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THE IMPACT OF CEMETERIES ON THE ENVIRONMENT AND PUBLIC HEALTH

AN INTRODUCTORY BRIEFING

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By the year 2000, public health risks caused by solid and hazardous wastes and soil pollution should be effectively controlled in all Member States.

ABSTRACT

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. This review considers the current state of knowledge on the fate of decomposition products from human corpses as they pass through the soil and into groundwater.

This report is intended to provide an introductory briefing on the state of knowledge regarding water pollution from cemeteries and the mechanisms operating to ameliorate the pollution potential. Some suggestions are provided on the siting and design of future burial sites. The findings of research by other workers in Australia, Brazil and Europe are also summarized.

Keywords

MORTUARY PRACTICE
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Introduction

The WHO Nancy Project Office has undertaken a short review of the current state of knowledge regarding the presence, or absence, of soil and groundwater contamination from cemeteries. This was due to an interest to identify more information on their environmental and health impact. There is little published information on whether cemeteries should be regarded as potential sources of pollutants. Few examples of groundwater or surface-water pollution from cemeteries have been found in the scientific literature references in the past. Consequently, this literature review was undertaken by the WHO Nancy Project Office to gather together more information on the subject.

Most existing cemeteries were sited without thinking about potential risks to the local environment or local community. Commonly, they are constructed close to settlements because of religious and culture circumstances. However, religious and sociological reasons for cemetery siting are outside of the scope of this project. This report concentrates on the geological and hydrological properties of burial sites. Often, these have not been investigated.

This review considered first, the mechanisms of decay of the human corpse, and second, the fate of the products of decomposition, both chemically and microorganically in the surrounding strata and groundwaters.

During putrification of the human corpse, there is a seepage of decay products into percolating water. This seepage contains bacteria, viruses and organic and inorganic chemical decomposition products. If the cemetery is located in a porous soil type, such as sand or gravel, movement of seepage can be rapid and mix easily with the groundwater beneath the site. This could conceivably be a cause of local epidemics from waterborne diseases where the groundwater is used as a water source. Typical microorganisms known to be responsible for waterborne diseases and present in seepage include micrococcaceae, streptococci, bacillus and entrobacteria.

Another important factor that should be considered before using aquifers beneath cemeteries as water sources, especially shallow aquifers, is the distance from cemeteries to water abstraction points. The quantity of decay products from buried people and wood, fabrics and plastics used in coffins is directly influenced by the age and number of the human corpses decaying in the cemetery at any one time. Ideally, coffins should be made of materials that decompose rapidly and do not release persistent chemical by-products into the environment.

Today, sufficient land area for cemeteries is difficult to find in populated areas, and in the near future areas sufficient space for cemeteries may not be found at all in cities in most parts of the world. For instance, in Australia about 1.34 million adults (>15 years) will die in the next 10 years. If just 40% of these are interred and 75% of them occupy new graves of an average size 1.1 m by 2.4 m; then 106 ha of land will be consumed. These new cemeteries ought to be constructed to bury the expected number of corpses, but land availability is uncertain.

In England, out of 10 000 planning applications between 1989 and 1997, a total of 104 (equal to only 1% of planning applications) were for burial grounds and cemeteries. Given the need for an increase in the number of burial sites in many countries, there is a need to identify more precisely if, or in what way, cemeteries have any harmful impacts on the environment and public health. One approach would be to establish a set of basic design criteria for the siting and construction of new cemeteries. In addition, more careful consideration has to be given to finding the most suitable soil types in which to bury human remains so as to minimize the effect of seepage on the environment and public health.

No reports have been found in the literature of epidemics or widespread disease outbreaks which were unequivocally the result of seepage from cemeteries. However, doubt and concern persist due to the paucity of sufficient and clear scientific data.

Microbiology of the human corpse

The microorganisms isolated from general tissues in human corpses are similar to those isolated from unfit meat carcasses or from the lymph nodes of humans and animals. Ninety percent of the organisms found in human tissues are strict anaerobes (bacteria spp. and gram positive non-sporulating anaerobes – bifidobacteria, etc.) with lower numbers of *Lactobacillus*, *Streptococcus spp*. (mostly *Enterococcia*) and *Enterobacteriaceae* (about 10% in all). In addition to these, small numbers of *Clostridia spp*., *Bacillus spp*., yeasts, *Staphylococcus spp*. and pseudomonas aeruginosa can be found *(1)*. Table 1 presents a list of the important bacteria in a healthy human intestine.

Tissues are known to remain relatively free of microorganisms during the first 24 hours after death unless the invading pathogen was of a type not previously encountered by the host. There is evidence that bacteria may penetrate the intestinal walls during the process of death and become distributed throughout the tissues in the blood stream. However, organisms distributed through the blood stream may be prevented from multiplying and may be destroyed by the antimicrobial defences of the body. These defences are not completely inactivated until up to 48 hours after death *(2)*.

The redox potential (Eh) of tissues falls rapidly after death so that by the time antimicrobial activity has been lost the Eh is low enough to prevent obligate aerobic organisms, such as *micrococci*, *pseuaidomonads* and *acinetobacters*, from thriving except very close to the surface *(2)*. Anaerobic microorganisms begin to replace the aerobic organisms within a few hours of death and, provided the prevailing temperature exceeds 5 °C, they will start to multiply. Although the intestine harbours a large variety of microorganisms, only relatively few groups have been implicated as major colonisers of human corpses during putrification (i.e. during the first few days after death); these are *Clostridium spp*., *Streptococci* and *Enterobacteria*.

Anatomy of the human body

Seepage waters from the cemeteries occur as a result of the putrification of human corpses. The seepage may mix with groundwater and may become a potential risk for the environment if the pollutants are not ameliorated before coming into contact with a host community. Before considering whether or not seepage is a potential pollution source, it is useful to first review the substances that are found in the human body.

The human body of a 70 kg adult male contains approximately: 16 000 g carbon, 1800 g nitrogen, 1100 g calcium, 500 g phosphorous, 140 g sulfur, 140 g potassium, 100 g sodium, 95 g chlorine, 19 g magnesium, 4.2 g iron, and water 70–74% by weight. The elemental composition of females is between two thirds and three quarters of that for males *(3)*.

Table 1. Important bacteria in a healthy human intestine

Families and genera represented	Prominent species	Other species isolated from the intestine
Pseudomonadaceae		*Pseudomonas aeruginosa (pyocyanea)*
Pseudomonas		*Ps. (Alkaligenes) faecalis*
Enterobacteriacene	*Escherichia coli*	
Klebsiella		*Klebsiella (Aerobacter) pneumoniae*
Enterobacter		*Enterobacter (Aerobacter) aerogenes*
Proteus		*Proteus mirabilis*
Bacteroidaceae		*Bacteroides capillosus. B. oralis*
Bacteroides	*Bacteroides fragilis*	*B. clostridiformis. B. putredinis*
		B. coagulans. B. ruminicola
Fusabacterium		*Fusobacterium mortiferum*
		F. necrogenes. F. fusiforme
		F. girans
Neisseriaceae		*Neisseria catarrhalis*
Neisseria		*Veillonella parvula*
Veillonella		*V. alcalescens*
Micrococcacene		*Staphylococcus albus*
Staphylococcus		*Peptococcus asaccharolyticus*
Acidaminococcus		*Sarcina centriculi*
Sarcina		*Acidaminococcus fermentans*
Peptococcus		*Streptococcus salivarius*
Streptococcaceae		
Streptococcus	*Streptococcus faecalis*	*Strep. sangius*
		Strep. viridans (mitior)
		Strep. faecium
Lactobacillacene		*Lactobacillus brevis*
Lactobacillus	*Lactobacillus acidophilus*	*L. casei*
		L. catenaforme. L. fermentum
		L. leichmanii. L. plantarum
Leptotrichia		*Leptotrichia buccalis*
Bifidobacterium	*Bifidobacterium adolecentis*	*Bifidobacterium (Actinomyces*
	Bifidobacterium longum	*lactobacillu) bifium (bifidus)*
		Bif. breve. Bif. cornutum
		Bif. eriksonii. Bif. infantis
Ruminoccus	*Ruminococcus bromii*	*Peptostreptoccus intermedius*
Peptostreptococcus		*P. productus*
Propionobacteriacene		
Propionobacterium		*Propionobacterium*
		(Corynebacterium) acnes
		Prop. granulosum
Eubacterium	*Eubacterium (Bacteroides)*	*Eubacterium contortum*
	Aerofaciens (biforme)	*Eu. cylinderoides. Eu. lentum*
		Eu. limpsum. Eu. rectale
		Eu. tortuosum. Eu. ventriosum
Corynebacteriaceae		*Corynebacterium (pseudo-*
Corynebacterium		*diphtheriticum (hojmanni)*
		C. xerosis. C. ulcerans
Bacillacene		*Bacillus cereus. B. subtilis*
Bacillus		*Clostridium cadaveris*
		Cl. innocuum
Clostridium	*Clostridium perfringens*	*Cl. maienominatum. Cl. ramosum*
	(weichii)	*Cl. sordellii*
	Clostridium paraputrificum	*Cl. certium. Cl. bifermentans*
		Cl. sporogenes. Cl. indolis
		Cl. sphenoides. Cl. feisineum
		Cl. difficile. Cl. oroticum

Source: Corry, 1978 *(2)*.

Survival and retention of bacteria and viruses

In order to identify the environmental impacts of cemeteries, information is needed on the survival of bacteria and viruses and the fate of the decay products from human corpses in soils and groundwater.

Both survival and retention are dependent on the type of the soil in which a cemetery is sited, the type of microorganisms present, the prevailing ground temperature and rainfall. Microorganism die-off rates increase approximately two times faster with every 10 °C rise in temperature between 5 °C to 30 °C *(4)*. Consequently, the survival of the microorganisms is prolonged considerably at lower temperatures. Several organisms in the soil are known to survive better in a pH range of 6–7, and die off more quickly under more acidic soil conditions.

Where soil pH is above 7, the fraction of bacteria and viruses retained by the soil decreases markedly. Furthermore, an increase in cation concentration of the seepage water from cemeteries increases the retention capacity of the soil for bacteria and viruses *(4)*.

Adsorption is the major factor controlling virus retention. Most polioviruses are held in the soil layer. Viruses may move through some soils to the groundwater with the help of rainfall and downward seepage flow. Polioviruses may move considerable distances through sandy forest soils and gravels, although it has been shown that trees intercept a portion of the rainfall *(5)*. Survival of the poliovirus was monitored in the soil at 4 °C and 20 °C for 84 days during which time its capacity to migrate was unchanged. Many soils which have a small pore size, such as clay, have a high adsorption capacity for viruses *(6)*.

The ionic strength of seepage water influences bacterial attachment through its effect on charge density and electrostatic repulsion. The presence of organic and iron oxide coatings also increases retention of bacteria on the surfaces of sand grains *(7)*. These organic and iron oxide coatings could break down during the putrification of the human corpses.

Other soil properties such as particle size, clay content, cation exchange capacity and moisture influence retention, but the relative extent to which they do this requires further research. Climatic factors such as rainfall also influence retention. They increase the mobilization of bacteria and viruses from tissues retained on soil particles, and facilitate their transportation to groundwater. Important factors affecting the survival of viruses in soil are given in Table 2.

Table 2. Factors affecting the survival of viruses in soil

Factor	Comments
Temperature	One of the most detrimental factors
Desiccation	Increased virus reduction in drying soils
Soil pH	May indirectly affect the survival of viruses by controlling their adsorption on to soils
Cations	Certain cations have a thermal stabilizing effect on viruses; may also indirectly influence virus survival by controlling their adsorption to soils
Soil texture	Clay minerals and humid substances increase water retention by soils and thus have an impact on viruses subjected to desiccation
Biological factors	No clear trend with regard to effect of soil microflora on viruses

Sources: Environment Agency, 1998 *(1)*.

Movement of bacteria and viruses through soils

Soils play a major role in the movement of bacteria and viruses. From laboratory work, it has been found that most of the microorganisms, such as polioviruses, are filtered out on or near the soil surface. Most polioviruses are held within the first 5 cm depth below the surface of loamy sandy soil *(6)*.

Whilst soil adsorbs most of the pathogens, adsorption decreases with increasing water velocity. Polioviruses applied to effluents may move considerable distances through sandy soils after rainfall. The adsorption pattern indicates that most viruses are adsorbed near the surface but the remainder may move much greater distances *(6)*, and studies have found that virus adsorption is also affected by the strength of the negative charge on the virus particle. Lance et al *(6)* have added that viruses with a net negative charge below a certain level were immediately adsorbed, while viruses with a stronger negative charge moved farther away.

Infective viruses have been isolated directly from vegetable crops *(8)*. Therefore, plants could possibly be used to remove some viruses and bacteria from the soil. Also, the movement of bacteria and viruses is restricted physically by the root system of plants. Planting of trees and border plants should be encouraged around cemeteries to help decrease the movement off-site of bacteria and viruses in seepage water and rain water.

Groundwater composition in the vicinity of the cemeteries

During the progress of decomposition within human corpses, the products of decomposition are released. The principal mechanism for the transport of decomposition products is percolating water entering the groundwater. Many of the decomposition products are identical to those present naturally in the environment. In addition, ammonia gas and carbon dioxide are also formed as decay products from human corpses. Another important point is the presence of wood, fabrics and plastics, which come from coffins. Little is known about the composition of their products of degradation.

Studies by Schraps reported high concentrations of bacteria, ammonium and nitrate ions in a contamination plume which rapidly diminished with distance from graves in Germany. On the other hand, van Haaren measured a very saline (2300 µS/cm) plume of chloride, sulfate and bicarbonate ions beneath graves in Holland. No information was given on the soil types in these studies. Also, recent studies by Dent *(9)* at the Botany Cemetery in Australia provided an opportunity to assess groundwater conditions near recent interments. The results showed a definite increase in electrical conductivity (or salinity) close to recent graves. Elevated chloride, nitrate, nitrite, ammonium, orthophosphate, iron, sodium, potassium and magnesium ions were found beneath the cemetery. In his study, he also found that the groundwater samples down-gradient of the cemetery and at control sites had very similar compositions. The groundwater was found to be suitable for irrigation purposes as specified in Australian water quality criteria. Three cemeteries at Woronora, The Necropolis and Guildford in Australia were also examined for their pollution potential *(3)*. In addition, recent work was conducted on groundwater samples beneath the Cheltenham Cemetery (Australia). The results from these investigations showed no significant presence of pathogens, with the exception of *Pseudomonas aeruginosa*, a pathogenic bacterium, which is responsible for waterborne diseases. The key analyses investigated are given in a combined table (Table 3).

Table 3. Typical parameters of groundwaters beneath cemeteries

Analyte	Botany cemetery			Cheltenham cemetery		Worona cemetery		Necropolis cemetery		Guildford cemetery	
mg/l or FU/100ml	BG	CBG	NRIR	NBB	IB	BG	ISW	CSW	ISW	BG	BDB
Hg	0	<0.005	0.008	–	–	–	–	–	–	–	–
Ni	0	<0.005	0	–	–	–	–	–	–	–	–
Pb	0	<0.005	0	–	–	–	–	–	–	–	–
Zn	0.692	0.17	0.103	–	–	–	–	–	–	–	–
HCO3	7.2	11	0	–	–	–	–	–	–	–	–
CO3	0	0	0	–	–	–	–	–	–	–	–
Cl	49	27	58.5	52–1120	107–576	85–170	24–41	40–45	42–390	133–160	20–33
NO3-N	14	6.05	6.16	0–0.6	0–11.4	0.2–0.3	0–1.16	0–2.2	0–14.3	0.4–6.3	4.1–33.2
NO2-N	0.01	0	0.07	0–0.34	0–0.01	0–0.001	0–0.003	0–0.002	0–0.056	0.002–0.315	0–0.015
PO4	0.1	0.9	3.4	0–7	0–6.2	0	0–0.85	1.6–2.55	0.5–1.6	0–1.9	0.06–4.7
SO4	24.2	15	57	22–255	52.5–179	57–77	17–56	3.2–3.7	48–290	66–95	0–21
NH3-N	0	0.13	1.24	0.01–0.59	0–0.53	–	–	–	–	–	–
F	–	<0.5	–	–	–	–	–	–	–	–	–
TKN	–	–	–	0.16–0.81	<0.05–0.61	–	–	–	–	–	–
TOC	–	–	–	1.6–28	1.3–21.2	2.0–19	1.6–12	2.0–4.0	0–30	58–73	4.0–23
BOD	–	–	–	<2–15	<2–16	5.0–21	3.0–16	4.0–6	0–9	<5–22	<5
CO2	–	–	–	210–325	135–220	–	–	–	–	–	–
Total coliforms	–	–	–	0–2000	0–17	0–2	0–>500	0	3–>2400	0–8	0–8
Faecal coliforms	–	–	–	0–1	0	0	0–2	0	0–10	0	0
Faecal streptococci	–	–	–	0–1	0	0	0	0	0–22	0	0
Pseudomonas aeruginosa	–	–	–	0–1	0–40	0	0–4	0	0	0	0–11

BG: background groundwater away from cemetery
CBG: background groundwater within cemetery
NRIR: groundwater within cemetery, Recently Interred Remains Study Area
NBB: near boundary bores, near the boundary but within cemetery grounds
IB: internal bores within the cemetery
ISW: internal seepage wells
CSW: comparative seepage well
BDB: bores down-gradient at boundary

Sources: Table 1 *(3)*, Table 1 *(9)*, Table 1 *(11).*

Three cemeteries in Brazil, at Vila Formosa, Vila Nova Cachoeirinha and Areia Branca, were studied by another research team *(12)*. Each cemetery exhibited geological and geophysical differences. The Vila Formasa basin is composed of tertiary sediments where the alternation of soil layers of varying thickness and grain size is frequent. In Vila Nova Cachoeirina, the basin is derived from granite alteration where clay-rich layers are predominant. Areia Branca is composed of quaternary sandy, marine sediments with high porosity and permeability. At each place, the groundwaters beneath the cemeteries were examined for their bacterial contamination. No coliphages (viruses that are parasitic to bacteria of the coliform group) were detected in the groundwaters. This is probably due to the fact that viruses are more readily fixed to soil particles than the bacteria and, consequently, fewer are carried into the groundwater flowing beneath the cemeteries. However, *Streptococci*, sulfide-reducing bacteria and *Clostridia* were found in the majority of samples collected by the researchers. No faecal coliforms were found in the samples and the work showed that the presence of *streptococci* and sulfide-reducing bacteria were more indicative when evaluating the quality of groundwater.

Geological properties of the cemeteries

The cemeteries reported on in the published literature and considered in this report have different types of geology. A review of their characteristics may provide an indication of the more suitable soil types to retain and ameliorate the degradation products in seepage from cemeteries. Table 4 lists the geological properties of the soils beneath several cemeteries.

Table 4. Geological properties of the selected cemeteries

Cemetery	Geology
Botany (Sydney/Australia)	Botany Sands
Worona (Sydney/Australia)	Hawkesbury Sandstone(sand clays and minor clayey sands, often lateritised, overlain by a quartz sandstone)
The Necropolis (Melbourne/Australia)	Fyansford Formation Brighton Group (densely unconsolidated silty sands)
Guildford (Perth/Australia)	Bassendean Sand (unconsolidated shallow marine deposits of clayey and silty sands and fine sands)
Areia Branca (Santos/Brazil)	Quaternary sandy, marine sediments with high porosity and permeability
Vila Formosa (Sao Paulo/Brazil)	Tertiary sediments (assumed: porous)
Vila Nova Cachoeirinha (Sao Paulo/Brazil)	Granite alteration where clay-rich layers are predominant

An unsaturated soil layer has been found in past studies to be the most important line of defence against the transport of degradation products into aquifers. It acts as both a filter and an adsorbent. It can also reduce the concentrations of some microorganisms and decomposition compounds that occur during the putrification of human corpses. It is postulated that the most useful soil type to maximize retention of degradation products is a clay-sand mix of low porosity, and a small to fine grain texture.

The size of the bacteria, the pore size distribution of the soil and the interaction between the bacteria and the solid phase should be taken into account to select the soil. The pore size distribution of the soil is an important factor for increasing the surface area for adsorption and also for the removal of bacteria. Therefore, a soil should have strong adsorbance characteristics to remove degradation products from seepage water and so minimize the impact of cemeteries on their local groundwater. Also, the size of the pores of the soil affects the efficiency of filtration. Soil-water content is another factor for removing microorganisms. The capacity of a soil to remove organisms increases with a decrease in soil-water content *(4)*. Therefore, measurements need to be made to find the most beneficial soil-water contents when sites for new cemeteries are being considered. Research is needed to determine the optimum values.

An unsaturated zone beneath a cemetery increases the opportunity for attenuation of the seepage during putrification of human corpses. The unsaturated zone is where faecal pollutants are degraded to innocuous compounds. Therefore, a maximization of the residence time in the unsaturated zone is a key factor affecting the effective removal of bacteria and viruses *(12)*.

Cemeteries can be regarded as special kinds of landfills, in that a limited range of organic matter is covered by soil fill *(3*). Therefore, it is useful to examine the fate of leachate from waste landfills as a potential analogue to leachate from cemeteries. Two landfills were considered in studies by Lewin and co-workers in the United Kingdom *(13)*. One of the landfills has a thick (>50m) unsaturated zone (Burntstump) and the other has a thin (<20m) unsaturated zone (Gorsethorpe). Leachate was passed through the shallow unsaturated zone, which produced only limited attenuation at Gorsethorpe before entering the groundwater. However, the deep unsaturated zone at Burntstump allowed the establishment of conditions conducive to methanogenesis and achieved a progressive and significant reduction in the organic strength of the leachate front. No firm evidence of groundwater pollution by leachate was recorded at Burntstump, either immediately beneath the landfill area or in the direction of groundwater flow. This study demonstrated that the unsaturated zone is one of the most important factors to protect the environment. This study supported earlier predictions, as described, for example, in Mather *(14)*. Most of the biodegradation of organic components occurs within the unsaturated zone, and a thicker zone increases the opportunities for attenuation of leachates.

The back-fill soil around a coffin is another factor that plays a role on the impact of degradation products in seepage water. The part of the soil between coffin and the ground surface is usually less compact. It allows some air to enter. Human corpses aerobically decompose quickly when aeration is provided. However, rainfall can also more easily enter the soil by this route and provide a means for microorganisms within the corpse to escape.

Hydrogeological properties of the cemeteries

The base of all burial pits at cemeteries should be above the highest natural water table to minimize seepage directly into the aquifer during putrification of human corpses. Cemeteries could also be planted with deep-rooting trees that consume large volumes of groundwater and seepage water passing through the unsaturated zone. Also, the water level beneath cemeteries will be decreased by trees and so further help to contain seepage within the environs of a cemetery.

Most viruses are adsorbed through the depth of the soil and some, such as polioviruses, are held near the soil surface *(6)*. After rainfall, these retained viruses may escape from the soil and move into groundwater if the permeability of the soil is high enough.

Another important point is the difference in elevation between a cemetery and the surrounding area. A cemetery should not be located in the lowest part of an area where the rainwater runoff collects and the infiltrated water comes into contact with interred remains. This, ultimately, would permit more decomposition products to be carried into the groundwater.

Conclusions

In cemeteries, human corpses may cause groundwater pollution not because of any specific toxicity they possess, but by increasing the concentrations of naturally occurring organic and inorganic substances to a level sufficient to render groundwaters unusable or unpotable. Viruses are fixed to soil particles more easily than bacteria and they are not carried into groundwaters in large numbers *(2)*. Nevertheless, pathogenic organisms are largely retained at or near the soil surface *(4)*. Because of these features, the risk of pollution would seem to be greatest for users of wells, which access a shallow water-bearing stratum.

Through the action of infiltrating rainfall, adsorbed pathogenic organisms can escape from the soil particles, mix with the groundwaters beneath the cemeteries and migrate considerable distances. This process is easier in some particular soil textures, such as sand and gravel, because their pore sizes are not small enough to filter and adsorb the microorganisms efficiently. The planting around cemeteries of trees and plants with extensive root systems can also reduce microbial populations. These trees absorb water and seepage to isolate some infective microorganisms from the soil. This also helps to reduce the quantity of the seepage water that mixes with the groundwater.

The thickness of the unsaturated zone in the soil is an important factor in determining the impact of cemeteries on the environment. Most of the biodegradation occurs in this zone and it is the most important line of defence against cemetery-derived pollution polluting underlying aquifers. Therefore, the maximization of the residence time and the thickness of this layer is a desirable factor for the removal and elimination of bacteria and viruses *(12)*.

The age, size and state of decomposition at burial of human corpses, and also the materials used in coffins, are important factors that affect the characteristics of seepage water during putrification *(3)*. The impact on groundwaters from the degradation of coffins and burial clothes is not known. Standards should be set for the types of material from which coffins are made to minimize their effects on the environment. Ideally, coffins and human corpses should decay rapidly and the products of decomposition become adsorbed or oxidised quickly. Access of air and moisture can facilitate this situation.

Studies by Schraps reported high concentrations of bacteria, ammonium and nitrate ions in a contamination plume which rapidly diminished with distance from graves in Germany. On the other hand, van Haaren measured a very saline (2300µS/cm) plume of chloride, sulfate and bicarbonate ions beneath graves in Holland. The studies by Dent *(9)* for Botany Cemetery in Australia, where an opportunity was available to assess groundwater conditions near recent interments, showed a definite increase in electrical conductivity (or salinity) close to recent graves, and elevated concentrations of chloride, nitrate, nitrite, ammonium, orthophosphate, iron, sodium, potassium, and magnesium ions beneath the cemetery. The studies found that salinity and chloride concentrations rapidly diminished with distance from graves.

Conceptually, cemeteries can be regarded as special kinds of landfills. Therefore, it is useful to examine the fate of leachate from waste landfills as a potential analogue to seepage from cemeteries. Research carried out by Gray and his group has shown that "the concentration of the highly soluble chloride ions which is extremely high in leachates from domestic refuse directly below a landfill, drops drastically in water samples taken a short distance away and at 100 m to 200 m falls to almost background levels" *(15)*.

In conclusion, aquifer pollution can vary greatly according to the geological strata and cemetery layout and management. Surface drains will intercept most surface runoff water entering a site from outside before any serious contamination takes place. The pollution potential from cemeteries is present, but in a well managed cemetery with suitable soil conditions and drainage arrangements, the risk is probably slight. The draft conditions given below could be used to site and design a future well managed cemetery *(1)*:

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

2. The place of interment should be at least 30 metres away from any other spring or watercourse and at least 10 metres from any field drain.
3. All burial pits on the site must maintain a minimum of one metre of subsoil below the bottom of the burial pit (i.e. the base of the burial must be at least one metre above solid rock).
4. The base of all burial pits on the site must maintain a minimum of one metre clearance above the highest natural water table. (Any variability in the water table should be taken into account.)
5. Burial excavations should be backfilled as soon as the remains are interred, providing a minimum of one metre soil cover at the surface.

***** This distance may be greater if the site has a steep hydrogeological gradient or the velocity of groundwater flow within an aquifer is rapid.

Suggested topics for future research

1. What are the safe distances between aquifers and cemeteries in various geological and hydrogeological situations?
2. What is the fate of materials used in coffins and burial clothes? Propose suitable materials which minimize their potential effects on groundwaters.
3. Why and how do most of the microorganisms, produced during the putrification process, <u>not</u> appear in the groundwaters beneath cemeteries?
4. Have there been any recorded disease outbreaks or epidemics caused by microorganisms seeping from cemeteries? What is the epidemiological evidence for population groups living near cemeteries?
5. What should be the desirable minimum thickness of the unsaturated zone beneath cemeteries?
6. Collect together existing regulations on cemetery siting and design from different countries and prepare, with the latest scientific findings, a set of common practices.

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