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A WATERY GRAVE - THE ROLE OF HYDROGEOLOGY IN CEMETERY PRACTICE

By

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Abstract

When rainfall reaches the Earth's surface it can runoff to streams or percolate into soil and rock to become groundwater. Plants use some water and other amounts evaporate directly. Waters that percolate through cemeteries will carry with them some elements of the interred remains. Any dissolved materials may eventually pass into the environment. The possible effects will vary greatly with the range of geology and groundwater (hydrogeology) settings that exist for various cemetery sites.

Water in permeable rocks and soils (aquifers) may represent a store of low priced water which can be used for the irrigation of the vast lawn and garden areas of cemeteries. It is expected that the cost of mains-delivered water will continue to rise in the foreseeable future; thus where it is present, the extraction of groundwater resources represents a cost-beneficial opportunity for improved cemetery management.

Some locations are already suitable for development while others are located in areas of poorer quality groundwater which may be treated to satisfactory standards for irrigation. Even where the cemetery is situated in an area without groundwater supplies there is still a need to adequately understand its position within the water cycle. It is expected that regulatory controls will tighten in relation to potential contamination of the environment and cemeteries could well come under the spotlight in the future. The trend of legislation overseas and more recently in N.S.W. is for Directors or people with primary responsibilities for land related operations to have some personal liability.

There are very few research studies of the hydrogeochemistry of human remains' decay in cemeteries. There are some anecdotal studies of microbiological contamination deriving form these and the apparent pollution of poorly sited drinking wells. However, at Botany Cemetery, Sydney; which partially sits on the edge of a small unconsolidated sand aquifer; the opportunity to examine the chemistry of groundwaters and to investigate the availability of groundwater supplies has been pursued.

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It was found that in this hydrogeological environment the downgradient groundwaters were of an acceptable quality compared to the aquifer's background. These waters are available for irrigation purposes but that their extraction has some technical difficulties at the present time. Research studies confirmed that the decay of interred human remains produce a salinity plume locally, but that it rapidly diminishes with distance from the grave.

INTRODUCTION

Cemeteries involve the interaction of degradable substances (body, coffin etc) and land. The land in turn comprises soil and rock that are acted on by processes including groundwater, surface flows as well as water geochemical activity and micro-organisms. At some locations, wind and erosion processes can also play an important role. Until relatively recent times, little geological analysis of these interactions and processes has been attempted. This is probably due to the belief systems and other views societies hold about cemeteries.

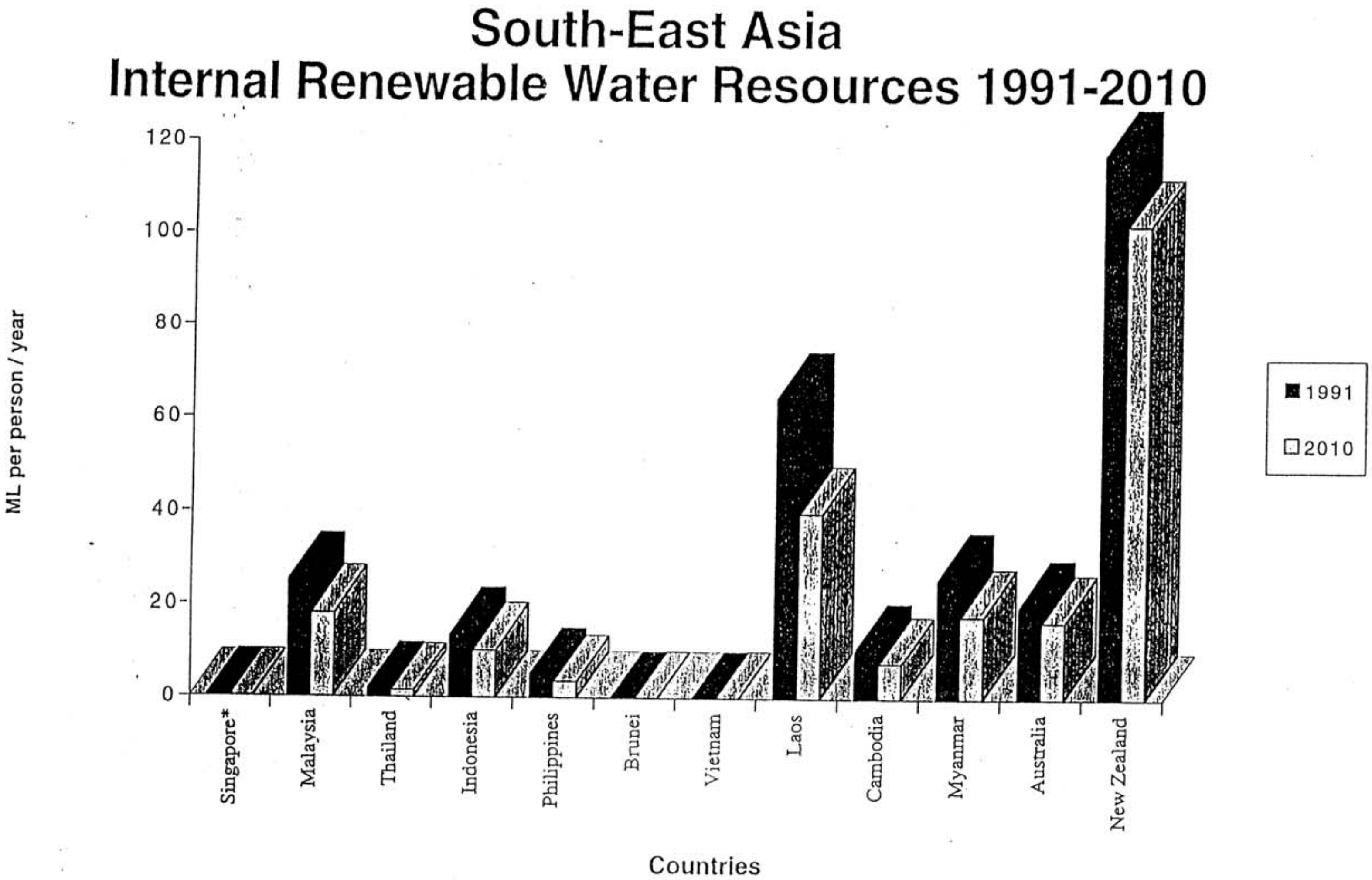
However, modern management of cemeteries now requires a thoroughly professional approach to such issues. The growing water requirement for maintaining attractive gardens and lawns is an example that will be of increasing concern. The current price of mains water in Sydney is 65c/kilolitre. This could double or triple over the next 10 to 15 years due to the need to raise capital in order to replace a substantial part of the decaying pipe system (42,000 km!, Pollett, 1995) over the next 20-30 years. Other Australian States and overseas cities are facing similar problems The World Bank has pointed out that water is considerably undervalued in the exploding cites of third world countries, Sevegeldin (1995).

The quantity of renewable water per capita per year is also declining worldwide including South East Asia and Australia in particular, Fig 1, EAAU (1994).

As a consequence of these trends, groundwater is becoming increasingly important in the financial part of the cemetery management equation. Where groundwater can be abstracted from the Botany Sands aquifer in Sydney, for example, it costs about 21c/kilolitre (Davies, 1992).

At this low cost, groundwater is an attractive source of water for irrigating, golf courses, parks and gardens and this occurs frequently on the Botany Sands Aquifer especially from Centennial Park to Botany Bay, Fig 2. Some cemeteries in Australia may be located on or near suitable aquifers, others will not but whichever is the case, water management in relation to the sub-surface soil and rock is an important issue in cemetery practice.

Environmental regulations and attitudes will also be critical future drivers in cemetery management. If the public and regulators perceive that a cemetery is in fact a specialised type of landfill that could potentially pollute groundwater or streams, such sites will come increasingly under the spotlight.



Note: * Singapore imports most of its water supplies from Malaysia

Fig.1 Renewable Water m^3 per capita per year for Australia and Countries in South East Asia (Data after EAAU, 1994)

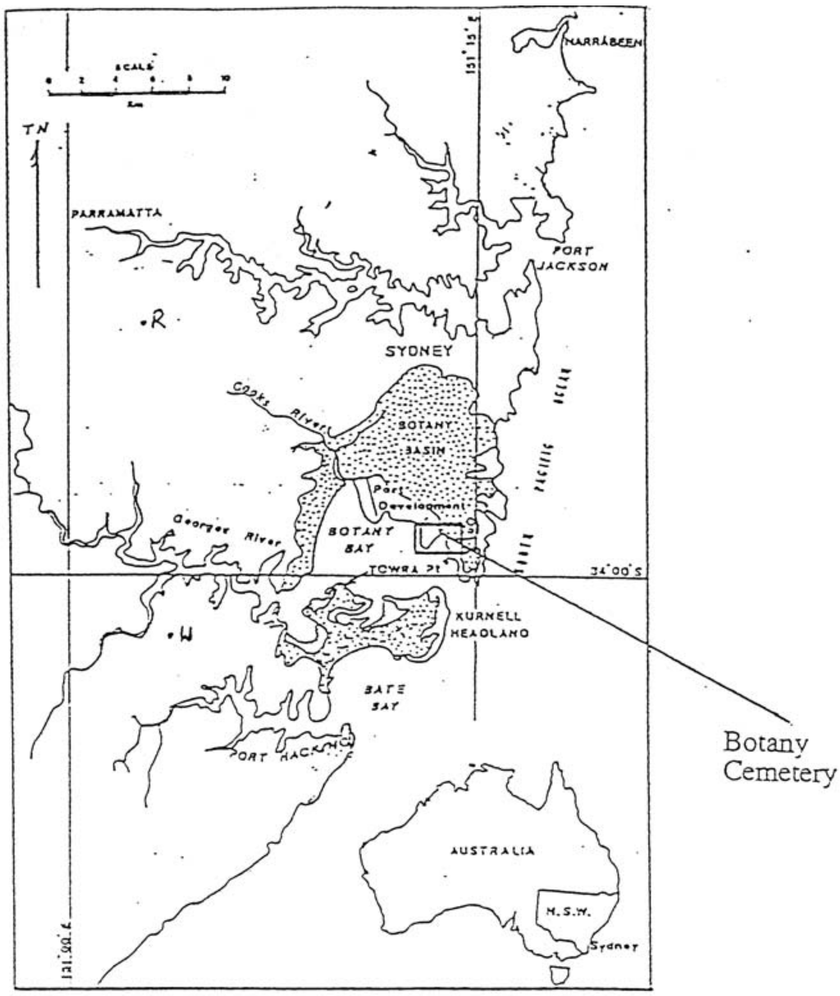


Fig.2 Location of the Botany Sands aquifer (stippled area) in the Botany Basin, Sydney (Data modified from Dent, 1995). Rookwood Cemetery (R), Woronora Cemetery, Sutherland (W)

It is of interest to note the insightful obsevations of Walter Bell first writing in 1924 on the Great Plague of 1665 in relation to disease transmission and water including groundwater below church grave yards:

"And London had learned nothing. Sanitary science had not been born. Foul streams like the Fleet, defiled from every overhanging house and neighbouring alley, were no better than open sewers, and in parishes aligned upon the banks of these pestilent watercourses - St. Bride's, St. Sepulchre's and St. Andrew's Holborn notably, and St. Giles's Cripplegate by the water-soaked moor- the Plague mark is most darkly drawn. Laystalls of rotting town refuse, the sweepings of streets, houses and middens, were piled high near inhabited quarters, poisoning the air. The dead were buried thickly in graveyards surrounding the City churches; the living drew from wells water for household use which had percolated through the graveyards. At St. Clement Danes, St. Bride's, Cripplegate (Crowder's Well) and many

more City places, each of the parish wells now closed, but commemorated by surviving pump or lettered tablet, is a churchyard well."

(Data after Bell 1994)

Conditions had not much improved by 1845 when Engels described the Pauper grave at St. Bride in London at a time when cholera epidemics (water borne) were striking London:

"The poor are dumped into the earth like infected cattle. The pauper burial-ground of St. Brides, London, is a bare morass, in use as a cemetery since the time of Charles II, and filled with heaps of bones; every Wednesday the paupers are thrown into a ditch fourteen feet deep; a curate rattles through the Litany at the top of his speed; the ditch is loosely covered in, to be re-opened the next Wednesday, and filled with corpses as long as one more can be forced in. The putrefaction thus engendered contaminates the whole neighbourhood. In Manchester, the pauper burial-ground lies opposite to the Old Town, along the Irk: this, too, is a rough, desolate place. About two years ago a railroad was carried through it. If it had been a respectable cemetery, how the bourgeoisie and the clergy would have shrieked over the desecration ! But it was a pauper burial-ground, the resting-place of the outcast and superfluous, so no one concerned himself about the matter. It was not even thought worth while to convey the partially decayed bodies to the other side of the cemetery; they were heaped up just as it happened, and the piles were driven into newly-made graves, so that the water oozed out of the swampy ground, pregnant with putrefying matter, and filled the neighbourhood with the most revolting and injurious gases. The disgusting brutality which accompanied this work I cannot describe in further detail"

(Data after Hoyles 1991) p137-138

Considerable advances have been made since those days! However as the public becomes more environmentally aware and health conscious, especially if a public health crisis occurs, they will demand a high degree of quality control and assurance at Cemeteries. This will be especially so in relation to off site impacts due to groundwater or surface water transport of solutes across Cemetery boundaries. Knowledge of cemeteries' hydrogeology could become a requirement in the future.

HYDROGEOLOGICAL PRINCIPLES

When rain falls on land, some water may infiltrate to become soil moisture and groundwater if permeable rocks or soils (aquifers) are present, other rainfall components may evaporate or run off into streams. Cemeteries like any other land use are situated in part of a hydrological cycle that will be particular for the topography and geology of the area. Figure 3 illustrates in a generalised way how solutes from cemeteries may interact with the water processes. and potentially reach groundwater and streams.

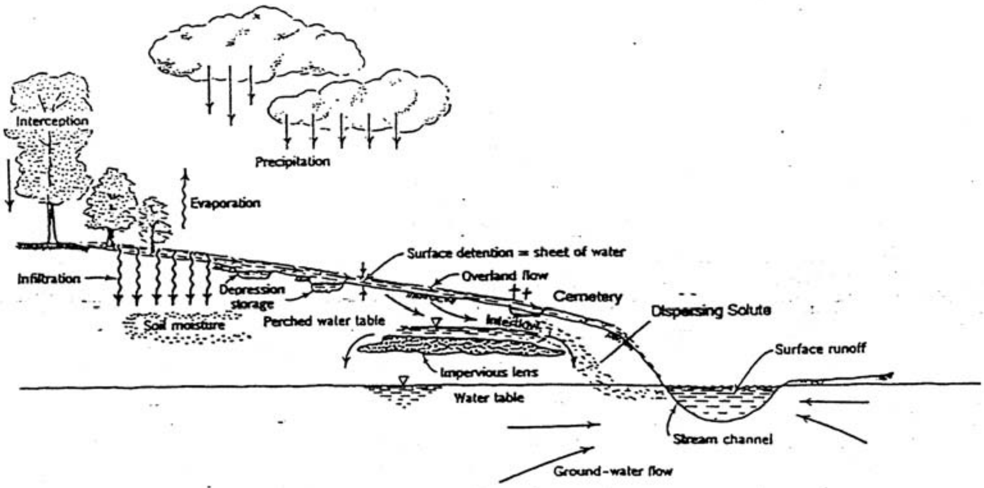


Fig.3 Generalised hydrological cycle in relation to cemetery land use. (Data modified from Davis and Dewiest, 1966)

Cemeteries will be located on a great variety of geologies and topographies. This in turn leads to various expressions or impacts on groundwater and streams.

Fig.4 Illustrates some (but not all) typical hydrogeologies.

Some rocks are essentially impermeable but they can have fractures and may become "fractured rock aquifers". Some apparently impermeable rocks can develop deep weathering zones of permeable material. This occurs in the Hawkesbury Sandstone of Sydney and some granites. Faults (breaks in the rock) can also be preferential pathways for water transmission (Fig.4d, e). In Victoria, including parts of western Melbourne, it is not uncommon for basalt flows to have buried past river channels containing gravel (Fig 4i).

Sometimes permeable sandstone layers are sandwiched between impermeable shale layers. This arrangement is known as a confined aquifer, (Fig 4g). If a cemetery was located where rainwater infiltrates eg at X in Fig 4g (recharge area) solutes could move down gradient and discharge in a spring a considerable distance away.

This highlights the need to take into account these regional or "big picture" hydrogeology as well as local site conditions.

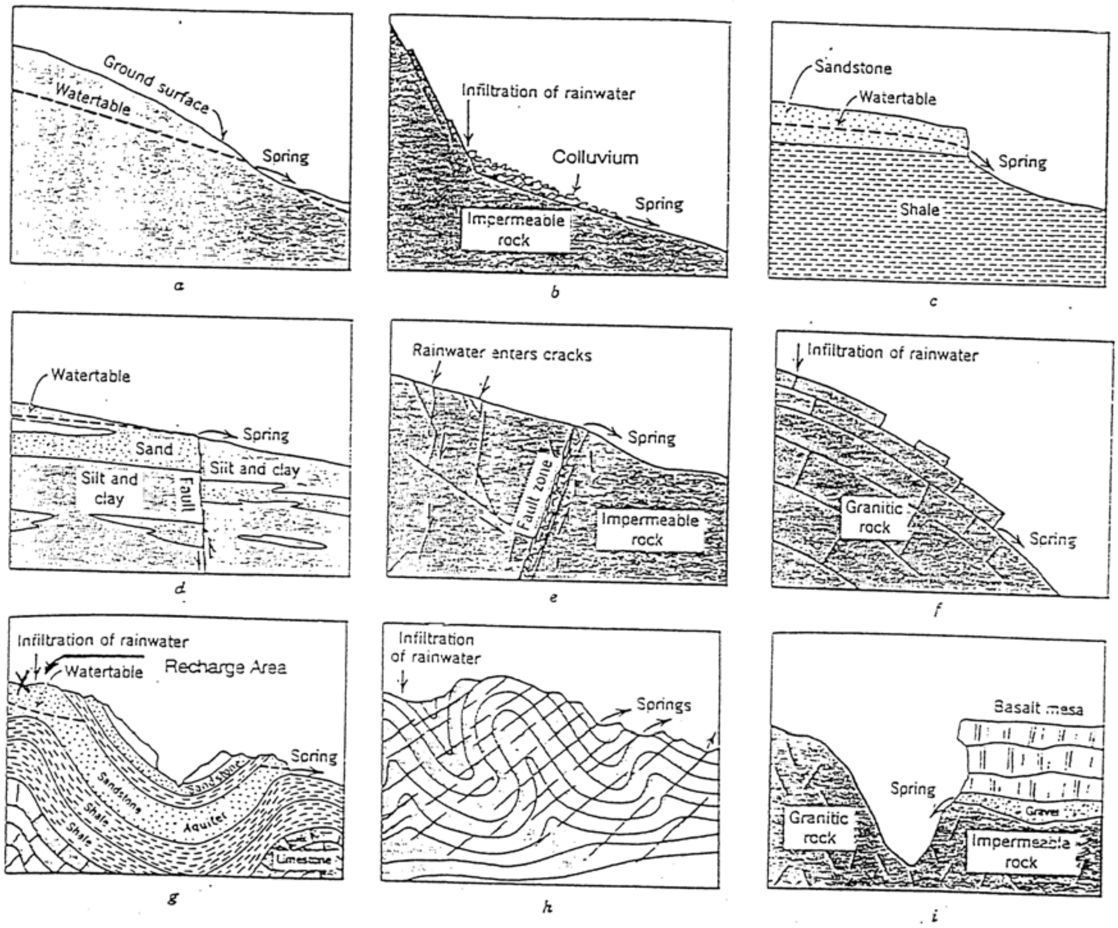


Fig. 4 A range of possible hydrogeological rock environments

(a) Spring formation where a watertable in a permeable layer intersects the ground surface
(b) Slope debris (colluvium) on an impermeable rock
(c) Perched aquifer in Sandstone on top of an impermeable shale (Note some shales eg Ashfield Shale in Sydney can be permeable due to fractures)
(d) Permeable sand in alluvium truncated by low permeable silt and clay causing spring discharge
(e) Fractured rock aquifer and fault in otherwise impermeable rock
(f) Fractured granite aquifer
(g) Sandstone aquifer confined between impermeable shale layers
(h) Folded and fractured sedimentary sequence
(i) Basalt lava (fractured rock aquifer) over a buried river channel gravel over an impermeable rock (Data modified from Davis and Dewiest, 1966)

Geology of Selected Cemeteries in Australia

To illustrate the variety of geologies and possible groundwater occurrences, Table 1 summarises a sample of cemeteries in Sydney, Melbourne and Brisbane.

Table 1 Geology and Potential Groundwater Occurrence in Selected Cemeteries of Melbourne, Sydney and Brisbane

Cemetery Location	Geology	Groundwater Occurrence Potential
Sydney		
Botany (Eastern Suburbs Memorial Park)	Botany Sands	Aquifer present. Fresh groundwater sources in valley bottom (some localised permeability problems)
Rookwood	Ashfield Shale	Essentially dry but some limited wet areas with clays (weathered rock)
Woronora Sutherland	Hawkesbury Sandstone	Minor perched wet zones in weathered rock profile. No aquifer
Melbourne		
Springvale	Fyansford Formation Brighton Group (sand)	Aquifer present Saline water >3000 mg/L Total Dissolved Salts
Melbourne General	Silurian mudstone	No groundwater. Clay from weathered mudstone
Werribee	Werribee Delta Sediment	Aquifer present Quality 1000-2000 mg/L Total Dissolved Salts
Brisbane		
Toowong	Bunya Phyllite* Very clayey to 2m	Perched groundwater. Graves often wet, groundwater at soil - rock interface
Mt. Gravatt	Neranleigh - Fernvale Beds Argillaceous (clayey) rocks mostly with minor sandstone and chert (silica)	Minor groundwater in fractures possible?

We are not aware of any systematic evaluation of the hydrogeologies of cemeteries nationally and it could be a useful exercise for the Industry to pool their resources and asse ss the range of issues. Some common solutions and opportunities may emerge as an outcome.

HYDROGEOCHEMISTRY OF CEMETERIES

Hydrogeochemistry is the study of the chemistry of water, soil and rock at a site.

A conceptual approach

Cemeteries can be conceptualised as a special kind of landfill, and from this model an understanding of the hydrogeological processes at work, can be developed.. Landfills in the classic sense are where, new land is created and the surface topography so altered that it bears little resemblance to the starting topography because of the addition of large volumes of new material. Cemeteries cannot comply with this definition, however, but they are a fill in the sense that some new material - a coffin and remains, is incorporated in a prepared space.

* A slate that has been altered (metamorphosed) to some degree.. The rock weathers to clay which contains the mica mineral muscovite.

The bulking of soils caused by excavation of the graves and coffin emplacement results in some alteration to the surface. At some later stage after the coffin collapses and the remains' space is decreased, the backfill settles. Some topping up may then be used to restore the land surface. This effect is more apparent where lawn areas are the completed surface expression. However, in areas where monumental masonry covers are used, some settlement and cracking of these may occur.

The space occupied by the fill materials is relatively low; about 9% of grave space allocated to them. Not all of this space is excavated since thin walls between adjacent graves are usually left. Where multiple interments in the one grave site are known to be required, the first coffin is usually placed deeper. The fill materials are of a special kind as they are mostly organic or organically derived.

The geochemical processes at work in a cemetery are dictated by a vast range of factors. These include the whole range of means of encapsulating and preparing the human remains, the age and attributes of the remains themselves, other inclusions in the grave, the soil conditions, means of grave construction and backfilling, grave density. the prevailing climate, and groundwater flow.

Possible effects of remains' decay on soils and water

In terms of decay products, the cemetery processes are dominated initially by the formation of NH_3 (ammonia gas) (Evans, 1963, and Mant, 1987) and presumably CO_2 (carbon dioxide gas) as resistant organics and cellulose (wood) and plastic are converted. The human remains also liquefy quickly, they contain much water, about 70 -74% by mass (Forbes, 1987), and this is responsible for the rapid release of Na^+, K^+, Cl^-, HCO_3^-, NO_3^-, PO_4^{3-}, NH_4^+ and SO_4^{2-} ions.

Decay of the remains is brought about principally by internal bacterial action and doubtlessly by chemical reactions with groundwater, soil gases and micro-organisms on the remains' surfaces but these are not yet documented. At this time, however, decay from the processes working on the body in its own niche entombment will have achieved different levels.

All decay, but particularly decay in the typical managed cemetery where different funeral practices abound, must proceed at very variable rates. Consequently, the estimation of the average body contribution to the ground is a complex calculation exercise.

Once decay products enter the soil or groundwater systems they are then influenced by all the factors that affect contaminant movement: adsorption, retardation, porosity, permeability, background hydrogeology, landform etc.. It also seems likely that for cemeteries in particular, the microbiological fauna will have a significant impact. The concentration of organic material from human remains probably also effects the formation of organic metal complexes and their migration.

There is another matter peculiar to a cemetery landfill. That is, the attraction to bone of certain elements. The studies in this regard are by no means complete but it has been well documented by Lambert et. al. (1985) and Henderson (1987) that a whole range of elements are attracted to bone in different stages of preservation.

Lambert et. al. (1985) in very careful experiments showed that *"aside from Na and Ca (which show losses), all studied elements are capable of significant influx (Al, Mn, Pb, Sr, Zn, K and Mg) to degrees that differ with pH."* Elemental influx also varies with degree of crushing and age of burial, although time effects are relatively unknown. These studies have implications for considerations of the migration of some elements from some parts of some cemeteries.

Confirmation of a salinity plume - recent interments study

The water cycle link with cemeteries is poorly documented. Some references relating to limited and incomplete studies are available from Europe, Brazil and Canada. Schraps (in Bouwer, 1978) reported high concentrations of bacteria, ammonium and nitrate ions in a contamination plume which rapidly diminished with distance from graves (in Germany), whilst van Haaren (in Bouwer, 1978) measured a very saline (2300 μS/cm) plume of chloride, sulfate and bicarbonate ions beneath graves in Holland.

The recent studies by Dent (1995) for Botany Cemetery, where an opportunity was available to assess groundwater conditions near recent interments, showed a definite increase in electrical conductivity (salinity) close to recent graves and that this was attenuated (diminished) downgradient. At this stage of research though, there is no other data about the time period over which the effect lasts, gas generation, or changes in pH, redox or bacteria.

The leachate plume was found to be high in:- chloride, nitrate, nitrite, ammonium, orthophosphate, iron, sodium, potassium, and magnesium ions. On average, the water pH was higher than for cemetery background or background waters - consistent with the decay processes at work.

BOTANY CEMETERY CASE STUDY

Overview

Botany Cemetery (Eastern Suburbs Memorial Park) is located approximately 11 km southeast of Sydney's Central Business District in a geographically constricted setting. It lies on the northern edge of a small unconsolidated aquifer of sand dune deposits over reworked beach and fluviatile deposits which occupy a former small embayment on the eastern edge of Botany Bay. The aquifer, which is about 80 ha. in size, is partially drained by a perennial stream which is fed by spring waters rising in the surrounding ridges of Hawkesbury Sandstone. This hydogeological unit has not been described before and has been called the “Yarra Aquifer”.

A comprehensive investigation was made of the ability of the aquifer to provide sustainable groundwater resources (to 50 ML per annum extraction) to meet the Cemetery's lawn irrigation needs. A partial hydrologic budget was developed which indicated an annual recharge to the aquifer of 130-140 ML with the likelihood of providing sustainable groundwater resources. A number of other bores (some active) were located in the general area.

Subsurface investigation of new aquifer

Within the boundaries of Botany Cemetery the "Yarra Aquifer" has been intensively investigated, primarily from the focus of its groundwater potential. Essentially three stages of investigation were conducted following an initial appraisal.

Stage One:(a) 3 boreholes finished with observation piezometers, were established in order to obtain an initial appreciation of aquifer conditions, and as control for geophysical investigations;
(b) a gravity geophysical survey along two lines - adjacent to the site's southern boundaries and over and along the apparent highest sand dune section;
(c) water samples were taken for determination of key inorganic and microbiological parameters.

Stage Two: (a) 39 hand augered boreholes (totally 126m) were put down in the period August to December 1994; many were completed with observation piezometers. During this phase, sediment samples were taken for sieve and x-ray diffraction analysis, and careful note paid to the level of the water table. Frequent monitoring of standing water levels (SWL) in the piezometers was carried out during the period.
(b) additional geophysical surveying - electrical resistivity - was attempted but his proved to be unsatisfactory in the conditions and was not pursued.
(c) numerous water samples were taken for field and laboratory testing for inorganic chemical analytes, and for x-ray diffraction studies of some suspended material (which turned out to be mostly silica).

Stage Three: (a) 3 more boreholes completed with observation piezometers and security covers, were established on the southern site boundary in a location suggested by earlier investigations as most likely to yield satisfactory groundwater supplies.
(b) the final borehole (#7), the "water bore", was then established using stainless steel screen, full metal casing and gravel pack. This bore was subsequently subjected to step drawdown and constant rate pump testing, and withdrawal and addition slug testing.
(c) additional water samples for inorganic chemical and key microbiological determinants were also tested.

Hydrogeochemical processes at Botany Cemetery

The results of these investigations were of interest from three perspectives: 1. the groundwater resource; 2. the chemical composition of the groundwaters; 3. the detailed considerations of cemetery hydrogeochemistry. Perspective 3 is discussed above.

The groundwater samples downgradient of the Cemetery were found to be of a very similar composition to the background groundwaters. Our conclusion is that the Cemetery has little impact on the groundwater system.

Even from a trace metal perspective, small quantities of copper and zinc were found in all samples indicating no concern, although these are more elevated close to the recent interment area. Boron levels were noticeably higher compared to backgrounds, closer to the recent interments and in some other samples. This cannot be adequately explained at present but may be related to some industrial fallout (it is also present in surface waters) or some funereal aspect.

Suitability of groundwater for irrigation

The Botany Cemetery Trust Board wanted to use its groundwater for the large scale irrigation of grass and garden areas in the reserve, with subsequent savings in the cost of mains water currently supplied. Extensive plantings of kikuyu grass and native shrubs and trees have been undertaken. Kikuyu is quite a salt tolerant grass (Hart, 1974) which is compatible with the salty air due to Botany being near the sea.

All of the chemical analyses undertaken have shown that the surface waters and groundwaters of the catchment would be suitable for the proposed irrigation. Hart (1974) has compiled data on a number of relevant parameters to assess whether toxic or harmful effects will occur to plants or equipment from the use of various waters. The relevant parameters assessed were: total dissolved solids, sodium adsorption ratio, residual sodium carbonate and boron content.

The water was classified as slightly acidic, low salinity (Class 1), with no sodium or boron hazard.

A further concern was that monument construction materials could be stained by the presence of dissolved iron or manganese in the groundwaters. Local samples of sandstone, granite, marble and tile were immersed in samples of the groundwaters for a period of 5 months while other specimens were left exposed to the weather. Staining problems could be overcome, but these samples indicated no likely effects.

The water samples taken for this study can be grouped as background i.e. upgradient of the Cemetery; Cemetery background; and specific samples associated with an area only containing recently interred remains -since August 1993. Typical parameters of these waters are presented in Table 2.

Table 2 Typical Parameters of Various Water Groupings – Botany Cemetery

Analyte (2)	1. Background	2. Cemetery Background	3.Near Recently Interred Remains (1)
pH	5.40	6.15	6.62
EC µS/cm	320	194	740
Eh mV	235	295	65
temp °C	20	19	20
Na	25.49	14.00	70.55
K	2.50	3.20	9.56
Ca	19.82	15.00	50.
Mg	4.02	2.80	19.00
Fe	0.29	0.27	5.00
Mn	0.007	<0.2	0.214
B	0.013	<0.1	0.188
Se	0	<0.005	0
As	0	<0.005	0
Cd	0	<0.001	1.502
Cr	0	<0.005	0
Cu	0.012	<0.005	0.134
Hg	0	<0.005	0.008
Ni	0	<0.005	0
Pb	0	<0.005	0
Zn	0.692	0.170	0.103
HCO_3^-	7.20	11.00	0
CO_3^{2-}	0	0	0
Cl^-	49.00	27.00	58.5
NO_3^- - N	14.00	6.05	6.16
NO_2^- - N	0.01	0	0.07
PO_4^{3-}	0.10	0.9	3.4
SO_4^{2-}	24.20	15.00	57.0
NH_3 - N	0	0.13	1.24
F^-	n/a	<0.5	n/a

(1) Groupings
1 background groundwater away from cemetery
2 background groundwater within Cemetery
3 groundwater within Cemetery -Recently Interred Remains Study Area

(2) Analyte values in mg/L.

Microbiology

In addition to inorganic sampling the key microbiological indicators - faecal coliforms, faecal streptococci and biochemical oxygen demand (5 days) (BOD_5) were also measured. The faecal bacteria counts have been shown to be an effective indicator of bacterial contamination from human sewage/human presence (Cohen and Shuval, 1973); although they have different survival rates in different geological environments and should be tested in tandem.

The results for faecal coliforms - nil and <10 colonies/100 mL; and for faecal streptococci - nil and 4 colonies/100 mL, indicate no significant pollution in the groundwaters in the lowermost part of the Cemetery, at the time of testing. The minor values obtained are less than background expected in a parkland environment.

The Biochemical Oxygen Demand (BOD_5) results (<1 and 4 mg/L) indicate an extremely low level of micro-organism and organic carbon substrate usage of oxygen. These values suggest an early satisfaction of organism oxygen demand and probably indicate a relatively low microbiological activity. Redox (Eh) results for the same samples also indicate an oxidising environment.

The accumulation of pathogenic organisms and their transmission in groundwater is reasonably well documented in hydrogeology, public health and medical literature. Some of these studies have been linked to cemeteries e.g. Pacheco et. al. (1991), Balcerzak and Mylroie (1989), but much of the evidence is limited or anecdotal, rather than vigorously investigated or proven.

For the Botany Cemetery the results are low, and the water is suitable for irrigation. However, these results could be a reflection of a number of factors e.g. density/age of interment, location relative to flow lines, and number of samples. Water borne bacteria and viruses are fragile out of water so this implies a relatively low risk in the spray irrigation use of the groundwater.

CONCLUSIONS

As the community demands on water supply infrastructure expand, and community expectations on the availability of natural waters for natural features increase, the cost of mains-delivered water will rise. It is inevitable that landscape features of the built environment, be they parks for recreation or cemeteries, will have to manage the increasing cost of water in relation to gardens and grounds. If groundwater resources of the right quality are available in quantities that can be sustainably exploited, then their development should be seriously investigated.

With increasing public concern, it is also confidently expected that environmental legislation will become more stringent. The question of pollution possibilities from cemeteries, their general location and features, will also be raised. Cemetery managers now need to consider the hydrogeology of their site to continue the development trend of professional good practice.

In the few cases where poorer quality groundwater resources are available for potential cemetery lawn irrigation, the cost-benefit issues of “cleaning up” these waters should be considered.

The hydrogeological settings of cemeteries are very varied. Some examples noted illustrate how some will be sited above potential groundwater aquifers while others may not. Consequently any one site’s investigation and development could vary greatly from another. Those localities not prospective from the groundwater in an irrigation context, nonetheless need to be considered from the likelihood of subsurface hydraulic links to surface or ground waters or whether other cemetery-related practices have an impact on the environment.

A world-wide search of the available documentation on the hydrogeochemical aspects of cemeteries has been made. There are very few published works concerning contamination or element dispersal from these sites, nor are there detailed understandings of the processes at work. A local leachate plume will develop from all interred remains, but this will not necessarily be large, and its effects need to be demonstrated in the field.

At Botany Cemetery, a groundwater resource suitable for irrigation has been demonstrated. Furthermore samples of these waters downgradient from the Cemetery have shown that dispersal of contaminants is minimal.

A national survey of hydrogeology of cemeteries could provide some useful principles for management and future siting. It would also demonstrate the Industry's commitment to professional good practice.

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APPENDIX

Explanation of Chemical Terms and Symbols

ion – an ion is an electrically charged chemical species; metal ions carry a positive charge (+), others also of significance are negative (-). Natural solutions are electrically balanced.
cation – a positive ion
anion – a negative ion
EC – electrical conductivity of a solution, measured in micro Siemens per cm (µS/cm) (of conductive pathway). This is an indicator of salinity.
pH – measure of acidity; a solution is acid pH < 7, neutral pH = 7, alkaline pH > 7.
Eh – redox potential; used as a natural indicator of oxygen present in the system; measured in mV - millivolts.
Total Dissolved Salts – the weight of the dissolved components in the water
mg/L – milligrams per litre of solution
ML – megalitres (one million litres)

Na	Sodium	Al	Aluminium
K	Potassium	Sr	Strontium
Ca	Calcium	HCO_3^-	Bicarbonate
Mg	Magnesium	CO_3^{2-}	Carbonate
Fe	Iron	Cl^-	Chloride
Mn	Manganese	NO_3^-	Nitrate
B	Boron	NO_2^-	Nitrite
Se	Selenium	PO_4^{3-}	Phosphate
As	Arsenic	SO_4^{2-}	Sulfate
Cd	Cadmium	NH_3-N	Ammonia Nitrogen
Cr	Chromium	-N	Nitrogen content
Cu	Copper	F-	Fluoride
Hg	Mercury		
Ni	Nickel		
Pb	Lead		
Zn	Zinc		

In Hydrogeological literature ion symbols are frequently written without the + or - sign.