VULNERABILITY AND THE UNSATURATED ZONE – THE CASE FOR CEMETERIES

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Abstract: Cemeteries are a special kind of landuse with direct impact on the unsaturated zone. In a cemetery organic waste (the deceased incl. coffin) is deliberately interred at a depth usually corresponding with soil C horizons via a series of purposely cut pits (graves). Ultimately the designated area consists of a highly disturbed surface layer with a framework of in-situ soil walls and corridors, all 'sitting' on a continuous, yet most likely variable, sub-soil or weathered rock, irregular surface. The variability is due to natural processes, and the irregularity is due to differences in grave invert levels and altered topographic grades at the outset. The functional part of the cemetery as a whole, and any one section within, is thus heterogeneous and anisotropic as a medium; this uppermost layer becoming a mixed Anthroposol and natural soil entity. The cemetery site experiences irregular infiltration and percolation effects, potentially very uneven distribution of infiltration processes or events, and ultimately of recharge to any local or regional groundwater system. A principal confounding concern is the local retention of water in the grave – *the bucket effect*.

Ex-cemetery impacts are essentially of four kinds: (i) an excess of groundwater (from mounding, grave buckets, etc.); (ii) the discharge of a salty plume (small, but well documented); (iii) a nutrient plume – essentially inorganic forms of nitrogen; (iv) the potential for the spread of pathogenic bacteria and viruses. For properly sited and maintained cemeteries these impacts are likely to be non-existent or very minor. Impact type 'iv' represents the greatest potential threat, but is in the general context, relatively small. Historically, cemeteries have been poorly and/or thoughtlessly located e.g. on drainage lines, swampy soils, cliff edges, adjacent to drinking water wells and close to watertables; or have no buffer zones or suitable plantings to reduce off-site water migration. For new cemeteries and extensions to existent ones, an assessment of these impacts must be made in regard to aquifer vulnerability and recharge zones.

Key words: unsaturated zone, vulnerability, cemeteries, decomposition products, interment

INTRODUCTION

When present, the unsaturated zone is clearly the first barrier to protecting groundwater systems from contaminant spills, applied chemicals or effluents, or the necessary resultants of society's functions and usual operations at the Earth's surface. In the latter context, the cemetery is an almost universally present human construct; it consumes vast tracts of land, is located in and around cities and on urban fringes, and if not a disused site it is generally continuously active. Despite the very large World wide variation in funereal and cemetery practices; at these sites, mostly organic waste (the deceased and typically wooden coffins and natural fibre clothing) is deliberately interred at a depth usually corresponding with soil C horizons via a series of purposely cut pits (graves) with the idea that natural decomposition will eventually return the remains as elemental contributions to hydrosphere cycles. The unsaturated zone becomes a repository, an intermediate host, and an agent of change.

Society is demanding a great deal from natural processes in the cemetery; and if this is compared to the death processes for other surface-dwelling organisms there are a number of important differences. For example, the interment (burial) process removes the waste (remains) from the activities of many scavenger organisms, such as might apply when a mammal lies on the surface; the remains are quickly placed in an anoxic environment (Dent et al. 2003) where the primary agents of decomposition become bacteria and fungi resident in and on the remains, and the in-soil organisms present when the remains are actually in contact with the environment. Furthermore, in the absence of atmospheric interaction there is a delay in the decomposition process of coffin and funereal artefacts, a buildup of deleterious unoxidised gases, for example, ammonia, methane, and a range of mercaptans (see Vass et al. 2004); an interference in the natural infiltration and percolation pathways of the soil so that precipitation of all kinds does not properly interact with the remains, and hence there can be a delay in removal (percolation or interflow) – compared to overland flow, of the decay (and remnant original) products.

In short, cemeteries exhibit a very large range of spatial and temporal decomposition processes, but with a negative slant to them in terms of a satisfactory timeframe for chemical or microbiological removal of the deceased. The delay in the decomposition processes increases the impact of these sites on the environment. They represent a special case of vulnerability of the unsaturated zone which demands careful consideration in their placement and operation. The traditionally considered filter function of soils is, more usually than not, unavailable to a significant extent compared to other land uses.

Cemeteries can be considered to represent anthropological point source impacts on the unsaturated zone. However, there are some important 'saving' aspects of their existence: the amount of interred wastes is small compared to the volume of soil available (Dent 2002), their internal function is dispersed in space and time so that

loads are not concentrated and to a significant degree the nature of the wastes is known (Dent and Knight 1998): the land used (as the whole cemetery) is generally reserved *in perpetuity;* and the inorganic decomposition products are generally at the low end of pollution inputs (Dent 2002). The largest unknown impact, in most cases, is the microbiological load: this load is intrinsic to the remains at interment and comprises much of the typical fauna of human existence but also can include pathogenic organisms present at, and maybe causative of, death. These organisms survive to different extents in the burial environment; their transmission further in the unsaturated zone and then to any nearby watertable is highly variable.

The Author has been studying the relationships of cemeteries and their hydrogeology since 1994. The information reported herein comprises a distillation of ideas from various studies and some data from the National Study of Cemetery Groundwaters (NSCG) (Dent 2002) for 9 designated sites around Australia.

GRAVE FUNCTION

The cemetery site u ltimately consists of a highly disturbed surface layer typically with a framework of *in-situ* soil walls and corridors, all 'sitting' on a continuous, yet most likely variable, sub-soil or weathered rock, irregular surface. The variability is due to natural processes, and the irregularity is due to differences in grave invert levels and altered topographic grades at the outset. At the outset, cemetery operators typically work from the natural given topographic surface; however, this can often become modified, sometimes in subtle ways not even apparent to the operators. Mostly, this is by deposition of excess fill from the grave excavation process, and/or road and path scrapings pushed to one side, filling/levelling of small depressions. In some places, for example Centennial Park Cemetery (South Australia) the lowermost part of the site was raised several metres by excess fill deposition, levelled and then utilised as natural; in Melbourne General Cemetery (Victoria) the lowest-most part of the site (which had been previously fully interred) was covered by about 2 m of fill then re-used; in Botany Cemetery (New South Wales) the central drainage/creek area was completely reshaped and levelled, several terraces were created in the dunes and a large area (about1/2 ha) was excavated into bedrock to about 2 m the rock broken up and refilled and then the area used as natural. In very sandy environments the idea of a grave pit surrounded by competent walls does not apply because the grave walls need to be retained during excavation and typically collapse upon backfilling.

The functional part of the cemetery as a whole, and any one section within, is thus inhomogeneous and anisotropic as a medium; this uppermost layer becoming a mixed Anthroposol and natural soil entity. Also within this framework are roads, pathways and service infrastructure. In general, until about a depth of 2.1m (possibly more in older sites like Cheltenham Cemetery, South Australia – 3 m) the sites are highly variable. This fact alone necessitates a careful understanding of these places at any time of geoscientific investigation. At this depth the excavation has typically entered the lowermost C horizon of any soils in most of Australia, and in many instances substantially engages the bedrock. In such situations there really is no soil unsaturated zone affecting the interment and consequently decomposition products are able, often quite freely, to migrate through bedrock joints, bedding planes or matrix.

Where the cemetery essentially comprises transported soils, for example riverine floodplains, fluviatile or marine embayment infills, sand dunes or colluvium on slopes or in dolines, the unsaturated zone may in fact be more homogeneous in composition. When graves are subsequently backfilled the homogeneity of material types is often not overly disturbed, for example in the case of sand dunes comprised of medium to fine quartz sand (Botany Cemetery), however, soil features like bulk density are altered and so to are any remnant weathering induced features such as ferruginous cemented layers ('coffee rock').

Depending on local management and cultural practices grave sites may be more or less covered by monumental masonry, gardens, lawn, bushland or some combination of these. Consequently, the cemetery site experiences irregular infiltration and percolation effects, potentially very uneven distribution of infiltration processes or events, and ultimately of recharge to any local or regional groundwater system. A principal confounding concern is the local retention of water in the grave – *the bucket effect*, Figure 1. In addition, this retention also occurs because the disturbed backfill over the interred remains has a higher porosity and permeability than the native soil. This is likely to be true in most cases except perhaps clayey sands if they are 'watered-in' at the time of backfilling thus allowing for repacking of grains and flushing of clays into pore spaces, and so as to work as cements and barrier layers.

Other backfill types ultimately settle and/or differential settlement occurs as the interred remains decompose and coffins collapse; some clayey backfills bridge – essentially leaving cavities at depth. With settlement, a surface depression develops; this forms an unsatisfactory collection point for water and gives rise to a greater potential infiltration at this grave. Typically, finished cemetery surfaces are poorly managed in terms of hydrological aspects. Whilst provision for generalised downslope runoff is made, complete shedding of overland flow into controlled drains, and the prevention of infiltration is the exception rather than the rule. Ponding also occurs against masonry plinths, curtain walls and risers that are placed parallel to contours, so that preferential infiltration pathways eventually develop. Sometimes these then lead to subsidence or uneven settlement, often evidenced by disruption of the masonry.

In terms of recharge, the grave bucket leads to a potential mounding effect for below-invert percolation to the groundwater system. This system may consist of one or more interflow pathways or a perched or a regional watertable, depending on the hydrogeological setting. It is also not unreasonable to expect that on a cemetery scale,

local groundwater flowlines develop and that these can resurface within the space available. These can be seen as springlines, seeps, scalds or diffuse seepage: they can be substantially influenced by the site topography. In moderately sloped, heavy clay soils, for example Carr Villa Memorial Park (Tasmania) broad seeps are common after shallow flow pathways, and are associated with increased iron pisoliths in discharge areas. In Woronora Cemetery (New South Wales) where well developed, sandy clay soils overlie jointed sandstone bedrock (Hawkesbury Sandstone), numerous springs and fracture-flow situations occur. Since soils depths are quite variable at this site, the existence of buffers and proper surface and sub-surface drainage is important. Fortunately, this cemetery has been developed with some good historical, but incomplete, attention to these issues.

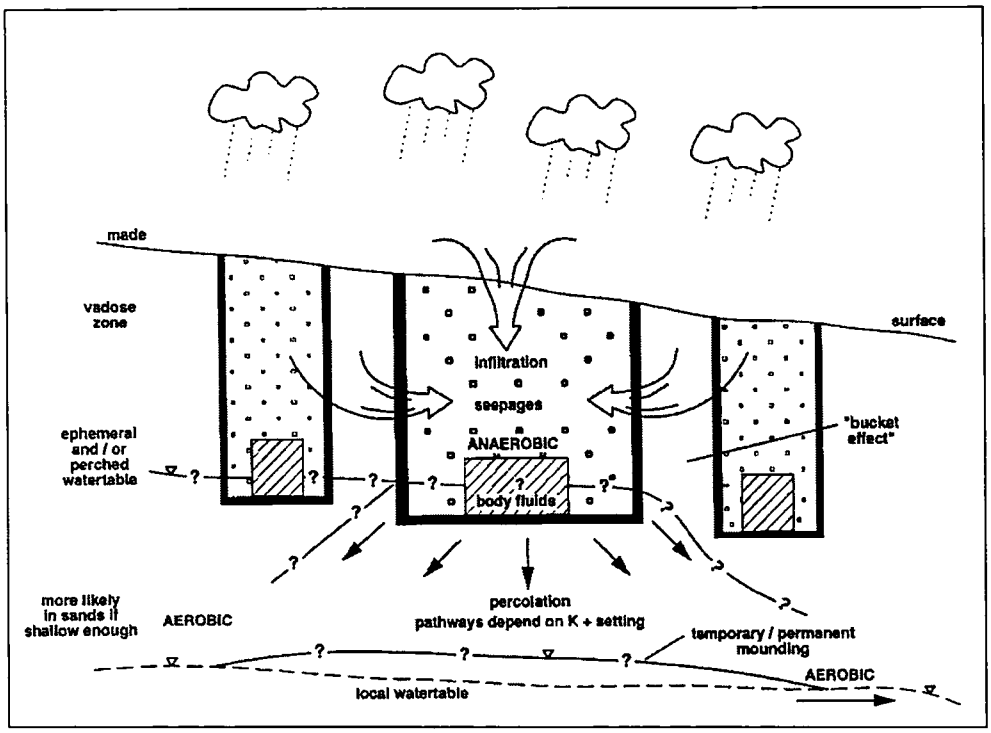

Figure 1. Representation of hydrological processes operable for a grave, and the possible relationships in percolation patterns that might develop.

Seepage effects may continue beyond a cemetery's boundaries and for a distance reflective of local conditions; but solely dependent on the local hydrogeology. In such cases, decomposition products may readily be introduced to surrounding ecosystems or natural waterways or groundwater systems. The presence of a well-planted buffer zone, particularly in topographic lows and where shallow flowlines may surface is a very important management aspect.

GROUNDWATER CHARACTERISATION

In order to establish ex-cemetery impacts, it was necessary to ensure that the characterisation of the cemeteries was as comprehensive as possible and this particularly meant collecting and analysing unsaturated and saturated zones' waters. Ultimately these impacts were determined to essentially be of four kinds:

(i) an excess of groundwater (from mounding, grave buckets, etc.);
(ii) the discharge of a salty plume (small, but well documented);
(iii) a nutrient plume – essentially inorganic forms of nitrogen;
(iv) the potential for the spread of pathogenic bacteria and viruses.

For properly sited and maintained cemeteries these impacts are likely to be non-existent or very minor, a reflection of the total loading, spatial and temporal aspects and the nature of the site. Impact type 'iv', however, represents the greatest potential threat, but is in the general context, relatively small. In addition to the standard

chemical typing of groundwater and the measurement of nutrients, a concerted effort was made in the NSCG to characterise groundwaters for heavy metals. Heavy metals are not correlated with decomposition products, and mercury in particular, being present in dental amalgam, was found to be of no consequence (Dent 2002).

Unsaturated Zone Sampling Issues

In the NSCG, a great deal of effort was made to capture unsaturated zone interflows, and other ephemeral percolation for hydrogeochemical and hydrogeomicrobiological analysis. The sampling of groundwater in the unsaturated 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 unsaturated 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 readily lend themselves to sampling the depth of profile required and particularly returning large volumes of fluid. Alternatives are the construction of standard type wells in the deeper part of the unsaturated 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 the NSCG meant that significant volumes of sample water (about 3 L) were required from the same location on a number of occasions. The amounts and timing of flows vary considerably. It was decided to implement a novel technique of capped, large scale/large diameter wells and trenches (Dent 2002). 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; that is, 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, 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. The wells subsequently installed worked very efficiently. Of the 34 seepage wells and 5 seepage trenches emplaced for the NSCG, only 5wells and 1 trench in total failed to produce any stored sample during the 2.5 years of the field study. A number of the wells had stored water but this was lost between some sampling events; this effect was most obvious at Woronora Cemetery and Melbourne General Cemetery. In both these cases losses through bedrock discontinuities are the likely cause.

Soils and Groundwaters – Correlation Analysis (NSCG)

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 inorganic analytes – Cl, SO_4, Na, Mg, Ca, Sr, NO_3-N,Total Inorganic N, Total NOx, Total N, PO_4,Total P were considered in each analysis, as well as additional overlapping soil chemistry factors – exchangeable bases, pH, CEC etc. This analyte grouping had elsewise been determined to comprise the most significant inorganic components of cemetery groundwaters (Dent 2002). A few negative correlations were found.

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 (unsaturated 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 (VB, SB) or In-cemetery location (V, S).

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* (G) statistic was determined. A minimum level of acceptable correlation was set at 0.6, and a marginal level of interest described for $0.5 < G < 0.6$. 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.

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 just for the unsaturated zone is given in Table 1. The physical property determinands 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' following classification consistent

with their description using the United States Department of Agriculture texture scheme. This methodology is highlighted here as one approach of several, but one which has proved satisfactory in other forensic contexts studied by the Author (see for instance Forbes et al. 2004) and which is properly discussed in Murray and Tedrow (1992).

Table 1. Correlation Analysis Results – Soils and Groundwaters (Non-Biological)

Soil		Significant Relationships				Marginal Relationships	
Group	Sub-Group*	Analytes	N	Kendall *tau*	p	N	Analytes
Unsaturated 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 42	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 40	EC & EC, Mg pH & pH, alkalinity Na & Na
Saturated Zone							
All	all	nil				81 78 76	texture & EC, Na, Mg EC & EC, Na, Sr Mg & SO4
Sandy	all	nil					nil
Clayey	all	nil				32 28	texture & Mg Mg & SO4
Sandy	SB	texture & 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 14 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	texture & SO4 texture & Na texture & K texture & 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 12 16 12 12	texture & 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 (G) is negative Hydr. Cond. = hydraulic conductivity
* Sub-Group classifications:
V = unsaturated zone, S = saturated zone, B = background, U = underlying aquifer

Increasing complexity of analysis:

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

Overall, these data suggest that in broad terms, soil-groundwater interactions are not very important in the considerations of cemetery hydrogeochemistry. However, there are some instances where the role of the major ions may have some influence and in the unsaturated zone the effect of these 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 because the data measured for groundwater analytes are found to be relatively low values. *In such 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 very hard to quantify.

From Table 1 other particular relationships are developed:

- The presence of SO_4 in finer soils is likely to be indicative of decomposition products – in the absence of other sources.
- 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 one site (Carr Villa Memorial Park) 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. 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.

MICRO-ORGANISMS AND TRANSMISSION

The matter of vulnerability from pathogenic organisms – that is the cemetery causing the vulnerability issue - is the most difficult to quantify; whereas primary salts and nitrogen load can be estimated to a reasonable extent. In many cases the cause of death of the interred remains is unknown to the funeral director or the cemetery operator, and the information can not be used in effective management of the cemetery. Thus bodies can be placed anywhere in the cemetery; at the same time there is a great temporal and spatial variation in interment events. If the disease cause of death was known, and/or legislation prescribed certain post-death disposal methods, e.g. cremation of tuberculosis deaths, then part of the issue dissolves. This is of course also unknown in the historic context. Compounding this ignorance, or the absence of disposal directions, is the lack of information on the survival of pathogenic bacteria and viruses in the coffin and/or soil environments.

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). 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 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 1990 and 1996, Haagsma 1991, Yates et al. 1985). 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.

Furthermore, 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.

Finally, there is 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. The great variety of cemetery sites' soils and hydrogeological conditions makes for a relatively complicated situation in the development and application of suitable criteria. These matters are not further discussed here, but see Dent (2002) for an explanation of them.

Figure 2 illustrates the occurrence of indicator bacteria measured at Botany Cemetery for the NSCG. The wells sampled were immediately associated with a significant area of recent interments, and represented a distribution along the flowlines down hydraulic gradient (Dent 2002). Before the result was registered as significant, the analysis cautiously required two indicator bacteria to be present in each sample. Despite the rigorous sampling, this most favourable environment produced very little in terms of significant bacterial presence; the values of the determinands were generally quite small (<500 CFU/100 mL).

In essence, 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:

(1) the amount of buried organic waste – harbouring organisms of interest in an organic substrate host – is small; 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;
(2) 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;
(3) 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.

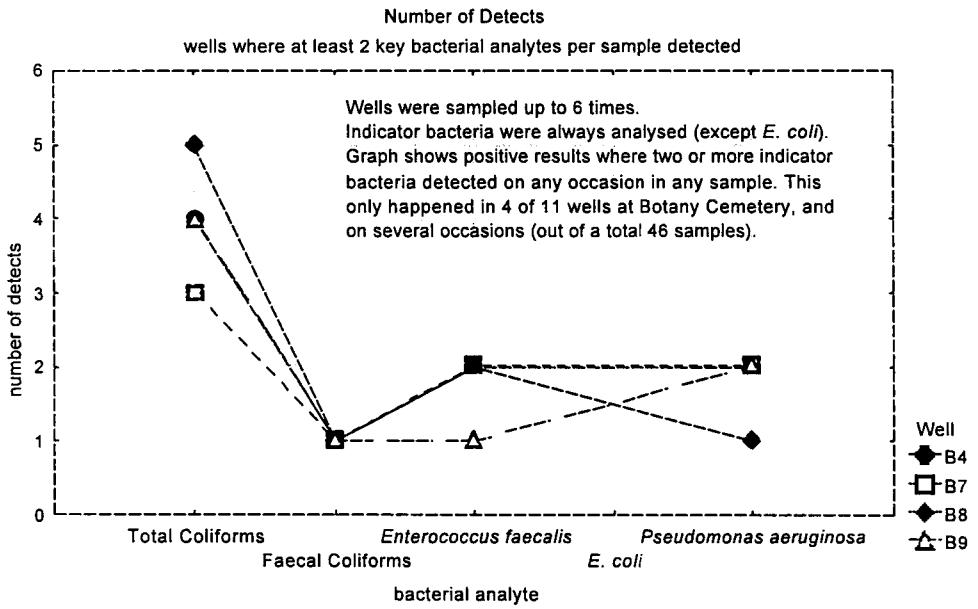

Figure 2. Persistence of indicator bacteria along flowline at Botany Cemetery study area (Mar 1997 – Aug 1998). Well #B4 furthest upgradient and at immediate downgradient edge of area (about 1500 m^2) of newer graves, #B9 adjacent to cemetery boundary and furthest downgradient. Inter-well distances in order along flowline: B4 - B7 36 m, B7 - B8 42 m, B8 - B9 51 m.

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, 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).

The full soil profile is not available to 'filter-out' or attenuate pathogen movement; in fact, once removed from the coffin environment, if pathogens are still viable, they are potentially in a favourable environment to be moved on. They may die out as food and energy resources diminish, or ecosystem competition increases, during the movement; but this type and degree of behaviour is mostly unknown for the special infective agents of concern. Viable pathogens entering a flowing groundwater system are free to leave the cemetery boundary. In the case of flooded graves the organisms are possibly free to migrate to the surface and be carried in overland flow.

SITE ASSESSMENT & CONSIDERATIONS

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 for example the gley soils of Europe. 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: in addition, they permit the final chemical weathering of bone.

A number of soil conditions influence decomposition product behaviour and cemetery operations. 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 set-back 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.

Historically, a great number of cemeteries have been poorly and/or thoughtlessly located, for example, on drainage lines, swampy soils, cliff edges, adjacent to drinking water wells and close to watertables; or have no buffer zones or suitable plantings to reduce off-site water migration. An unsuitable corollary is that some cemeteries have permitted drinking water wells to be located within their boundaries.

Part of the automatic solution to ensuring that cemetery landuse has a proper place in society's environment, is to ensure that cemeteries have reasonable buffer zones, reflective of soil type and topography, at their boundaries; and that they be carefully located with respect to streams, drainage lines and sensitive ecosystems. Cemeteries need to be considered as a landuse potentially effecting aquifer vulnerability and/or the recharge process. Cemetery site location planning must be made in the context of knowledge of the potential inputs and outputs: new sites and extensions must be properly assessed geoscientifically.

Buffer zones should be planted with locally adapted, deep-rooting native vegetation; this will assist in intercepting local flowpaths and should at least effect any nutrient migration. Lengthened flowpaths also have the advantage in permitting consumption of subsurface food resources for bacteria and viruses, as well as generally extending the opportunity for them to be attenuated by soil filtering mechanisms.

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