery reserve on a family farm, historic monument or grave, disused parish churchyard, mass grave. In these circumstances an entirely different approach is warranted.

Restating previous discussion: the issues of concern are the transmission of pathogenic micro-organisms, preservative chemicals, excessive inorganic nitrogen or other salts, heavy metals due to coffin corrosion, or paints and lacquers of coffins, from the grave to the potable groundwater. These decomposition products can be further considered in three groups: (i) micro-organisms, (ii) organic and (ii) inorganic chemicals. The evaluation of any risk related to the water well location relates most specifically to the matters of, the age of the interments, the known cause/s of death, the number of interred bodies and the separation of the grave invert from any watertable.

In Chapter Six it was shown that although micro-organisms of concern can remain viable and transportable for many years following interment, they are attenuated by soils, they eventually die-off or lose viability, and after several years exposed to natural conditions are likely to be inconsequential. Accordingly, if the grave invert level is correctly separated from the level of any maximum watertable rise, and the remains are likely to have been broken out of the coffin and/or plastic liner and/or body bag for some time, then there is little likelihood of a potential problem. The key factor at work is time. Using the criteria developed for Table 6.5, after 3 years of interment most micro-organisms are likely to be dead or dispersed, and after 10 years are unlikely to survive particularly if diffused into the soil.

If the cause/s of death is/are known for all or many of the interred, for example due to cholera or typhoid or hepatitis or tuberculosis, then a moderated position on separation, requiring greater time-travel would be a useful precaution. But the context of time rules; 50 years is a good working limit for botulism, tuberculosis and anthrax (Table 6.2), and from the evidence available to date is likely to be a useful timeframe in most cases, in temperate and desert climates – probably less in tropical areas, more in cold climates (see Lewis et al., 1982, Mant, 1987, Janaway, 1997).

In the case of group (ii) decomposition products – organic compounds, these are likely to be attenuated by natural bacterial and chemical reactions and weathering processes. These chemicals are interred as solids, or they are generated from the decaying remains. Although it could be expected that these products will migrate into soils, their amounts are very low and their greatest proportion will generally be very simple compounds like low molecular weight organic acids or methanal; the exceptions are likely to be from paints, lacquers and plastics. If the grave/s is/are correctly sited it would be expected that natural soil attenuation would reduce the majority of these compounds to acceptable levels within a short distance and timeframe, and that the primary breakdown products would be simpler organic acids, alkanals or phenols, then water and carbon dioxide for most.

In the case of group (iii) decomposition products – inorganic solutes, these are likely to be traceable as a plume for some time if groundwater movement is in an orderly fashion from the gravesite/s. However, they are initially present in small quantities (Chapter Six) and are attenuated by dilution. The modelling represented in Figure 6.4 shows that by 20 years after interment, even in the situation of repeated loadings (interments), the rate of decomposition product loading is about constant. In the situation where no more loading is occurring, then a 20 year timeframe is likely to be satisfactory for an acceptable attenuation of these products, in a temperate setting; probably less in a tropical setting, and more in an arid or cold setting. The previous analyses for heavy metals, including mercury as dental amalgam (Chapters Five and Six) indicate that these are unlikely contributors to major problems in the usual situation.

A particular case for potential metal contamination arises in respect of metal coffins comprised of large amounts of toxic metals like zinc, copper or cadmium; or bodies embalmed with arsenic or mercurial salts. If this information is unknown, unsaturated soil separation thicknesses and number of interments are mitigating factors to potential risks.

On balance, in the special cases considered here, with at least 1 m grave invert separation from any watertable level, then generalised cemetery/grave – well separations could be considered as outlined below. The usual precautions concerning no burials within the immediate well-head zone – an arbitrary 30 m separation (Soulesby et al., 1999), also need to be observed. Suggested criteria, based on time since last interment, and horizontal distance from nearest grave to well are:-

- one grave - 20 years and 30 m horizontally; 50 years if cause of death due to water-transmissible, pathogenic micro-organisms;
- small family plot, row of graves (say less than 10 to 16) – 50 years and 30 m;
- small disused churchyard, historic cemetery; mass grave – 50 years and 100m. The case of a mass grave related to deaths from pathogenic infection, would require different treatment and needs to be evaluated on an individual basis.
- closed cemeteries – 100 years and 100 m (see below**), or 200 m.

There will be situations where the above guidelines are conservative, and it should be possible to vary the proposed well sitings on the basis of a detailed hydrogeological investigation. One of the difficulties with older sites is the quantity of unknowns, for example, preserved below-ground crypts hosting a substantial pathogenic biomass, or an unknown reservoir of organic substrate hosting pathogenic bacteria in what might otherwise be a dry area. However, with the passage of time, the potential risk greatly diminishes (see previous discussion in this Chapter, and refer to Table 6.2).

> ** Hydrogeologically, this time-distance separation is roughly equivalent to the distance travelled by groundwater through sandy soils of K = 1E-5 m/sec, effective porosity of 30%, and a gradient of 0.001; perhaps like a river floodplain.

BUFFER ZONES

The use of a buffer zone to separate a waste disposal activity (and many other high-impact activities, for example quarrying) from other urban land use has been widely practised since the 1960s and nowadays is generally incorporated as a planning tool before approvals are given. In the case of cemeteries the use of this tool is quite specific and is not related to hiding the activity, controlling dust or noise. Rather the buffer zones on cemeteries are an essential aid in the attenuation of any decomposition products leaving the cemetery boundary.

This Study recommends that buffer zones (Figure 7.4 and Note D; other discussions on soil aspects above and Chapter Six) be created around the whole of sites at default distances:

- ❖ 20 m in sandy soil if the boundary is down hydraulic gradient or on a topographic low; otherwise 10 m. This distance should be greater (to 25 m) in sandy areas with high hydraulic gradients, say more than 0.05 (5 %). From Table 7.6 it can be seen that groundwater can easily leave the cemetery boundary in 1 – 2 days at this gradient;
- ❖ 10 m in clayey soils if the boundary is down hydraulic gradient or on a topographic low; otherwise 5 m. For heavy clay soils (CL – CH) this can be reduced to 5 m.

There may be some instances where the default distance is inappropriate or too restrictive to the cemetery development: either too short, for example where a cemetery on steep aeolian deposits borders a wetland; or too great, for example where a clayey site adjoins a landfill; and these should be resolved following appropriate geoscientific evaluation.

In the buffer zone a further effort should be made to attenuate groundwater flow by removing it naturally, that is, through evapotranspiration with suitable vegetation – one of the forms of phytoremediation. The planting of deep-rooting, locally adapted, native vegetation is likely to provide the best type of planting, although there are many cases where other species have proved effective in a particular use.

The analyses in Chapter Five and Six have shown that the most likely inorganic chemical of concern to leave the cemetery boundary is nitrogen. The next most concerning elements are Cl, SO_4, Na, Mg and P (Table 6.1). Overall the levels are small, but N and P have the propensity to cause environmental degradation because they are plant nutrients. If these nutrients could be consumed en-route this would be advantageous for wetlands or aquifers that receive the groundwaters. Fortunately, as discussed in Chapter Five, although P is very mobile in soils it is either rapidly consumed or adsorbed.

Consumption of the groundwaters might also lead to local delays in migration rates with the consequent retarding of bacterial and viral migration. Other more subtle implications are that a dense network of roots can trap and hold bacteria and salt deposits (Corapcioglu,1992, Alexander, 1999, Sutthersan, 2001). Whilst the first situation is likely to be positive if the bacteria subsequently die out, the second situation is likely to be negative if soil salt stores are increased (and later contribute to salinity issues). Continued infiltration in buffer zones should aid the attenuation of other products through dilution; whilst natural microbial actions should begin to ameliorate the problem of any remnant organic compounds.

Some natural microbial transformations can also occur; these would be relevant in the denitrification of nitrogen-oxygen compounds, cyanide and sulfate radicals (CN^-, SO_4^{2-}), and others. Unfortunately, most inorganic products can only be changed to forms with different solubilities and motilities, but this can lead to their precipitation, volatilization, sorption and dispersion (Mench et al., 1999, Suthersan, 2001).

The levels of N in soils and groundwater has been a major concern in the European Union for some years and now stringent rules apply to protect groundwater sources from excessive accumulation. Various strategies have been employed, but phytoremediation is now being seriously considered: for example, Hefting and de Klein (1998) have reported on the successful use of the technique in riparian zones for non-point pollution sources in the Netherlands. In the Americas, the situation for nitrogen uptake in agroforestry is receiving attention from both the angles of input to soil and extraction (Kass et al., 1997).

Nitrogen Fertilizers

A related matter is when N and P fertilizers are used on the large lawn areas of cemeteries. In this context the fertilizer impacts should be evaluated in the same manner as for other agricultural or open space land uses. Buffer zones will also provide a service for the attenuation of any excesses due to their usage.

If excess nutrients penetrate beneath the root zone then they have the opportunity to impact on soil and groundwater measurements made in cemeteries. This matter was carefully considered for the sampling in this Study. Fortunately, not all cemeteries use vigorous fertilizing regimes and many virtually require or use, none. WOR, LAU, and CEN are in the first category, whilst BOT, MEL, HEL and GUI are in the latter. The others – SPR and NEW did employ fertilizers during the Study but in areas and ways that were considered to have had no impact on the results. In the case of NEW, where newer lawns were being established, these are atop heavy clay fill where the likelihood of the unconsumed portion of moderate fertilizer applications being flushed through the unsaturated zone in the time of the Study, was assessed as almost negligible.

In the sites with clayey soils, the same considerations apply in respect of whether the unconsumed portions of previous fertilizing events would impact on results. Again this occurrence was assessed as almost negligible, but the consideration and analysis of the nitrogenous sample data over the whole time of the Study should have mitigated any potential impact in this regard.

The application of sewerage sludge and sewerage effluents is now routinely used for large parklands around the World. This provides a ready source of nutrient rich compostable material or water: since many cemeteries have large grassland areas requiring ‘greening’ and care, such resources are ideal. The use in this role, however, is not without debate: in the USA for example, many angles from cost-benefit analysis, to metal contamination from sludge have been aired (New York Times, 1974 a and b, Dakes and Cheremisinoff, 1977, Lang and Jaeger, 1990). In Australia the issue has been considered in detail for Enfield General Cemetery, South Australia and NEW: the managers of these sites are desirous of using treated sewerage effluent for irrigation of the extensive lawns.

ROLE OF BONE IN CEMETERY MANAGEMENT

One of the cemetery's raw materials may in fact be an advantageous addition. For a long time it has been known that bone attracts various elements from the surrounding soil and grave/mausolea artefacts during the decomposition processes of its organic parts. This phenomenon has been widely studied with essential considerations directed at determining past dietary attributes, environmental pollution and effects of various diseases.

Badone and Farquhar (1981) have pointed out that bone is known to attract around 25 environmental elements, many of these in trace amounts; the list mainly includes cations like the metals – uranium, barium, manganese, iron, vanadium, scandium and cobalt, but also anions such as fluorine. It seems that the primary mechanism is the presence of complex organic acids as the organic part of bone disintegrates which in turn leads to the precipitation of inorganic minerals from solution around the bone exterior (Parker and Toots, 1976, Badone and Farquhar, 1981). Lead has been considered from both a dietary and environmental input perspective (Waldron, 1982, Grandjean, 1988) and found to be preferentially resident in bone.

It seems that the type of geochemical changes that bone undergoes are very dependent on in-soil parameters (Behrensmeyer, 1978, Pate and Brown, 1985), and that bone characteristics can in some cases be calibrated against time since death, and weathering rates in the soil. As soil pH decreases for instance, the solubility of Ca and P from the hydroxyapatite (bone mineral) increases which is why bone tends to disappear most readily in moist, acidic soils. Sodium is also leached, whilst iron, aluminium, potassium, copper, manganese and barium are typically enhanced, and zinc and strontium remain mostly unaffected (Pate and Brown, 1985).

Bone is somewhat difficult to recover and analyse successfully so that the integrity of specific site-related or diet-related characteristics is maintained. The selection of different bones and parts thereof, as well as suitable analytical techniques has received considerable investigation (Waldron, 1982, Price and Kavanagh, 1982, Von

Endt and Ortner, 1984, Lambert et al., 1985, Grandjean, 1988, Grupe, 1988).

Given that bone is essentially a metal attractor for many types of metals it was considered that this might be beneficial in the cemetery context. The issue being considered is whether interred remains, when at the stage of being mostly bone (form about 11 years after interment, Table 6.5), could attract and trap some metals being mobilised within the cemetery vadose zone and which probably come from buried coffin or artefact material. Presumably there is also some potential for decaying bone to trap some of the body's metal load if it is slow to migrate into the surrounding soils. As the bone is lost from the system, mostly by chemical weathering, the entrapped metals might remain behind as micro-geochemical anomalies. This appears to be the case at the Sutton Hoo inhumations which have been extensively examined (Bethell and Carver, 1987, Bethell, 1989).

The analyses of metals in the saturated zones of cemeteries (Chapter Five) have shown a statistically significant deficiency of Ni, Cr and Mn for In-cemetery results. Results for the unsaturated zone studies were not as clear-cut. It is conjectured that this deficiency may be related to entrapment of these metals by bone. An exact mechanism for explaining the absence of transmission and hence the attenuation of these metals is not obvious. However, it might be possible that in the cases of BOT and GUI, because of the shallow and fluctuating watertables present and the generally thin separation distance between grave invert and watertable, that any metals which did make it to the watertable are removed or trapped in graves when the watertable re-enters them. Another possibility is that mounding of watertables and the "bucket effect" brings percolating water into contact with bone more-often leading to entrapment, or that percolation pathways in these porous soils put the metals in contact with bone.

Nickel has not been widely reported upon for its attraction to bone, whilst as noted above, the effects for Mn are variable depending on soil parameters, but it is usually enhanced (Parker and Toots, 1976). Chromium was found to be enhanced in the silhouettes (remnants of interments) of the Sutton Hoo excavations (Bethell, 1989) where the soil has been described as an acidic (pH 3.5 – 5.0) very free-draining sand with very minor clays (Bethell and Carver 1987).

If bone can function as an metal attractor then if it was placed in cemeteries so as to be downgradient, or at topographically lower positions, in some manner line a ‘wall of bone’; then it might prove to be of some limited use in the mitigation of some metals moving through the soil or in shallow watertables, if this was to occur. A mechanism to do this might be the development of cemetery portions by the early interment of remains in the lowest most or hydraulically downgradient sections of the cemetery, at maximum possible depth, parallel to the boundary immediately adjacent to the buffer zone.

An interesting recent development in the treatment of contaminated sites is to exactly use the principles being discussed here: Lerner (pers. comm., 2000) has mentioned a case study in Africa where bone-meal was to be used to assist in the clean-up of metals.

*

CHAPTER EIGHT

RECOMMENDATIONS AND CONCLUSIONS

Contents

The conclusions from this Study are very clear. The amounts of decomposition products leaving cemetery boundaries are very small (Chapter Six); they are identifiable and measurable (Chapter Five) but will in most cases be quickly attenuated within the sub-surface environment (Chapter Seven). Exceptions will occur in the coarsest soils or aquifers, and in these cases if the hydraulic gradient is moderately steep this will result in relatively rapid product migration. Generally, cemeteries have little contamination impact on the environment provided that they are correctly sited and operated; the greatest potential threat is the off-site migration of pathogenic bacteria or viruses (Chapter Seven).

Despite the very large natural variability of hydrogeological settings, several generalized scenarios present themselves for cemetery function and decomposition product movement. Mostly these devolve to whether the soils are essentially sandy or clayey; the USCS provides a satisfactory system for generally delimiting the soil response. The sandy sites permit free product movement, encourage decomposition and eventually chemical weathering of the skeletal remains, whereas the clayey sites considerably retard decomposition, may preserve various tissues, offer a much reduced opportunity for off-site product migration but harbour potentially pathogenic bacteria for longer; however, they are generally more workable. An alkaline environment also generally retards decomposition; it also encourages the survival of many undesirable bacteria.

An ideal cemetery situation is one where the site is only gently sloping and hosts a deep, acid soil with an intermediate range of properties such as a clayey sand or sandy clay, with a regional watertable which is always at least 1.0 m below the invert level of any grave and which will not be flooded. These soils would be quite workable and would encourage the decomposition of the interred remains and artifacts, with a reduced likelihood of bacteria or virus migration off-site.

Almost all cemeteries have some potential for contamination if natural phenomena like floods (especially) or landslip or subsidence/settlement act on the graves (Chapter Seven), or there is inappropriate natural sub-soil drainage to streams, wetlands or the coast. If the essential nature or operation of parts of the cemetery change, for example, more shallow burials, higher interment density, then this may also affect the cemetery's impact on the environment.

The decomposition products from cemeteries are widely dispersed in time and space. Accordingly, the cemetery is best thought of as 'black box' and its geoscientific impact assessed at the boundary. The decomposing remains generate a slightly saline plume enriched in forms of inorganic nitrogen and sometimes containing phosphorus. As this plume percolates through the vadose zone it is likely to take with it bacteria and viruses from the interred cadavers.

REVISITED IDEAS

Some studies by others have for a number of years heralded concepts promulgated in this Study: the significance of the previous work needs to be recognized in formulating further guidelines for geoscientifically based operations and management practices in cemeteries. In concert with Australian and UK practices, from which they were derived, and which were ultimately codified in legislation, some of these other studies simply reiterate accepted cemetery practices without detailed scientific analysis or explanation for their usage (Chapter Three).

However, it is quite clear that previous generations of health officials and planners have been alerted to the likelihood of cemetery decomposition products moving offsite, and/or contaminating groundwaters, including municipal drinking water supplies. A common thread that can be found is the need for all new and any proposed extension to existing cemeteries to be properly investigated geoscientifically. The disposition of groundwater and the relationship of the proposed site to its physical environment has to be determined before any interment commences.

In Brazil: the situation is exacerbated by the space demands in their cities where municipal codes usually require that bodies be exhumed after 3 – 5 years. This in turn seems to have led to some inappropriate operational and management conditions, particularly shallow burial and mishandling of exhumation funereal artifacts, and possibly also mishandling remains. Interments in older cemeteries are known to lie in, at least ephemeral, perched watertables, and possibly in some permanent ones. The constant exhumations and re-handling of remains probably leads to some unsanitary practices and conditions at surface level, but is frequently attended by the occurrence of adipocere on the bodies.

From Canada: investigations of formaldehyde (methanal) and elemental species of concern in the environmental context arising from cemetery groundwaters are widely cited in industry and literature. Although these studies were quite limited and contain some intrinsic difficulties in methodology and understanding, they both reported that there was no noticeable contamination effect.

The European Union: in introductory briefing report has set out some useful recommendations for development of new cemeteries. These included that grave inverts be underlain by at least 1 m of soil above rock, be at least 1 m above any level to which watertables may rise, and be at least 30m from any spring or stream, 10 m from any drain, and 250 m from any well, borehole or spring from which a potable water supply is drawn.

In Germany: Matthes (1903) reports the earliest known study of cemetery waters: eight wells were regularly sampled, about once per year, between 1883 and 1901, and later-on, 7 subsoil drains were also sparsely sampled. The focus of this work was detection of contamination in the wells; which was not conclusively shown. Further investigation of some rainfall events for the cemetery was an unskilled attempt to place the study in a hydrogeological context. Other researchers investigated the suitability of various soils and cemetery practices. Schraps (1971, 1972) concluded that perched or permanent groundwater tables had to be at least 0.7 m below proposed grave invert levels for sandy loam soils and more in sands.

From Greece: Stournaras (1994) suggested the need for adequate investigations and the unsuitability of certain sites (a reference to near quarries); but also raised the possibility of developing domestic waste landfills for cemeteries.

From The Netherlands: several key studies have come from here including those of van Haaren (1951) who was probably the first person to publish details of a structured investigation of cemetery ground- and surface- waters. No substantial chemical connection could be proved between in-cemetery and surrounding drain waters, however, both types were considerably impure. The work did detect decomposition products in the cemetery groundwaters.

van der Honing et al. (1986) in a reasonably comprehensive study of cemetery groundwaters concluded that there were no increased concentrations of physio-chemical, microbiological, and toxicity parameters near cemeteries. However, they also made a suggestion that the waters should not be used for recreation or irrigation of consumption crops. This suggestion was not actually supported by their data and conclusions, however, is thought to represent prudent practice.

In Spain: the need for proper investigations has been highlighted, as well as the unsuitability of certain soils and hydrogeological settings, a 500 m exclusion zone for urban development around cemeteries is required. Arche et al. (1982) implored the cessation of using plastic coffin liners and bags. This latter matter is the only other known reference to discontinuance of this practice.

From the UK: The Environment Agency (1999 – 2001) has produced a relatively complete report which sets out guidelines for the development of cemeteries. One of the useful aspects of that report is that it reviews relevant wellhead protection protocols operating throughout the UK. Most of these conform to a combination of MAFF (1998) and Environment Agency guidelines for groundwater protection. They include:

- ❖ "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 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 carcase; when first dug, the bottom of the hole must be free of standing water."

(MAFF, 1998)

and: "that cemeteries not be located in Zone I areas, that is, where travel time is less than 50 days"; see Chapter Three.

Three contemporary studies of cemetery groundwaters have also been completed in the UK; none of these produced any startling or otherwise unusual results, however, they once again confirmed the detection of decomposition products in groundwaters. In concert with many countries that find older city areas are now short of cemetery space, studies have been done in the UK in respect of grave re-use. At this time the studies concern the sociological aspects of grave re-use, but show a positive response to the concepts. The idea of 'Woodland Burials' is now being extensively used in the UK; this represents a combination of practices which are in themselves likely to have a low impact on the environment – provided the cemeteries are correctly sited.

From the USA: The likely leaching of arsenic, lead and mercury from embalmed bodies interred between the early 1880s and 1910 in the USA has received some consideration. Although purposeful studies of this phenomenon in groundwater have not been published there appears to be some limited evidence for it. A related issue represents a modern-day equivalent, namely the leaching of formaldehyde (methanal) solutions from embalmed bodies. Although there has also been no purposeful groundwater testing for methanal (formaldehyde) in the cemetery context, it is a matter of concern. After reviewing the risks from cemeteries, Wendling (1991) concluded that proper siting of cemeteries and geoscientific evaluation was probably of much greater importance than testing for formaldehyde (methanal). The Canadian work is often cited in this regard.

IDEAL INDICATORS FOR CEMETERIES & SOIL PROPERTIES

It has been shown (Chapter Five, Tables 5.5 and 6.1) that a suite of inorganic chemicals can be used to generally characterise cemetery groundwaters whether from the vadose or saturated zones. In each hydrogeological zone the forms of nitrogen feature prominently; three groupings (Factors in analyses) of analytes are recognised as major contributors. The presence of P is very dependant on soil conditions, although it is quite a mobile element, it is readily adsorbed to the soil matrix. The analytes reflect total body composition (see Table 6.9), except calcium. Despite the exhaustive considerations of this Study, it is not yet possible to describe *ideal* indicators for cemetery groundwaters: more study of organic molecules including human metabolites or human pharmaceuticals or hormones, or isotopic signature studies of nitrogen, is required.

Maximum variability of compositions is represented by the saturated zone Factors:

- Cl + SO_4 + Na + Mg + Sr
- NO_3-N + Total Inorganic N + Total NOx + Total N
- PO_4 + Total P

The considerations of bacterial presence in the cemeteries' waters was far from conclusive. Although pathogenic bacteria like *Enterococcus faecalis* (Feacal strepococci), and *Pseudomonas aeruginosa*, and indicator bacteria like *E. coli* have been widely found, there is no evidence that cemeteries are underlain by festering pools of bacteria waiting to pollute all soils and waters in the neighbouring district. The soil is generally capable of attenuating bacterial and viral migration if the cemetery's interment practices are of the required quality and occur with sufficient regard to the site's geoscientific aspects (Chapter Seven). However, significant problems and risks arise in some cemetery settings.

Cemeteries are located on a vast array of soil types, although some types have been well-recognised for centuries as being of considerably poorer quality for the location of a cemetery (Chapter Seven). If one accepts the proposition that the purpose of interment is to allow in-soil decomposition of the remains, then the best soils to accomplish this are acidic clayey sands or sandy clays. These soils are sufficiently permeable to allow percolating groundwaters to aid the dispersion of decomposition products; allow for some permeation of oxygen into the unsaturated and saturated zones and the escape of decomposition gases from the grave; adsorb most virus particles and trap most bacteria; and permit final chemical weathering of bone.

A number of soil conditions influence decomposition product behaviour and cemetery operations (Table 7.5). Soil parameters like pH, CEC and particle grading work in different ways, not always complimentary to any one operational or decompositional matter; for instance, a clean quartz sand enables rapid and complete decomposition but it necessitates significant cemetery-boundary and cemetery-well criteria in order to establish suitably sanitary operations which don't pollute or affect drinking water supplies; heavy alkaline clay soils don't encourage decomposition but attenuate the decomposition products very well, however, they are problematic if the area is subject to flooding.

THE IMPACT OF CEMETERIES

The data and arguments of this Study are strongly supportive of the idea that cemeteries have a minimal impact on the environment: but that this conclusion needs to be heavily qualified. If one designates “pollution”, in the cemetery context, to be an unnaturally induced increase in some analyte of the representative natural environment’s surface- or ground-waters and soils beyond the cemetery boundary, then this pollution can certainly be detected and quantified. However, the typical inorganic chemical loads imposed by cemeteries are very small. Often, groundwaters within cemeteries are chemically ‘cleaner’ than those without the cemeteries where they are severely impacted by other anthropogenic activities.

There are six main categories of decomposition products which need to be considered when delineating potential pollutants:

- pathogenic bacteria and viruses
- nutrients – N and P
- increased abundance of the ions – Na, Cl, Mg, SO4, Sr
- heavy metals including As
- a range of non-specific organic molecules, mostly low molecular weight acids
- formaldehyde (methanal).

For the majority of cemeteries which are properly located – either by good historical design or deductive reasoning; or because of correct geoscientific investigation; or because correct management practices have meant that proper regard has been paid to the prevailing hydrogeology of the site, there is almost no pollution, or the levels are unimportant in the context of other urban or landuse practices. Furthermore, interment and management practices of Australian cemeteries are largely in accord with the correct practices and policies for running and developing cemeteries and hence satisfy the requirements of public health and good interaction with the environment.

There is an important caveat on all of the preceding, namely that: **some cemeteries in some hydrogeological settings, at some times, and in different ways and at times differently within themselves or at times for different portions within themselves do produce a contamination problem.** This is brought about by natural variations within and between sites. In addition, except where there have been obvious deficiencies in the planning, operation or location factors of any one site, all cemeteries have some potential for pollution. The most serious situation is the escape of pathogenic bacteria or viruses into the environment at large.

The answer to the question as to "whether any one cemetery pollutes?" is – "it depends!" Whence the argument becomes somewhat circular, because "it depends" on the location and operation of the site in adherence to all the previously identified factors. The issue can only be resolved by a comprehensive geoscientific investigation with a focus on the hydrogeological setting. But even this kind of assessment has a small potential to miss ex-cemetery effects if the practices and/or usage patterns within the cemetery change, or if there are unaccounted changes in impacting natural phenomena like storms, floods or landslip.

The evidence and arguments from this Study surpass in quantity, breadth and rigour, those of any previous related study anywhere. Furthermore, they reinforce and enhance the broad distillation of most previous works with which they accord. Even those studies with controversial promulgations, for example Pacheco et al. (1991) in respect of Brazilian cemetery practices, have elements acceptably interpretable within the paradigm advanced by this Study.

RECOMMENDATIONS FOR CEMETERY PLANNING AND PRACTICES

Drinking Water Wells and Well-head Protection

The relative placement of drinking water wells – whether municipal or domestic – to any interred remains or cemetery located above, or contiguous with, an unconfined aquifer is a matter that has and will continue to generate considerable debate. The ideas suggested in the literature, and deriving from or supporting legislation, show some variation; however, generally when the matter has been codified the separation required is of the order of 250 m or more; which is quite conservative. The matters like the soil type and hydrogeological setting are lumped together for the ease of the planning burden introduced by such requirements.

In order to permanently remove any likely conflict of interest or effect due to a change of land-use pattern, no drinking water well should lie within a cemetery boundary; then it must be at least separated by any buffer zone from any interment.

The concept of the cemetery being involved in a well-head protection zone nearest to the actual well (for example a Zone I) is considered to be generally unsatisfactory; but such an outcome can only be avoided in new establishments: this issue is discussed in Chapter Seven. As a principle in the protection of the quality of drinking water for human or stock purposes, it is, however, necessary to sensibly separate cemeteries and water supply wells.

In the absence of real site evaluations of the hydrogeological setting and the pumping well's demand, a well should not lie within **200 m (horizontally)** of a cemetery boundary (see Chapter Seven; this is a reduction to separations proposed by other sources). Ideally though, cemetery-well separation distances would be developed on the basis of the intersection of the steady-state pumping well's/s' cone/s of depression and the cemetery boundary such that the effective hydraulic gradient induced during pumping was related to appropriate travel time distances for bacteria and viruses (being greater than 100 days).

Any variation to the above general rule should only be made after a comprehensive field and laboratory investigation of the hydrogeological conditions surrounding the site, and which includes the ruling-out of the presence of highly conductive zones along potential groundwater travel paths to the well. In addition, the location solution should be one that places the well with its maximum induced drawn-down hydraulic gradient **(1:1 by default) at least 100 travel days** from the cemetery boundary.

Given that the relative well-cemetery location is now to be properly evaluated, then some consideration for adjustment in buffer zones and/or mandated land-use within relevant part/s of the cemetery boundaries may also be possible; provided that the proposed location of any well/cemetery is consistent with the required groundwater protection. That is, a well might be able to be more closely located to a cemetery or *vice versa,* after a comprehensive hydrogeological evaluation relative to the proposed, in-cemetery, land-use pattern. This might be a particularly useful situation for the location of stock or irrigation wells; a well within the cemetery boundary is likely to only be available for in-cemetery irrigation.

In this latter instance, the water quality including indicator microbial content would need to be monitored, and adjustments of the water chemistry or disinfection carried out before its use.

Buffer Zones

The idea of surrounding cemeteries with a buffer zone is consistent with well-established practice for landfill sites and industries where the escape of pollutants to the subsurface is possible. The intention of the zone is to permit greater attenuation of decomposition products in the vadose zone and greater dispersion and dilution within the saturated zone. The delay of decomposition product movement also helps the die-off processes for pathogenic bacteria and viruses.

Difficulties in applying simplistic models of dispersion of plumes occur because of the nature of cemetery operations that is, in general the spatial and temporal variation of interments. These sites don't work or generally function like an identifiable point source. A standardised and instituted buffer zone therefore helps to even-out the resultant effects.

Buffer zones planted with deep-rooting indigenous vegetation for the climate zone of the site, are an addition to the processes of delayed decomposition product migration because they consume vadose and/or saturated zone groundwaters. They are likely to be most useful where thicker vadose zones are present and/or there are substantial, transient, vadose zone flows like at WOR and other sites with variable pathways in sandy clays (for example, NEW and LAU) or heavy clays (for example CEN).

Buffer zones need to be wider for sites with sandy soils (SM, SC, SP – SW Unified Soil Classification) up to 20 m if within 5m of an aquifer comprised of SW sands, to about 5 – 10 m in heavy clay soils (CL – CH). General working distances could be:- 20 m if topographically downhill or hydraulically downgradient in sandy sites, 10 m in clayey sites; 10 m if topographically uphill or hydraulically upgradient in sandy sites, 5m in clayey sites.

Buffer zones are likely to be satisfactory areas for the scattering or storage of individuals' cremation ashes, however, these matters need to be further considered. There should be no disposal within 2 m of the cemetery boundary or in any way such that surface runoff can carry fine material across the cemetery boundary. The essential issues here are the mobilisation of heavy metals and phosphorus.

The ideas in this section are summarised in Table 8.1.

RECOMMENDATIONS FOR FUTURE INVESTIGATIONS AND STUDIES

There are some matters referred to within this thesis that are limited by the absence of suitable information or data. These matters are suitable for further scientific laboratory or long-term field measurement. Their investigation would produce significant information relevant to an enhanced understanding of cemetery groundwaters' characterization and cemetery function. Some of the data may ultimately assist in developing or re-defining cemetery location principles or lead to the quantification of cemetery location risk, or health or environmental risk/s associated with the interment or cremation of human (and other animal) remains.

Table 8.1 Summary of Cemetery Planning and Practices

- **Proper burial and management practices impose little effect on the environment and re-use is a sustainable activity**
- **Depth of burial is only limited by site conditions and ability to safely excavate; but this does not imply mass burials**
- **There are no separate issues for burials without coffins; however, plastic coffins, liners and bodybags should be disallowed**
- **No burials should lie at the cemetery boundary - buffer zones are needed; 5 -10 m in clayey soils, 20 m or more in sandy soils**
- **The invert of a grave and hence the deepest burial depth, must be at least 1m above any level to which a watertable fluctuates - more in clean coarse sandy or gravelly soils**
- **The influences of perched and ephemeral watertables and springs need to be taken into account: don't bury near springlines and never in swampland**
- **The best soils for cemeteries in order to favour decomposition and with good decay product attenuation are well drained clayey sands**
- **New sites and extensions should be properly evaluated geoscientifically: floodplains, swamps, clifflines, shallow soils (to some extent), drainage areas to lakes or waterways, some fills - are not suitable areas**
- **Drinking water wells should be at least 200 m (default) horizontally from any cemetery or 100-day travel days from the boundary after groundwater modelling**
- **Develop cemeteries from the outside-in and around the perimeter first**
- **Preserve and plant deep-rooting native trees and shrubs - particularly in buffer zones.**

It is recommended that the cemetery industries or applied geosciences institutions of the World undertake studies to:-

1. better characterise the total bacterial and viral component of cemetery groundwaters;
2. specifically investigate the in-soil survival of tuberculosis-causing bacteria and hepatitis-causing viruses;
3. characterise the dissolved organic components of cemetery groundwaters and specifically as 'acids', proteins, carbohydrates and fats;
4. investigate the prospect of characterising cemetery groundwaters by the identification of isotopic signatures or medical drugs or human metabolites or hormones;
5. determine the average composition of cremated human remains;
6. with respect to areas for the disposal and/or scattering of cremated remains, measure relevant soil properties in order to assess the impact of any geochemical anomalies;
7. comprehensively document the survival of human tissue – soft and bone (including the inorganic phase of bone) from interment in soil;
8. determine the timeframes of in-soil breakdown and leaching of adipocere in a variety of soils;
9. examine the role of interred human bones in the attenuation of In-cemetery metals' migration;
10. repeat the basic investigations of this Study in arid, tropical and cold climate areas.

AMOUNT OF SPACE

In Chapter One the amount of land consumed by cemeteries was discussed. The actual area involved depends on the permitted size of individual graves, the amount of grave re-use and the amount of infrastructure developed. From any viewpoint the amounts are large, the demands are highest in cities, and the demands are growing as worldwide populations either age, as typical for Australia, UK and USA or increase rapidly as in China and India, or suffer the ravages of disease as in South Africa.

The solutions to the land demand lie in the greater use of cremation and greater re-use of existing space. Details of different practices have been outlined in Chapter Three and they vary widely from place to place.

The problem isn't a new one, it's been recognised in crowded communities for centuries and is widely documented. A thoughtful exposition of the issues with respect to London by Holmes (1896) stated:

> "What we have to consider is how to dispose of the dead without taking so much valuable land from the living. In the metropolitan area alone we have almost filled (and in some places overfilled), twenty-four new cemeteries within sixty years, with an area of above six hundred acres; and this area is nothing compared with the huge extent of land used for interments just outside the limits of the metropolis. If the cemeteries are not to extend indefinitely they must in time be built upon, or they must be used for burials over and over again, or the ground must revert to its original state as agricultural land ….. " (Holmes,1896).

The use of more creative burial forms, or starting interments deeper and adding multiple burials, or developing higher (not greater in area) mausolea, are really only interim measures. So to is the common practice in many countries of exhuming remains after 3 - 10 years and adding the skeleton to an ossuary of some kind. All eventually fill the existing or new space in rapid time, or demand even more space, for example for ossuaries.

The better solutions lie in: (1) using existing grave space "over and over" without subsequent removal of skeletal material, and, (2) cremation. In addition, for Australia, the use of already created grave space should be maximised by converting perpetual, non-utilized grave leases to a more appropriate form of tenure.

The issues of grave re-use in Australia generally have been under consideration for some time (see for example Department of Lands, 1989), however, the arguments have lacked a scientific underpinning which can state whether the practice would be hygienically and environmentally acceptable. This Study represents the first known geoscientific evaluation of grave re-use practice; preliminary findings were originally presented in Knight and Dent (1998), but now the issues are fully developed - see Chapters Five and Seven.

There are some significant matters that accompany the cremation argument: the composition of the remains (see Chapter Two), air pollution, ash pits for crematoria residues, disposition of the ashes (interment and/or scattering), and possibly the cost of the energy of burning. Economic arguments, however, are rarely mounted in this context and must, when done, take into account the whole 'lifecycle' costs of the post-death dealings. These issues are beyond the present Study.

The actual pollution from most cemeteries is minimal and is predominantly confined to some major ions and inorganic forms of N and P. However, the potential for contamination is considerable, particularly for bacterial and viral pathogens, if incorrect methods of cemetery location and operation are practised. Nonetheless, earth burial is an ecologically sustainable activity.

Whilst arguments may rage about the efficacy of cremation, the reverence and dignity of cremation for peoples with certain religious affiliations, economic or other matters, there is some comfort in now knowing that interment practices can continue if the correct geoscientific parameters are taken into account.

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