ENVIRONMENTAL RISK ASSESSMENT, MONITORING AND MANAGEMENT OF CEMETERIES

Report to the
Water Research Commission

by

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SUMMARY

Project Background

Investigation for cemetery sites require the detection (i) of a wide range of different contaminant groups, (ii) at typically very low to concentrations (if present), (iii) natural and geological impacts on the proposed developments; and (iv) with important human and ecosystem health effects, if undetected. The issues of interment and how we deal with the deceased in general transect disciplines of natural science, engineering and social science. Given the sensitive nature of interment and the established notions of acceptable practice at an individual and personal level, assessment of cemeteries is often frowned upon as being an infringement on people's humanity. Cemeteries are, therefore, considered to require understanding of environmental or sanitary aspects, geotechnical or engineering aspects, and social aspects.

The project detailed in this report developed as part of a long-term series of projects on vadose zone hydrology. Detailed concisely in Box 1, the development of the research topic fits into the broader context as follows:

- Vadose zone hydrology, notably of the interstitial (primary) vadose zone and applied to a variety of anthropogenic changes (2011-2014 – published as Dippenaar et al., 2014, report TT 583/14)
- Intermediate vadose zone hydrology, related to the mechanical and hydraulic properties of the fractured (secondary) vadose zone (2013-2016 – not yet published; project K5/2326)
- Contaminant transport and unsaturated flow systems at the hand of cemeteries (2015-2018 – this document; project K5/2449)
- Karstic vadose zone hydrology, related to the mechanical and hydraulic properties of the karstic (tertiary) vadose zone (2016-2019 – in progress; project K5/2523)
- Complex and anthropogenically altered vadose zone, related to the interaction between urban development and the subsurface water flow and quality (2018-2021 – in progress; project K5/2826).

Case Studies and Experimental Work

Case studies overlap between these projects. Subsequently advances made are based on collation of extensive literature studies and field and laboratory studies. Experimental and field studies incorporated into this project form part of the vadose zone research projects and are listed chronologically as Vadose Zone Study Areas (VZSAs). Those pertaining to this project include:

- VZSA3: Temba Cemetery: site characterization (Dippenaar et al., 2014)
- VZSA4: Corrosion of burial materials; leaching of metals and formaldehyde from cemeteries
- VZSA5: Unsaturated flow through the soil-rock interface
- VZSA6: Fontein Street Cemetery: isotopes, hydraulic tests, water quality
- VZSA7: Welmoed Cemetery: isotopes, hydraulic tests, water quality
- VZSA8: Microbiology from cemetery sites

Investigation Guidelines

Proposed guidelines improve data acquisition to better assess risk posed to man, development, and the environment through land use change to cemeteries. Risks assessed include those related to human and ecosystem health, and the safety of people on site and the general public. Building on existing best practice, standards and appropriate legislation, assessment protocols for engineering geological/ geotechnical and hydrogeological/ geohydrological investigation are supplied. These can be used as terms of reference in tenders or requests for proposals to ensure comparable and adequate scopes of work.

For completion of environmental impact assessments (EIAs) and water use licenses (WULs), Phase 2 investigations conducted by professionally registered competent specialists are required. Recommendations should include continuous environmental monitoring.

Box 1. **Project Summary.**

BOX 1. PROJECT SUMMARY

(a) Background to the Project

Interment by burial in cemeteries is a very old practise embedded not only in sanitation and healthy living conditions, but also in culture and religion. It is, however, a practise that attracts development regardless of its initial remoteness as people have the need to be near cemeteries where their loved ones are buried, and often also rely on infrastructure and services in proclaimed cemeteries that are not available in informal developments or certain suburbs.

This project, subsequently, emanated from the main findings of a Water Research Commission funded project (report TT 583/14) on the vadose zone, quantification of unsaturated hydraulic parameters, and implications of various development types of development on the vadose zone and vice versa. It was highlighted that cemeteries, generally considered to be fairly low-risk inert landfills, may pose more hazards in situations where hazards do in fact exist, and, in such instances, exposure to these hazards may result in very substantial risk. In areas where pollution from cemeteries does occur, receptors are at very high risk given the very complex and highly variable array of potential contaminants. Further to this, the complex flow systems in the vadose zone are also affected given the disruption of site materials, and subsequently contaminant transport is also affected.

Proximity of groundwater and surface water users, other potential sources of contamination, interrupted and altered surface and subsurface flow systems, and health and safety implications of excavations supply important reasons for further research into this topic. Although a fair amount of literature exists on the individual contaminants, on the history of significant cemeteries, and on the need for greener burials, very little has indeed been done to collate available knowledge on cemeteries, and to expand with new contributions. Site investigation and monitoring, in particular, are not truly addressed extensively. Improved methods may, however, reduce associated risks.

Partnering with representatives from the South African Local Government Association (SALGA), the project team, under new funding from the Water Research Commission, aimed to investigate certain identified research questions pertaining to cemeteries. These results are incorporated into this study to eventually supply standard terms of reference for the investigation, management and monitoring of new and existing cemeteries.

(b) Project Outline and Findings

Results from case studies are collated with available literature, improving understanding of the risks posed by cemeteries. Social, environmental/ hydrological, and engineering/ geotechnical aspects are covered in detail, adding new advances and contributions to scientific understanding emanating from this project. New advances are based on a set of case studies available in the report.

Risks mostly pertain around possible contamination and safety issues associated with the stability of the excavations. These risks are typically exacerbated by developing cemeteries on unsuitable land, or through not anticipating the impact of the cemetery development on the subsurface hydrological regime. Contributions are made to improved understanding of these complex flow systems through detailed investigation and proper understanding of hydrogeological methods.

Final recommendations are made regarding standardized protocols for hydrogeological (geohydrological) and engineering geological (geotechnical) investigation for new cemeteries, as well as for the monitoring and management of existing cemeteries. This serves as a standard terms of reference or scope of works for new cemeteries based on spatial extent and anticipated geological constraint.

Significant contributions detailed in the study relate to:

- Field-scale investigation of geologically variable terrains
- Improved use of isotopes in studies for cemeteries
- Improved understanding of the behavior and transport of microorganisms through the vadose zone
- Unsaturated flow across the soil-rock interface
- Leaching and mobility of metals and formaldehyde from cemeteries.

Novelty can be applied by the scientific profession to advance understanding not only of cemeteries, but also of contaminant transport and corrosion in hydrologically complex vadose zone conditions.

Further to this, the proposed guidelines is for used by professional consultants and local government, aiming to mitigate risks posed by cemeteries, and to ensure proper monitoring and management of cemetery sites.




READ MORE:
ADAPTED FROM: Dippenaar et al. 2014; Dippenaar 2014; this document

Novel Findings

For this particular study, relevant to cemeteries, the following main findings resulted:

- Environmental conditions affecting the leaching, mobility and persistence of selected metals have been addressed. Mostly, leachate from sands are more enriched (possibly solely due to the higher rate of seepage through sands given higher permeabilities), although clays are more corrosive to metals. Retention of moisture in clayey soils is very likely the reason as to why less flow is observed than in sandy soils. Low pH, intermittent water supply, unsaturated conditions, fine-textured soils, and warmer temperatures are some of the controls enhancing corrosion of metals. Metals tend to mobilise fairly soon on, but at highest concentrations around week 16-24 of experiments. This may very likely continue beyond 6 months, at higher or lower rates.
- Environmental conditions affecting the leaching, mobility and persistence of formaldehyde have been addressed. Formaldehyde did not appear to affect the plate counts of *E. coli* and break down within days in the subsurface. However, formaldehyde keeps on leaching out in the first days to weeks, with highest concentrations leaving the system around week 8 of experiments.
- Flow at partial saturation from soil into fractured bedrock is complex, but affects natural flow and any cutting or excavation such as a grave. Dispersion plumes are found to exist in soils over open fractures due to capillary barriered scenarios, from where various flow mechanisms result. Saturation tends to decrease with depth in the fracture, coupled with increasing flow rates to maintain continuity.
- Some *E. coli* were found to be antibiotically resistant at one of the field study sites. Although this might not necessarily be a result of the cemetery itself, it does inform about the behaviour of certain microorganisms in the vadose zone.
- The use of isotopes in vadose zone systems entailing interflow, perched water tables, and interaction between the surface water and groundwater have been highlighted in adding more detailed understanding to the complex subsurface flow systems affecting and affected by cemeteries. Using isotope results together with hydraulic and laboratory data improves results and subsequently understanding of the complex flow systems.
- Geological complexity is added to conceptual models through addressing a wide variation of different earth materials, climatic regimes, and land uses.

TABLE OF CONTENTS

LIST OF EXPLANATORY BOXES

LIST OF FIGURES

LIST OF TABLES

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SECTION A: INTRODUCTION

Matthys DIPPENAAR & Jana OLIVIER

1. ABOUT THE PROJECT

1.1. Project Rationale

Throughout history, almost all societies have employed different practices for disposing of the dead. Burial sites ranged from the pyramids of Egypt to mass graves for those deceased during wars.

Burial of the dead in cemeteries has been the traditional practise in more recent times. The siting of cemeteries has, however, changed over time. During Roman times, cemeteries were located outside the borders of the towns; between the 10th and 19th centuries, parish churchyards were popular; and from the 19th century, burial outside the towns borders became the norm again (Cemeteries and cemetery reform forum n.d.). Burial sites were determined by social factors such as economic status of deceased, land ownership, religious affiliation and kinship patterns (Cottle, 1997).

It was in the mid-19th century that the health hazards associated with burials became known. According to Tarlow, (2000), the first person to recognize the health hazards of cemeteries was the British surgeon Dr George Alfred Walker in 1839. Warnings about the dangers of burying the dead near water sources were given further impetus with research conducted by Snow in 1854, in which he established a clear link between water and cholera (Cork City Council n.d.). Consequently, it became widely recognized that water from wells could be contaminated by raw sewage as well as by decaying bodies. Subsequently, the opening of new cemeteries within city and town boundaries was prohibited throughout Europe and North America (Ann's Studio n.d.). Research conducted over the last century and a half has indicated that cemeteries are potentially even more hazardous than previously thought.

Bodies decompose, and during this process, leachates that contain bacteria, viruses and organic and inorganic chemical decomposition products are produced. Pathogens such as Anthrax, Smallpox and TB are known to survive in soil and water and some are even able to multiply if soil conditions are favourable (Dent, www.science.uts.edu.au/des/StaffPages/BoydDent/story). It is therefore possible that certain pathogenic bacteria and viruses could percolate to groundwater, spreading diseases such cholera, smallpox typhoid and hepatitis A (Ford, 1999).

Other contaminants include arsenate pentachlorophenol and formaldehyde – a known carcinogen – released from burial materials and embalming fluids (Best Available Science, 2004; Goodman, 2006; WHO, 1998). Furthermore, coffins also decompose, and are usually fitted with metal handles, hinges and accessories, and many are varnished or painted. A wide range of heavy metals and other potentially harmful compounds may be released from coffins to eventually seep into the groundwater, and from there to boreholes or streams (Bitton et al., 1983; Dent, n.d.; Rogers, 2004; Vass, 2001).

Chemicals that may be released to groundwater include substances such as arsenic and mercury which were used in embalming and burial practices in the past, varnishes, sealers and preservatives used on wooden coffins and metals such as lead, zinc, copper and steel from metal coffins, from handles, hinges and for decorative purposes (Spongberg and Becks, 2000). The possibility, therefore, exists that harmful persistent toxins and heavy metals may be transported from the graves through seepage and leach into groundwater, posing environmental and human health risk.

The first comprehensive studies that were carried out to analyse groundwater and surface water in cemeteries and also in areas surrounding the cemeteries were conducted by Dent and Knight (1998) in Australia between 1996 and 1998. They identified potentially harmful elements from decaying bodies in ground water aquifers below cemeteries in diverse environmental settings. They further showed that rainwater plays a major role in transporting contaminants to the groundwater beneath graves. However, the risk of groundwater contamination through leachate from cemeteries is not uniform as it is influenced by a number of physical and other factors, the most important being the soil characteristics (type of soil, depth, pH, permeability and porosity), climate (rainfall and temperature), geology, the hydrological setting, and terrain features.

Until recently, the most important factors in establishing cemeteries were the type of soil (it had to be sufficiently soft and deep to facilitate digging), accessibility and proximity of existing habitation (Lotz, personal communication, 2007). This resulted in numerous cemeteries being located in areas subjected to flooding, in wetlands, in swamps, on drainage lines, on cliff edges, close to wells and water tables, and in ecologically sensitive ecosystems (Dent n.d.). Not much thought was given to potential risks to humans or the impact on the environment (WHO, 1998).

The correct siting of cemeteries is of the utmost importance for human health of nearby communities. Unfortunately, this was neglected in the past and Dent comments that "… proposals for cemetery development do not seem to generate the high level of investigation and geoscientific focus that landfills do" (Dent n.d.). These are serious deficiencies and are becoming a matter of global concern.

1.2. The South African Situation

In South Africa, as is the case worldwide, groundwater is becoming increasingly important for human needs as the quality of renewable water is deteriorating due to the pollution of rivers (Knight, 1996). At present, almost 60% of the country's rural communities rely on groundwater resources (Pienaar et al., 2007). Although there are many problems associated with groundwater quality, they are aggravated by the very high rates of urbanisation and population growth.

Urban areas are expanding and encroaching into former rural areas. Thus, cemeteries that were once far removed from urban areas, are now surrounded by residential developments and people use water from boreholes located adjacent to cemeteries (Tumagole, 2005).

The South African population is not only growing, but is also ageing. In 2000, only 5.9% of the population was over the age of 60, but in 2005 this reached 6.8% (STATS SA, 2007). The death rate is further increasing due to the high incidence of HIV/AIDS (Clark, 2002; Development Works, 2005; Noble, n.d.; Richards et al., 2004).

Traditional burial is still the preferred method of disposing of bodies (Development Works, 2005) and, according to The Cremation Society of Great Britain (2004), only about 3% of the dead in South Africa are cremated.

The rapidly increasing population, increased urbanisation, and the increasing death rate are creating unprecedented development pressures and demand for land. This 'race for space' is already a major concern in KwaZulu-Natal and Gauteng where the increasing numbers of HIV/AIDS deaths have resulted in large numbers of informal burials, as there is no longer space in formal cemeteries. Hundreds of hectares are being dug up for gravesites in parts of the country with little cognisance of the ecological impact and dangers of seepage into groundwater that supplies communities with drinking water (Clarke, 2002). It has been reported that many bodies are buried in makeshift graves, usually in soft soil, and that these skeletons and decomposed bodies are often washed into watercourses during heavy rain or flooding (Sunday Independent, 2003). These informal burials may have to do with the shame of a relative dying from AIDS or the inability to pay for a formal burial (Development Works, 2005).

The competition for land and the development of new cemeteries is becoming a major problem to urban planners and developers. As land suitable for burial is difficult to find, recycling of graves is becoming necessary (The Herald, 2008; Cape Times, 2008). This involves the reuse of the same gravesite for more than one body. When recycling of the grave involves the burial of unrelated persons it usually includes the exhuming of human remains of the original body, which is then reburied at an alternate site (Development Works, 2005). Sections of cemeteries previously used for pauper burials are now being prioritised for recycling purposes (Development Works, 2005). These practices would serve to extend the 'life' of a cemetery, but it would also introduce new sources of pollution in erstwhile old and 'safe' cemeteries. The recycling of graves in incorrectly sited cemeteries will only aggravate the pollution problem.

In view of the potential hazards of cemeteries, rules and laws are needed when planning new cemeteries and certain factors need to be taken into account. Until 2004, there was no legislation governing the siting of cemeteries. Only basic guidelines existed (DWAF, 2004; Richards et al., 2004) and, until very recently, many developers did not use even these guidelines. In Cape Town, most of the city's existing cemeteries are waterlogged and can no longer be utilised (This Day, 2004; The Cape Times, 2008). In November 2006, graves dug in the Welmoed cemetery, Cape Town, were flooded with 50 cm of water (Cape Argus, 2007). Most of the existing cemeteries in Port Elizabeth are on floodplains or at the bottom of hills (The Herald, 2006). During 2008, a number of cemeteries were closed due to potential environmental problems. For instance, the Polokwane cemetery was closed due to potential seepage into the Sand River, which supplies a large proportion of the city's water. The Dutch Reformed Church cemetery in Polokwane was also closed since it is located just above a spring which was used by local communities as a water source (Personal communication, Lotz). In 2005, Tumagole found that the water from boreholes close to cemeteries in Digiteng near Tshwane, were contaminated with bacteria and hazardous for human health.

Moreover, in a study on potential metal contamination at Zandfontein Cemetery in Tshwane, Jonker (2012) and Jonker and Olivier (2012) found that cemetery soils and groundwater in the vicinity of the cemetery were contaminated with high levels of a variety of minerals (there was more than eight times more manganese, cobalt, titanium, caesium and nickel in soils in cemetery soil compared with soils outside the cemetery boundaries. There was 2.5 μg/l mercury in a borehole near Zandfontein Cemetery. This exceeds the DWAF guidelines for drinking water (1 μg/l) by more than double. The high mineral content probably originated from the 109 tons of metals that have been buried in 60 000 graves over the last 60 years. These results seem to be in contrast with the Department of Water Affairs' statement in which it is indicated that "… the risk of pollution posed by cemeteries to the quality of the water resource, especially the quality of drinking water, is regarded as acceptable, and in most instances, negligible…" However, this statement pertains to bacterial and viral contamination and does not address the possibility of health risk due to high mineral concentrations in groundwater.

In order to address the pollution problem and to avoid groundwater and surface water contamination, a set of comprehensive guidelines and criteria has been developed by the Council for Geoscience (CGS) in 2005 (Development Works, 2005) and later by Dippenaar et al. (2014) and Dippenaar (2014). The latter conducted a provisional assessment of the Temba Cemetery (Tshwane) and proposed guidelines for the vadose zone assessment component. The need for proper assessment protocols towards the protection of water resources are clear, given increased interments via burial in cemeteries and the concomitant need for protection of proximate groundwater and surface water resources. The CGS recommended that factors that need to be considered are: soil excavatability and permeability; stability of grave sidewalls and workability of soil; proximity to domestic water as well as drainage features and site surface drainage; site topography/slope; nature of basal buffer zone; size and lifespan of intended cemetery; and social and cultural factors. Dippenaar et al. (2014) elaborated on these and recommend a set of minimum requirements as well as a so-called vadose zone assessment protocol.

Currently, the siting of a cemetery is controlled by legislation (Bloemnuus, 2007). This legislation indicates that new application of the establishment of new cemeteries must include a geohydrological (hydrogeological) survey, geotechnical (engineering geological) investigation, archaeological study and an Environmental Impact Assessment (EIA) (Bloemnuus, 2007). Due to legislation it takes up to two years for suitable sites to be identified (Cape Times, 2008).

If the guidelines laid down in the legislation are followed, the hazard posed by cemeteries can be significantly reduced. However, existing cemeteries cannot be moved and may not conform to present siting regulation. These could constitute a hazard to human health and the environment. It is therefore essential to identify those cemeteries that are potentially hazardous with regards to mineral contamination and to determine the possible health risk associated with these.

1.3. Legislative Norms

In addressing the legislative requirements for the siting, monitoring and management of cemeteries, it becomes imperative to understand where cemeteries fall into the legal framework. This section briefly outlines main legislative norms, emphasising the clear absence of very formal requirements for the disposal of the deceased.

1.3.1. Waste and the disposal thereof

The National Environmental Management: Waste Act (NEMWA of 2008) supplies the following definitions:

- "**General waste** means waste that does not pose an immediate hazard or threat to health or to the environment, and includes…" domestic, building and demolition, business and inert waste.
- "**Hazardous waste** means any waste that contains organic or inorganic elements or compounds that may, owing to the inherent physical, chemical or toxicological characteristics of that waste, have a detrimental impact on health and the environment"
- "**Inert waste** means waste that… does not undergo any significant physical, chemical or biological transformation after disposal; does not burn, react physically or chemically biodegrade or otherwise adversely affect any other matter or environment with which it may come into contact; and does not impact negatively on the environment because of its pollutant content and because the toxicity of the leachate is insignificant".
- "**Waste**" means any substance, whether or not that substance can be reduced, re-used, recycled and recovered… that is surplus, unwanted, rejected, discarded, abandoned or disposed of; which the generator has no further use of for the purposes of production; that must be treated or disposed of; or that is identified as a waste by the Minister…", and includes waste generated by any sector, but "… a by-product is not considered waste; and any portion of waste, once re-used, recycled and recovered, ceases to be waste.
- "**Waste disposal activity** means any site or premise used for the accumulation of waste with the purpose of disposing of that waste at that site or on that premise".

NEMWA (2008) implicitly, in s4(d), excludes the disposal of animal carcasses as regulated by the Animal Health Act (AHA of 2002). Although AHA defines an animal to be "any mammal, bird, fish, reptile or amphibian which is a member of the phylum vertebrates, including the carcasses thereof", the somewhat inconspicuous definition is taken to exclude humans. The National Health Act (2003) and the *Regulations relating to health care waste management in health establishments* (Department of Health, 2014) do not directly mention human waste other than those resulting from medical procedures.

The amendment to NEMWA through the National Environmental Management: Waste Amendment Act (2014) defines hazardous waste to include "wastes from human or animal health care and/ or related research (except kitchen and restaurant wastes not arising from immediate health care), but gives no direct mention of the deceased.

1.3.2. Water and pollution

NEMWA (2008), however, does, in section 9, require remediation of contaminated land. In the instance of detection of contamination from cemeteries, NEMWA therefore intrinsically applies. This is mirrored in the "polluter pays" principle of the National Water Act (NWA 1998).

NWA (1998) is given authority in s65(1) and s65(2) of NEMWA, as well as in s20 of the Environmental Conservation Act (ECA 1989). Specific mention in s21(a) and s21(b) of ECA (1989) to the involvement of the Minister of Environmental Affairs in matters pertaining to land use and transformation, and waste and sewage disposal.

The Department of Water and Sanitation (DWS; previously DWAF and DWA) is involved in land use planning according to s13 of NWA to classify water resources and water quality objectives. In this context, cemeteries are potentially incorporated as possibly damaging aquifers by waste disposal and related activities, through development of domestic waste landfills and hazardous waste landfills, and through handling of animal wastes and feedlots. Further mention is made to diffuse sources associated with urban development; peri-urban development. Based on the importance of the aquifer for supply, it should be classified accordingly as (DWAF, 2000):

- **Sole-source aquifer** – used to supply >50% of urban domestic water for an area for which there exists no reasonable alternative water source
- **Major aquifer** – high-yielding system with good quality water
- **Minor aquifer** – moderate-yielding system of variable water quality
- **Poor aquifer** – low- to negligibly-yielding system of moderate to poor water quality
- **Special aquifer** – any aquifer system designated as such by the relevant Minister.

Water use licenses may be required for water uses stipulated in s21 of NWA (1998) if any water is taken, stored or diverted on the site. This therefore requires licensing if water is to be used for irrigation or any other purpose of such land. For cemeteries, s21(g) specifically mentions the "disposing of waste in a manner which may detrimentally impact on a water resource".

1.3.3. Land use

In terms of stability, the Spatial Planning and Land Use Management Act (SPLUMA 2013) define the following (verbatim):

- **Land development** means the erection of buildings or structures on land, or the change of use of land, including township establishment, the subdivision or consolidation of land or any other deviation from the land use or uses permitted in terms of an applicable land use scheme
- **Land use** means the purpose for which land is or may be used lawfully in terms of a land use scheme, existing scheme or in terms of any other authorisation, permit or consent issued by a competent authority, and includes any conditions related to such land use purposes.

In SPLUMA (2013) s25(1)(d), a land use scheme should promote "minimal impact on public health, the environment and natural resources". Cemeteries, although not implicitly mentioned, is therefore a potential impact and a change in land use.

1.3.4. Safety and geotechnical requirements

In terms of safety, the Machinery and Occupational Safety Act (MOSA 1983) states that "no persons shall work under unsupported overhanging material or in an excavation which is more than 1.5 m deep, which has not been adequately shored or braced if there is a danger of the overhanging material or the sides of the excavation collapsing".

All associated infrastructure, such as offices, parking areas, crematoria, chapels, and so forth, are subject to SANS 634:2012 on Geotechnical Investigations for Township Development, and may be amended as appropriate if, for instance, comprising less dense development, if situated on dolomite, or if buildings are to exceed two storeys in height.

1.4. Research Aims and Research Approach

Investigation for cemetery sites require the detection (i) of a wide range of different contaminant groups, (ii) at typically very low to concentrations (if present), (iii) natural and geological impacts on the proposed developments; and (iv) with important human and ecosystem health effects if undetected. Some fundamental research questions and case studies are employed to address knowledge gaps. All complete experimental and case studies are presented in the Appendices. Relevant findings are incorporated into the body of this document.

The issues of interment and how we deal with the deceased in general transect disciplines of natural science, engineering and social science. Given the sensitive nature of interment and the established notions of acceptable practice at an individual and personal level, assessment of cemeteries is often frowned upon as being an infringement on people's humanity. Nonetheless, it has become inevitable to better understand this land use (Box 2).

Cemeteries are, therefore, considered to require understanding of:

- Environmental or sanitary aspects, pertaining to human and ecosystem health, and therefore incorporating the entire water cycle
- Geotechnical or engineering aspects, pertaining to the ease of engineering works and safety, and therefore incorporating all mechanical properties of the subsurface
- Social aspects, pertaining to religious, cultural, constitutional or other rights to burial and association.

These all overlap to highlight important implications and considerations of cemeteries, including matters around land use, water services, and health and safety associated with excavations and water quality.

The project detailed in this report developed as part of a long-term series of projects on vadose zone hydrology. Detailed concisely in Box 1, the development of the research topic fits into the broader context as follows:

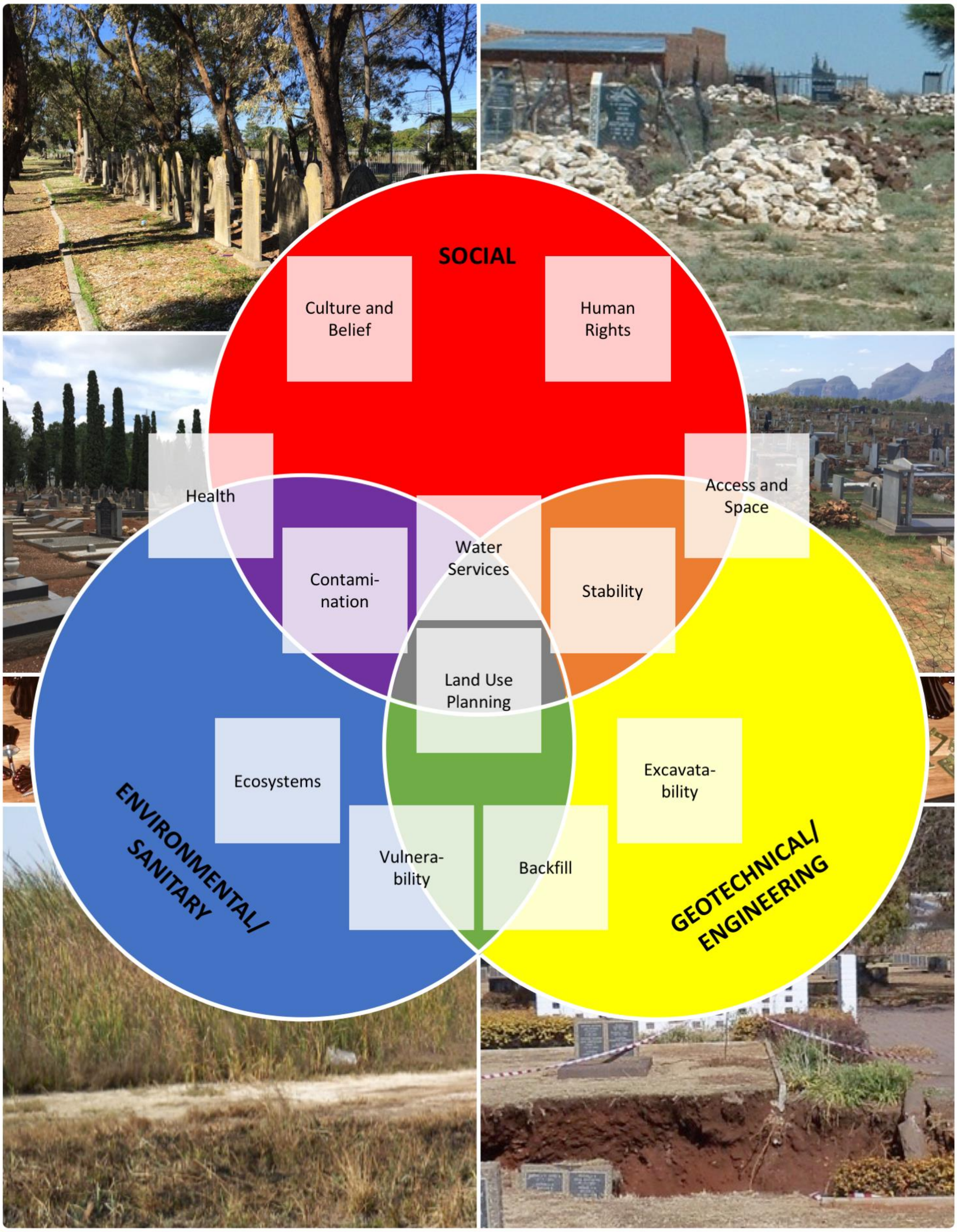
- Vadose zone hydrology, notably of the interstitial (primary) vadose zone and applied to a variety of anthropogenic changes (2011-2014; published as Dippenaar et al., 2014, report TT 583/14)
- Intermediate vadose zone hydrology, related to the mechanical and hydraulic properties of the fractured (secondary) vadose zone (2013-2016; not yet published; project K5/2326)
- Contaminant transport and unsaturated flow systems at the hand of cemeteries (2015-2018; this document; project K5/2449)
- Karstic vadose zone hydrology, related to the mechanical and hydraulic properties of the karstic (tertiary) vadose zone (2016-2019; in progress; project K5/2523)
- Complex and anthropogenically altered vadose zone, related to the interaction between urban development and the subsurface water flow and quality (2018-2021; in progress; project K5/2826).

This report addresses the social (§2,3), environmental/ sanitary (§4,5), and geotechnical/ engineering considerations (§6) sequentially. This is followed by an overview of existing applicable site investigation approaches (§7). Final recommendations are made with a standard protocol for site investigation for existing cemetery sites, as well as for the monitoring and management of existing cemeteries (§8-10). Novel findings are addressed in the summary (§11). Supporting case studies are supplied in the later sections (§12-17).

Results from supporting case studies are incorporated into the relevant sections of the text.

Box 2. Considerations with respect to Cemeteries.

BOX 2. CONSIDERATIONS WITH RESPECT TO CEMETERIES



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SECTION B: HISTORY AND SOCIETY

Sunette VAN ALLEMANN, Jana OLIVIER & Matthys A. DIPPENAAR

2. HISTORICAL BACKGROUND

2.1. Early Hominoids

The discovery of the burial grounds of *Homo naledi* in South Africa in the early 21st century casts new insight on ancient burial practice. *H. naledi* represents the earliest known hominoid species to date (at an estimated age of 1-2 million years) to have possibly intentionally buried its deceased in the Dinaledi Chamber of the Rising Star Cave system in the Cradle of Humankind World Heritage Site in Gauteng (Bothma, 2015; Philips, 2015; Rawood, 2015).

2.2. Early *Homo sapiens*

Within the species of *Homo sapiens*, of which all living humans form part, ancient graves mostly comprised a mound of earth or stones above the body or ashes of the deceased (Moore and Lundell, 2012), and evidence exists of more primitive people disposing of corpses in the open, on platforms or in trees (Pearson, 1999). Preserved specimens have been discovered well before Egyptian times with questions about whether embalming was intentional or natural (Trochu, 2015).

2.3. Ancient Egypt

Although dates are hard to establish, Egyptian ancestors mummified their pharaohs using embalming fluids sourced from at least 1000 kilometres from the grave sites. Carbon dating of the embalming fluids suggests burial between 4200 and 3150 years ago with a mixture of animal fats and plant sterols with 5-20% composed of pine resin, aromatic plant extracts, plant derived sugars and natural petroleum, with many of these ingredients serving antibacterial purposes to aid in the preservation of the body (Jones et al., 2014; Perkins, 2015; Philips, 2015).

Ancient Egyptians coupled the use of embalming fluids with sarcophagi, such as that of the famous king Tutankamen from the Valley of the Kings. The first two coffins were made of cedar and oak wood decorated with green-blue tin-glazed pottery and a thin layer of gold. A third coffin was made out of solid glass with each coffin fastened with silver strips and nails. Like a series of Russian dolls, these were nested inside each other and finally in a large quartzite sarcophagus (Carter, 2014; Falck and Wettengel, 2008; Ikram and Dodson, 1998; Jones, 2008).

Burial was expensive and, in the manner of King Tutankamen, a special privilege of a very limited few. Although some material objects were buried with the deceased, some were fully embalmed whereas others were merely washed and wrapped in reed matting or simple textiles. Coffins were scarce, and reuse was quite common during the Third Intermediate Period with sarcophagi of the 19th Dynasty generally being excavated after about 150 years or after the passing of seven generations when no family remained to perform rituals. The reused sarcophagi were redecorated with 20th Dynasty paints, whilst the poor would use miniature or imitation versions of the sarcophagi, all mostly made with granite or wood (Cooney, 2013; Ikram and Dodson, 1998).

2.4. Ancient Greece

Early Romans mainly practiced cremation, but eventually adopted inhumation (burial; interment) resulting in an increasing demand for sarcophagi during the later periods. The ancient Greeks and Romans washed corpses with water, wine and essential oils prior to being wrapped for burial. Sarcophagi – for those who could afford so – were made of marble encased in lead (which promoted preservation), whereas wood and limestone were used as more affordable alternatives (Deviese et al., 2011; Kampassakali et al., 2003; Papageorgopoulou et al., 2009).

Wrapping of bodies was common practice in 2900 BC in ancient Greece with evidence of direct treatment of the bodies clear through the presence of terpenes in the bone and soft tissue. As in ancient Egypt, these compounds served antibacterial and antifungal functions that, coupled with dehydration substances, preserved the mummy (Deviese et al., 2011; Papageorgopoulou et al., 2009).

2.5. 19th Century America

The American Civil War of 1861 transformed the way in which the deceased were interred. Given lack of access to battlefields and the costs of transporting the deceased, proper burials as was accepted during the early Victorian Age became less possible. Embalming was eventually employed, but the inefficacy of the methods of the time resulted in decomposition initiating prior to arrival of the body at the place of burial (Fraust, 2008; Gagnon, 2015). Given the issues in transport, preservation and identification of the deceased, formal legislation and national cemeteries were promulgated two years after the Civil War in 1867 (Niven, 1965).

The women generally washed bodies, while the men obtained wooden caskets and buried the bodies. Initially sited outside of city boundaries, industrialization and development eventually resulted in cemeteries eventually becoming enclosed by development. It was during this time that funeral practitioners enjoyed popularity for their embalming practices and alternative space than the family's house for storing and handling the corpse (Bern-Klug et al., 1999).

2.6. The Early 20th Century

During the early 1900s, embalming fluids mostly comprised arsenic, which is highly toxic and persistent (Konefes and McGee, 2001; Singh et al., 2011). Alternatives of the time included mercury and creosote, both posing very similar hazards to those of arsenic (Johnson, 1995).

Religion has always played a significant role in the handling of the deceased. Hinduism and Buddhism required cremation, whereas Lutherans had to distinct stance (Bern-Klug et al., 1999). Roman Catholicism opposed cremation until the late 20th century, after which it was permitted but not encouraged (Order of Christian Funerals 1990). Jewish practice still prefers burial to cremation (Kastenbaum, 1994).

2.7. Recent Times

The late 20th century and early 21st century saw embalming fluids containing formaldehyde, distilled water, phenol and glycerol. 10 litres containing 1.5 litres of formaldehyde is required for a 70 kg body (Anat, 1993; Karmakar, 2010).

Coffins are mostly wood treated with preservatives to minimise decay and rapid leaching (Spongberg and Becks, 1999). Chromated copper arsenate (CCA) was used as treatment for the wood until 2004, but environmental risk has since seen these replaced (Janin et al., 2011).

Coffin paints historically contained toxic metals such as lead, arsenic, mercury, manganese, nickel, copper, vanadium, cadmium, zinc and chromium, with many modern paints still containing some of these compounds (Gondal et al., 2011).

Recent statistics indicate that an estimated 60 000 tonnes of steel and 18 million litres of embalming fluid are buried annually in the United States of America alone which, according to Johnson (2013), is "… enough steel to build eight Eiffel Towers and fill eight Olympic size swimming pools".

2.8. Moving towards Green Burials

More than 50 million people die annually with traditional burials still being the preferred means of disposing of the deceased. Vast amounts of potentially harmful compounds support alternative means of disposal, such as cremation or natural burial, reducing contamination and saving cost (Grover, 2014; Johnson, 2013). Green burials save cost on embalming fluids and caskets, while cremation is not dependent on space for burial. Cremation, however, contributes to air pollution, releasing toxins such as formaldehyde, hydrogen chloride, dioxins, mercury and greenhouse gases (Grover, 2014; Rose-Innes, 2013).

Green coffins or ecoffins are nowadays made of bamboo, pine, woven willow, recycled cardboard or banana plant cord, and the body is buried – without embalmment – in a biodegradable cloth or casket (Johnson, 2013; Rose-Innes, 2013).

3. SOCIAL CONSIDERATIONS

Burial of the deceased forms an integral part of human history and is still an important social right and/ or religious custom. Even though alternative means of disposing of the deceased are available (e.g. cremation as an alternative), the social rights of those surviving the deceased still trump issues concerning the scarcity of land for burial and the potential environmental risks posed by burial.

Through engagement with local government authorities, consultants, the media and the general public, certain additional social considerations were highlighted.

3.1. Residential Encroachment of Cemeteries and Surrounding Developments

Cemeteries are mostly placed at acceptable distances from residential developments. However, given that cemeteries often have facilities not available in the proximate formal or informal residential areas, such as flushing toilets or running water, residential developments tend to expand to the boundaries of the cemeteries for use of these facilities. This inevitably results in overuse of municipal services and loitering.

3.2. Vandalism and Safety

Vandalism and theft are common in most cemeteries given the usability of tombstones for other purposes. Further to this, visitors are often alone or in small groups making them vulnerable to attack. In general, many individuals fear visiting graves of the deceased, and subsequently management and keeping of individual graves are no longer maintained. Subsequently, cemeteries often become littered and vandalised and no longer represent the tranquil final resting place intended for the deceased.

Monitoring infrastructure such as boreholes, and available services such as taps to running water, is also commonly vandalised, compromising the sanitary integrity of monitoring data and potable water.

3.3. Unclaimed Bodies and Exhumations

The rights of the deceased are often not met in the absence of living relatives taking responsibility. In these instances, the wishes of the deceased cannot always be met in instances when bodies have to be exhumed and/ or relocated. Similarly, the final wishes cannot always be met in instances such as double burials if the initial grave was not excavated to the required greater depth.

Where bodies are unclaimed, officials are forced to make a decision about interment options. Cremation or special burial arrangements cannot be assumed, and subsequently unclaimed deceased may likely be interred in conflict with their religious or cultural practices. The question arises as to who should accept the financial burden if an interred unknown person is being claimed and a request is made for exhumation and reburial or cremation.

Exhumation of bodies buried with the consent of the living family should, however, be queried by the relevant authorities, and the financial responsibility should be allocated prior to exhumation.

Cremation may be considered in order to save cost and limit the use of land for unclaimed burials. This, however, would require social studies to ensure that it falls within the human rights of the majority.

3.4. Double Burials

Graves for double burials have to be deeper than 1.80 m to at least 2.10 m. Exhumation may be necessary in the event that the first to be buried was not at the required depth.

It is also not acceptable to insist on double burial in the event that this was not decided prior to burial of the first body, seeing that the grave need to be prepared for double burial. This may be in instances of changes in wills and testament following divorces, second marriages, and so forth.

3.5. Cemeteries as Green Space

Cemeteries are increasingly being proposed as additional green space options for urban settings. This, however, requires cemeteries to be safe, clean and accessible, and to be maintained by the local authorities as well as the proximate community. Communities need to take ownership of cemetery sites, contribute to the upkeep, and promote the use of the facilities as parks or areas of recreation. In line with this, cemeteries should be vegetated and landscaped in appropriate manner to not excessively require irrigation or alien vegetation.

3.6. Crematorium Waste

It should be understood that, following cremation, more ashes are generated than what is given to the family. The excluded portion includes, for instance, coarse fragments and contents that cannot be incinerated such as large bones or teeth. In this instance, it should be acceptable practice to have a single grave for the collective ash remains from the crematorium after the relevant families have claimed the individual remains. This does not pose additional environmental impacts.

3.7. Undertakers

Undertakers have social and environmental duties that need to be formalised. They are not allowed to discharge waste, including those from embalming, in illegal manner. Similarly, it is expected that undertakers will not loot the deceased and will not use emotional trauma to unreasonably abuse the emotions of the deceased for financial gain.

SECTION C: WATER, HEALTH AND ENVIRONMENT

Matthys A. DIPPENAAR, Simon LORENTZ, Roger E. DIAMOND & Jana OLIVIER

4. HYDROLOGICAL CONSIDERATIONS

4.1. Water in the Subsurface

The hydrological cycle, and the distribution and movement of subsurface waters, are explained in Box 3. Complexity arises are media change between intergranular and fractured, and as degrees of water saturation change. Understanding the movement of water from land surface to the groundwater system (phreatic zone) is therefore complicated and requires proper investigation and quantification.

Further to this, the type of aquifer plays an important part in the risk posed by surface or shallow subsurface contamination. The concept of the hydraulic head and hydraulic gradient is explained accordingly at the hand of different aquifer types in Box 4.

4.2. Urban Water

Urban settings are prioritised in the context of assessing vadose zone contaminant transport for a variety of reasons. These are generally well understood and have been discussed by a wide number of authors. Lerner (2002) notes the following:

- Recharge in urban areas is significantly more complex. Impermeable areas are present due to surface sealing and drainage channels and drains remove stormwater. Direct recharge is likely to occur in parks and gardens with localised recharge along edges of roads and paths.
- Imported water contributes to deep percolation despite the possible removal of surface runoff resulting in decreased infiltration. Significant urban water losses through leakage of underground pipelines contribute vastly to subsurface water budgets.
- Over-irrigation through excessive landscaping results in localised infiltration, which may furthermore result in recharge.

Vásquez-Suñé et al. (2005) expand by acknowledging the following:

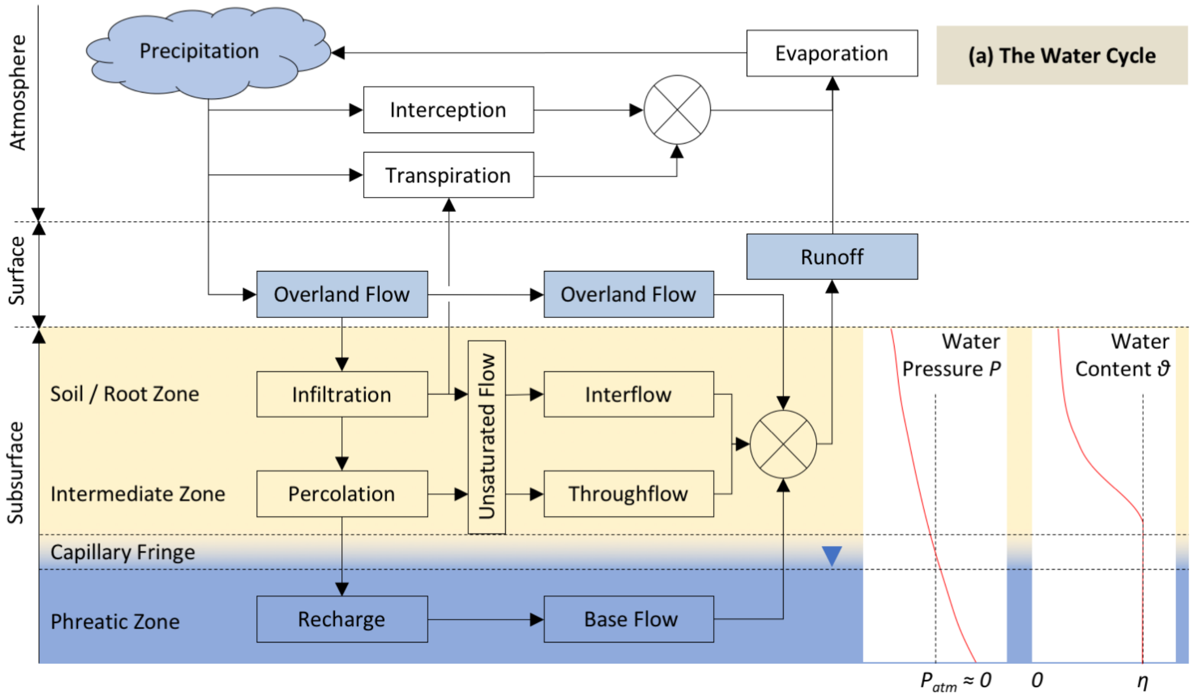
- Underground structures, urban groundwater abstraction and dewatering acting as flow paths and/ or flow barriers influence local water budgets.
- Subsidence can ensue due to long-term regional groundwater lowering through pumping for, for instance, dewatering or industrial purposes. On cessation of pumping, rising water levels can flood underground construction such as basements and the like.
- Complex mixtures of contaminants are sourced from urban areas, most notably from the sewerage system. Mixing of sanitary wastes (e.g. sewage water) and chlorinated drinking water has been noted to form toxic chlorinated and recalcitrant compounds.

Urban settings, therefore, pose very special implications through adding additional water at some places (leaking water reticulation pipelines, stormwater discharge), removing additional water from certain places (drainage, dewatering, stormwater removal) and altering flow paths (through altering subsurface flow systems and materials). This together with the very complex suite of potential contaminants emanating from urban settings, contaminant transport and risk assessment become increasingly difficult.

Box 3. **Subsurface Water and Unsaturated Flow.**

BOX 3. SUBSURFACE WATER AND UNSATURATED FLOW

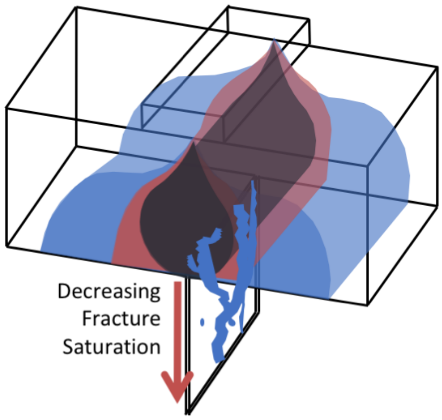
Water **infiltrates** into the subsurface from where **evapotranspiration** can remove the water upward, or it can drain further vertically to the intermediate vadose zone where **percolation** results. On reaching the groundwater table, groundwater is said to be **recharged**. Lateral movement of water in the vadose zone is termed **interflow** or **throughflow**.



The **vadose zone** is well understood in both international and South African literature. Defined as the zone between the land surface and groundwater table or phreatic surface where void space are typically not water-saturated and pore water pressures lower than atmospheric pressure (e.g. Dippenaar et al. 2014), this forms the pathway of contaminants from interments and any other surface or shallow subsurface source of contamination. Whereas contaminant transport occurs through this zone to the groundwater, it also acts as a zone of natural attenuation for some contaminants, thereby reducing the actual contamination of the groundwater regime.

The **plant root zone** or the **soil zone** is that portion of the subsurface from the land surface to the maximum depth of influence of evaporation and transpiration (collectively evapotranspiration). Here, water has the ability to be moved upwards back to the atmosphere and flow is not essentially governed by gravity.

Beyond this, water can percolate (essentially vertically under gravity) or move as throughflow or interflow to discharge or percolate further downslope. In this **intermediate vadose zone**, the influence of evapotranspiration is minimal.



(b) Unsaturated Flow between Soil and Fractured Rock

Water flow from soil into a single rock fracture depicts the complex flow mechanisms occurring as water from a dispersion plume in soil enters fractured rock. Here, flow occurs in aerated state and at highly variable rates depending on the level of saturation. Progressive rewetting of the so-called dispersion plume in the soil (indicated by red and black) eventually allows a capillary barrier above the fracture to breach, allowing water entry into the fracture. Water movement in the fractured system is then intrinsically different from the soil system.

Further complexity results in fractured systems where fracture orientations change over fracture intersections. In general, horizontal fractures are easier to saturate, whereas vertical fractures will drain more quickly at lower rates of saturation.

READ MORE: ADAPTED FROM: (a) Dippenaar et al. 2014, after Driscoll 1989; Fetter 1994; Fitts 2002; Todd and Mays 2005; Younger 2005; (b) Brouwers and Dippenaar 2018; Jones et al. 2017; Jones et al. 2018.

Box 4. **Heads, Aquifers, and their Vulnerability.**

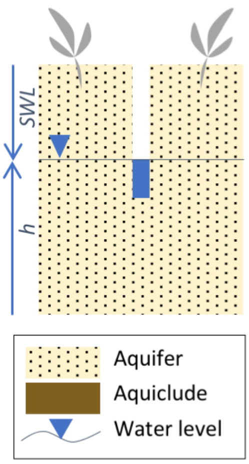
BOX 4. HEADS, AQUIFERS, AND THEIR VULNERABILITY

(a) Water Levels and Hydraulic Heads

The **static water level** (SWL) is measured from land surface downward to the water level.

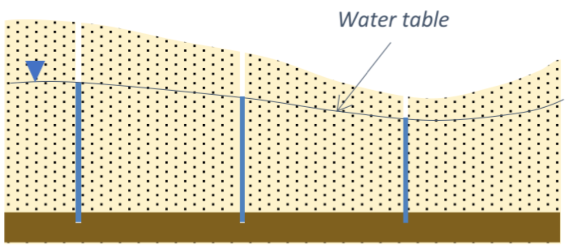
The **hydraulic head** relates to the total mechanical energy per unit weight of water. With the units of length (e.g. metres), it is measured vertically upward from some datum level to the water level and is denoted by h.

The hydraulic heads of different monitoring points such as boreholes are required to determine the direction of groundwater movement as well as the **hydraulic gradient**.

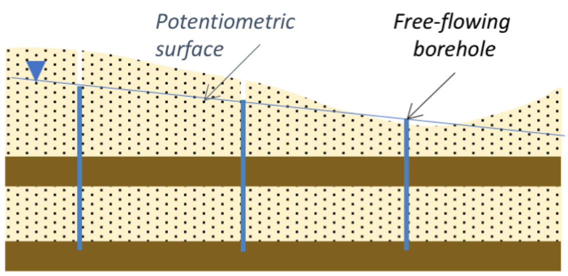


(b) Hydraulic Gradients in Aquifers

Unconfined aquifers are open to the atmosphere and have a distinct water table where pore water pressure equals atmospheric pressure. Water levels as measured in boreholes closely resemble actual water tables in the aquifer. Being in direct contact with the atmosphere, contaminants can enter the phreatic zone fairly easy given the absence of confining layers.



Confined aquifers, on the other hand, have a low permeability aquiclude above the aquifer. Water is therefore at significantly higher pressures, and water levels measured in boreholes resemble the potentiometric surface and is higher than the top of the saturated zone. Occasionally, as indicated, boreholes may become free-flowing. The confining layers here protect the aquifer from the entry of contaminants.

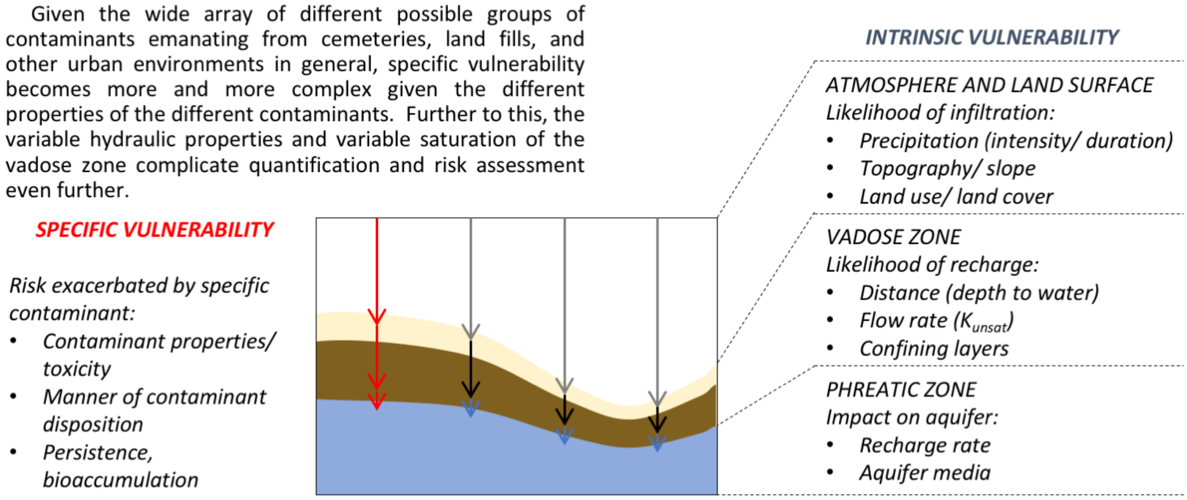


(c) Aquifer vulnerability

The concept of aquifer vulnerability relates the influence of the atmosphere and surface supplying water to the subsurface, and the properties of the vadose zone protecting the groundwater from contamination, to the protection offered to the phreatic zone. Specific contaminant properties related to, for instance, persistence, bioaccumulation, toxicity, natural attenuation or decay could be incorporated for a better risk assessment.

With respect to the vulnerability of the aquifer to pollution, the type of aquifer needs to be understood. Confined and unconfined aquifers behave differently, with the prior generally being more protected to contamination. Proper understanding of the direction and gradient of groundwater movement is also required, as determined from measurable hydraulic heads in boreholes.

Given the wide array of different possible groups of contaminants emanating from cemeteries, land fills, and other urban environments in general, specific vulnerability becomes more and more complex given the different properties of the different contaminants. Further to this, the variable hydraulic properties and variable saturation of the vadose zone complicate quantification and risk assessment even further.



READ MORE: ADAPTED FROM: (a)-(c) Dippenaar et al. 2014; Driscoll 1989; Fetter 1994; Fitts 2002; Todd and Mays 2005; Younger 2005; (c) Foster 2002; Saayman et al. 2007; Sililo et al. 2001

4.3. Influence of Cemeteries on the Water Cycle

Some hydrological influences of cemeteries are depicted in Box 5. Important here is to understand the alternating aerobic and anaerobic conditions, as well as the possible routes of contaminant transport to the phreatic (saturated) zone or proximate water bodies and river channels.

Detailed engineering geological investigation, hydrogeological investigation and isotope hydrology have also been used in VZSA3 (Dippenaar et al., 2014), VZSA5 (§14), VZSA6 (§15) and VZSA7 (§16) to infer hydrological behaviour at cemetery sites. Some new contributions from these studies and the available literature are detailed in this section.

4.3.1. Throughflow, shallow interflow, and perched systems

Subsurface flow systems are often controlled by the shallow perched or shallow interflow systems acting as throughflow systems from upper slopes to lower wetlands or drainage channels (e.g. Figure 4-1). This is often linked to the soil-rock interface (VZSA5; §14) that is also intrinsically altered during excavation and backfilling of graves.

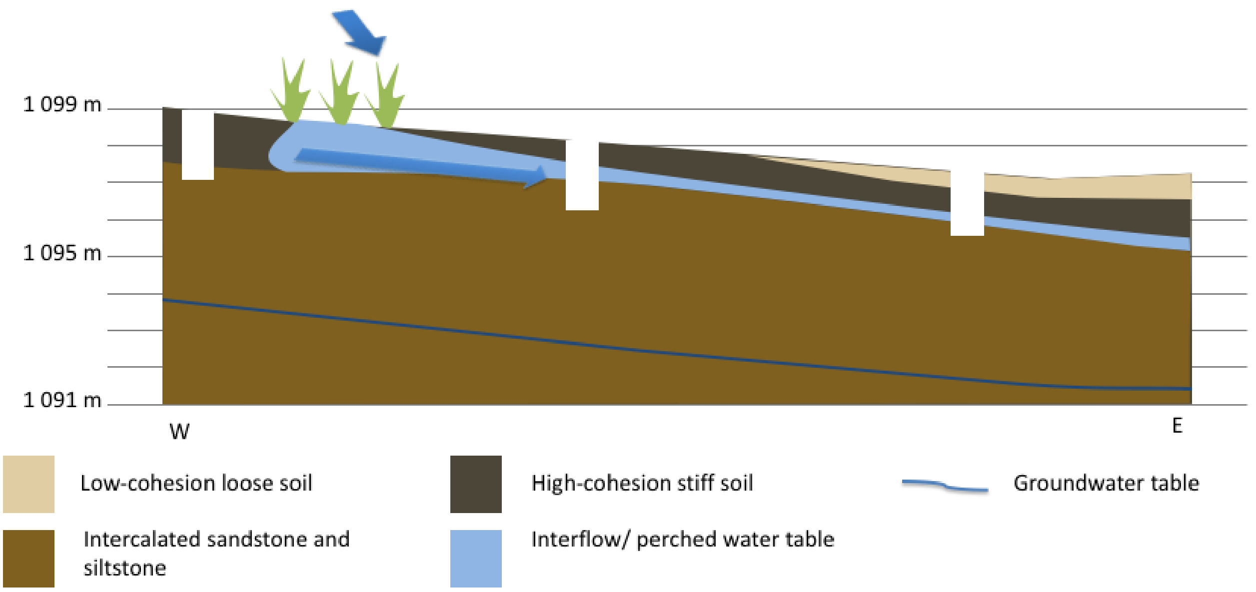


Figure 4-1. Conceptual model of the throughflow system at VZSA3 (Temba, Dippenaar et al., 2014; Dippenaar, 2014).

4.3.2. Altered water budgets

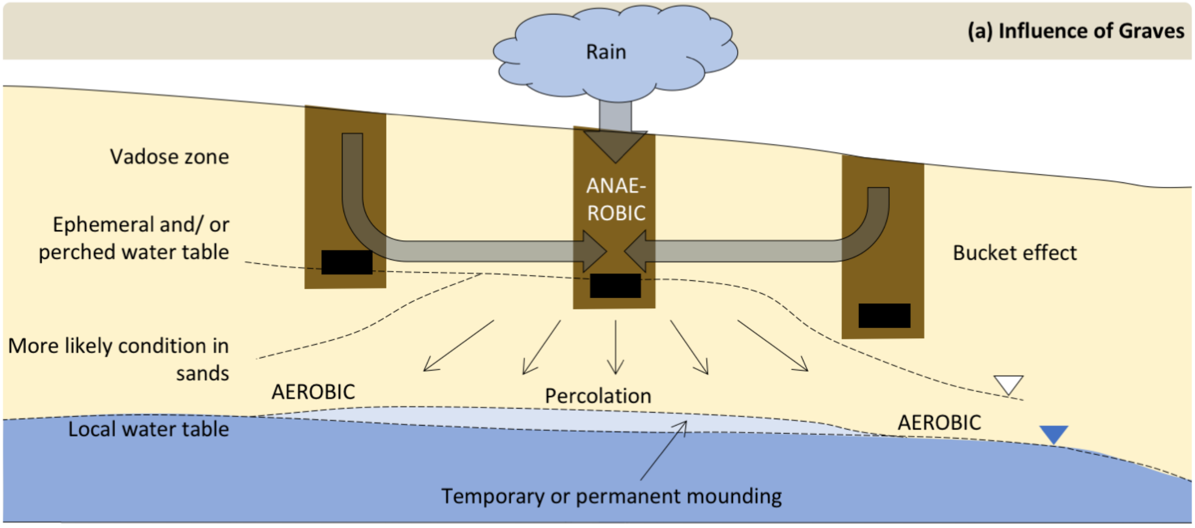
Subsurface water budgets are also affected through disruption of subsurface earth materials and/ or water input into the subsurface. Examples of such influences include, for instance:

- The proximity of leaking underground pipelines
- Stormwater management practices concentrating infiltration of water at certain positions
- Drainage systems installed to manage water on-site retroactively
- On-site abstraction of groundwater increasing hydraulic gradients towards the sites
- Off-site abstraction of groundwater mobilising groundwater flow from the cemetery off-site.

Box 5. Impacts of Cemeteries on Water Resources.

BOX 5. IMPACTS OF CEMETERIES ON WATER RESOURCES

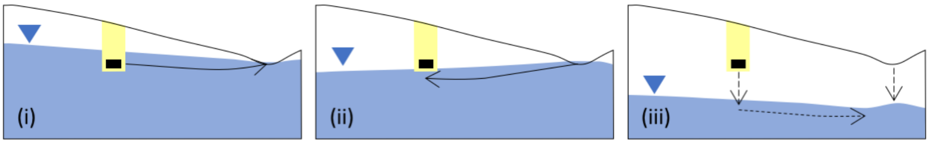
(a) Influence of Graves



The groundwater table is affected through a so-called bucket effect, whereby graves can act as preferential infiltration zones due to their poorer compaction in comparison to the natural soils. Water will then flood the backfilled graves, from where percolation is promoted to the deeper subsurface.

This has important implications in the changing aerobic/ anaerobic conditions in the vadose zone, possibly resulting in attenuation of certain organics and/ or microbial contaminants, while storing and temporarily precipitating some salts and metals. Any contaminants stored in the vadose zone may be flushed out to the groundwater table at later stages following prolonged and intense rainfall events.

(b) Interaction Between Surface Water and Groundwater

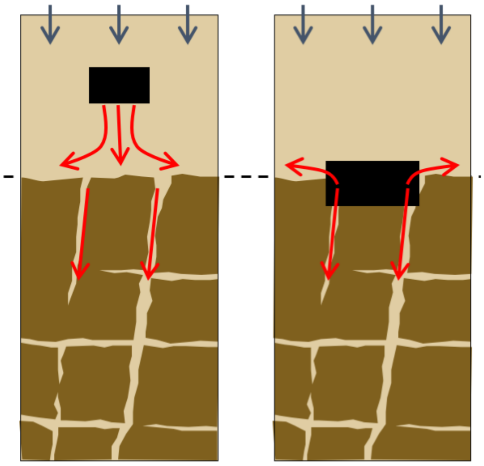


Groundwater and surface water are also in constant interaction. By some means or another, the surface water is either supplied by the groundwater, or it is supplying the groundwater. The presence of a vadose zone between surface water and groundwater prevent direct interaction, but interaction is still occurring through movement of water in the vadose zone. This may, however, result in some attenuation of contaminants, given that conditions are more aerobic. Important, however, is to anticipate urban encroachment around cemeteries, which may alter these natural flow interactions.

(c) Soil-rock Interface

Whether the grave is excavated into soil or across the soil-rock interface has significant implications on whether subsurface moisture will likely percolate into fractures or perch above the bedrock interface. This will subsequently also contribute to whether graves are dry or flooded, whether water will build up in graves to surface, and what the redox conditions in the grave will be.

Coupled with the properties of the backfill material, the backfilled grave can direct water into or away from the grave, from where further deeper percolation can be influenced by the depth and properties of the interface between the soil and bedrock. Whether burying above, over or below this interface is important in understanding how natural subsurface flow systems will be affected. Proper geological understanding will advise regarding bedrock type and soil thickness, aiding in envisaging the behaviour of water in the subsurface.



READ MORE: ADAPTED FROM: (a) Dent and Knight 1998; (a),(b) Dippenaar et al. 2014; Dippenaar 2014; (c) this document, Brouwers 2017; Brouwers and Dippenaar 2018

5. WATER QUALITY CONSIDERATIONS

5.1. Principles of Contaminant Transport

In addressing the role of the vadose zone in contaminant transport and the possible attenuation of contaminants, apportionment of different contaminants and contaminant groups become important. Urban settings, therefore, pose a much broader spectrum of contaminants.

Different contaminants will be transported differently. In light of this, the vast array of potential contaminants from cemetery sites, as with landfills, require understanding of which contaminants to consider, as well as how they will be transported.

Contaminants in water move through a variety of mechanisms. In general, transport with the movement of groundwater is termed advection. Dilution of contamination can occur mechanically through dispersion or chemically through diffusion, with both these collectively being termed the hydrodynamic dispersion. Retardation also occurs through a variety of processes attenuating contaminants (Box 6).

5.2. Influence of Cemeteries on Water Quality

Contaminants emanating from burial practices are, for the purpose of this study, distinguished based on:

- Their sources (whether from the body's decomposition, accessory burial materials, or associated activities)
- The rate at which they are released to the subsurface
- Their mobility and persistence in the subsurface, and
- Their toxicity or health effects on receptors.

For these, the sources of potential contamination typically include (i) the actual decomposition of the corpse and the associated microbial contamination, (ii) the metals and organic compounds mobilised from the ornamental coffins and embalming processes, and (iii) nutrients from the landscaping practices. Some of these are detailed in Box 7 and, focusing specifically on the decomposition of the human body, in Box 8. Apart from these listed, certain other contaminants should also be anticipated, such as pharmaceuticals (e.g. Fiedler et al., 2018).

Lessons learnt from all case studies VZSA3 to VZSA8 together with available literature contribute to the findings of this section.

5.2.1. Human Remains (Interment and Cremation)

The human body is made of essentially of water with lesser carbon and other elements. Different references have marginally different compositions, with Van Haaren (1951) suggesting approximately 64% water, 20% protein, 10% fat, 1% carbohydrates and 5% other minerals. Depending on a variety of factors, the water percentage has been estimated as high as 74% (Forbes, 1987). Nevertheless, the human body decomposes in different stages with inorganic chemical weathering of remaining bone, teeth and cartilage occurring last.

Depending on weather the burial is within a coffin or direct contact with the soil, and on the oxygen available within the coffin, decomposition rates may vary drastically. Nonetheless, the process is explained in Box 7 and Box 8.

Box 6. **Contaminant Transport.**
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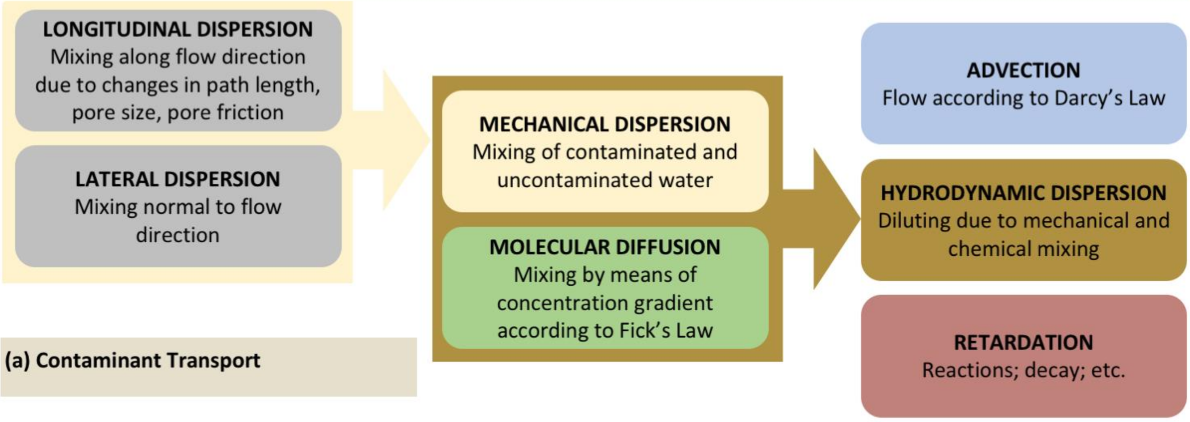
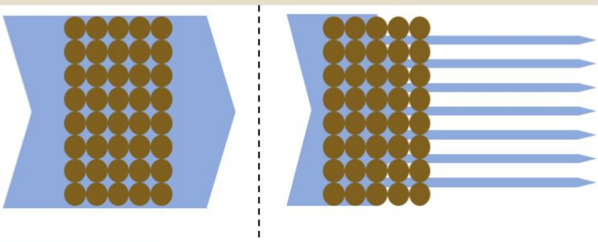
BOX 6. CONTAMINANT TRANSPORT



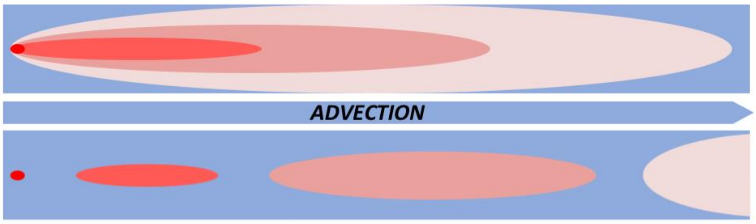
(a) Contaminant Transport

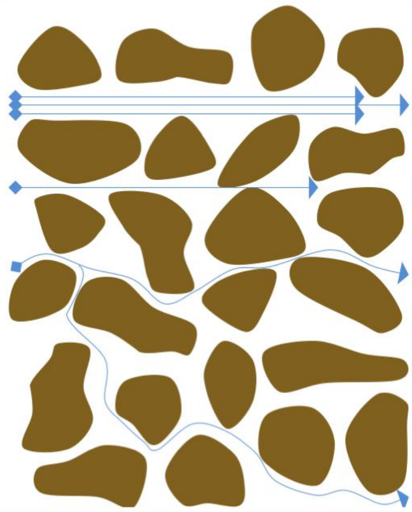
(b) Advection

Transport of contaminants with the movement of groundwater according to the average linear flow velocity calculated with Darcy's Law (right) as opposed to the specific discharge (left). It relates the hydraulic conductivity (the ability of the medium to transmit water), the hydraulic gradient and the effective porosity (void space contributing to the movement of water) to each other to determine the velocity in units of distance per time or velocity.



(c) Hydrodynamic Dispersion, Mechanical Dispersion, Molecular Diffusion





Whereas advection follows a hydraulic gradient defined by Darcy's Law, molecular diffusion follows a concentration gradient according to Fick's Law.

For a single point source (indicated by the red circle), the concentration of contamination will decrease as the extent thereof increases. This dilution effect is solely due to contaminants moving from high concentrations to low concentrations if stationary, and may be influenced by dispersion (changing flow pathways and directions) when flowing.

For a continuous contaminant release the contaminant plume will remain at the source. However, for a once-off release, the plume will progressively move away from the source.

Dispersion in the subsurface cannot be distinguished from diffusion, and combined are termed hydrodynamic dispersion.

(d) Retardation

Any of a number of processes which can slow down contaminant transport. These include, but are not limited to, chemical reactions, natural or radioactive decay, decomposition and so forth.

READ MORE:
ADAPTED FROM:

Box 7. **Contamination from Cemeteries.**

BOX 7. CONTAMINATION FROM CEMETERIES

(a) Typical Contaminants and their Sources

Cemeteries pose different types of contaminants that include not only the decomposition of the body itself, but also all chemicals used in the embalming processes and coffins, metals from the ornamental hinges on coffins and jewellery, and other nutrients and pathogens sourced from poor sanitary practices or landscaping.

Approximately 0.4-0.6 litres of leachate is produced per kilogram of body mass. With a high density of roughly 1.23 kg/l, it has a high electrical conductivity, pH and biochemical oxygen demand.

Apart from the decomposition of the body itself, additional contaminants can include:

M	**Metals**	Ti, Cr, Cd, Pb, Fe, Mn, Ni, Zn, As
N	**Nutrients**	NO_3, PO_4, Cl, salts of Ca, Na, K, Mg
O	**Organics**	formaldehyde, methanol
P	**Pathogens**	bacteria, viruses, microorganisms, fungi

These are typically sourced from:

- Chemical substances such as those used in chemotherapy or the embalming processes (including arsenic, formaldehyde and methanol)
- Makeup such as cosmetics, pigments and other chemical compounds
- Other items such as cardiac pacemakers, paints, varnishes, metal hardware, chemicals from batteries and dentures
- Microorganisms such as bacteria, viruses, intestinal fungi, protozoa and other pathogens.

(b) Sources and Corrosivity of Metals

Metals are typically sourced from the accessory materials buried with the corpse, i.e. jewellery and screws and hinges used in the coffin.

These metals are corroded with the corrosion rates strongly affected by environmental conditions such as soil type (governing porosity, permeability and surface tension), pH (governing acidity versus alkalinity), temperature (for mild temperate to warm climates), wetting (intermittent or flushing rain events versus permanently waterlogged) and hardness (specifically as calcium carbonate, related to the mineralization of soil moisture).

The table below indicates some environmental parameters **promoting** (*and retarding*) the corrosion of selected metals used in coffins. This is further exacerbated by, for instance, the presence of organic matters, and nutrients such as chloride or sulphate. Sand is well-drained, and therefore the initial water leachate may be more contaminated, whereas this is retained and thus retarded in clayey soils. In general, finer-grained soils are known to be more corrosive.

	Al, Cu, Fe	Zn
Soil type	**clay** (*sand*)	**silt** (*sand*)
pH	**acidic** (*alkaline*)	**acidic** (*alkaline*)
Temperature	**high** (*low*)	**high** (*low*)
Wetting	**intermittent** (*waterlogged*)	**intermittent** (*waterlogged*)
Hardness	(*hard water*)	(*hard water*)

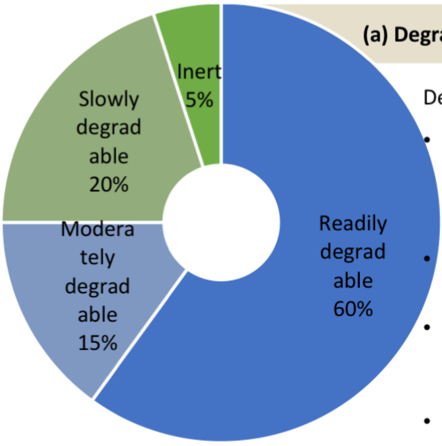
(c)	Contaminant	Mobility and Rate of Leaching	Persistence in Vadose Zone	Toxicity
M	**Metals**	Corrosion of interred materials Leaches out in months to years	Stored in vadose zone Years or more	Variable; chronic Occasionally carcinogenic
N	**Nutrients**	Source variable and not solely due to interment	Stored/ attenuated Months to years	Variable; chronic Organoleptic; non-carcinogenic
O	**Organics**	Embalming agents: days Lacquers, etc.: days to months	Days Highly variable	Variable Often carcinogenic
P	**Pathogens**	Interred body and environment Leaches in days to weeks	Variable: days to years *E.coli* days	Variable; acute to chronic Infectious disease

READ MORE: ADAPTED FROM: (a),(c) Fineza et al. 2014; Dent et al. 2004; EA [Environmental Agency] 2004; Rodriguez and Bass 1985; Żychowski and Bryndal 2015 ; (b),(c) this document; Van Allemann 2017; Van Allemann et al. 2018

Box 8. **Human Decomposition.**

BOX 8. HUMAN DECOMPOSITION

(a) Degradation of the Human Corpse



Degradation rate depends on:

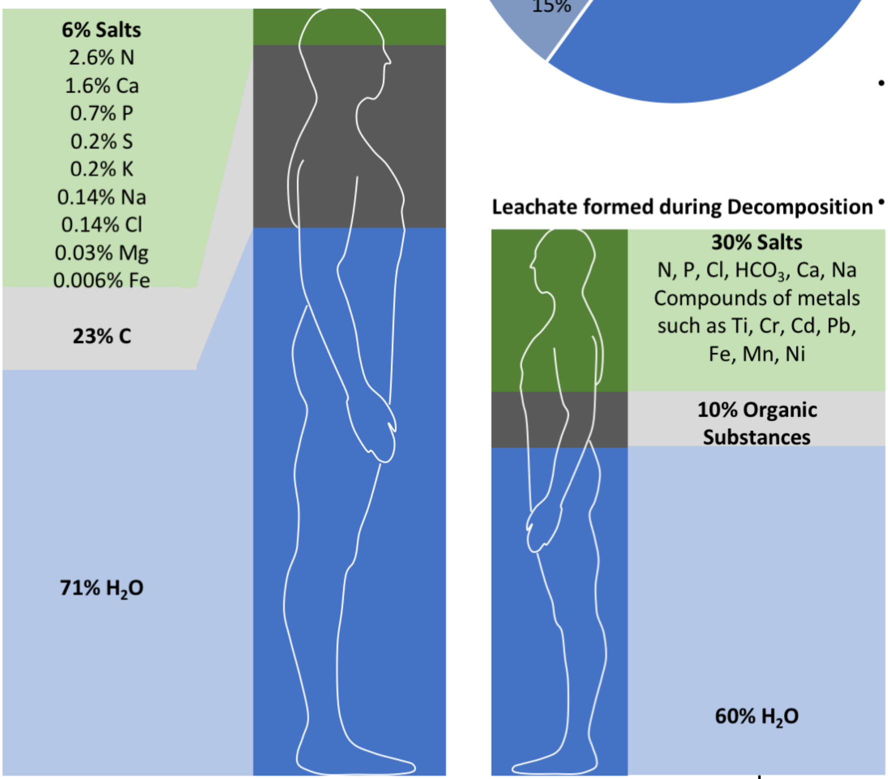
- Nutrient (C, N, P, S) and moisture availability with C:N:P ratio of roughly 30:3:1 favouring rapid degradation
- pH with neutral conditions being favourable
- Climate with warm temperatures accelerating decomposition
- Soil lithology with well-drained soil accelerating and poorly drained soil retarding the process
- Burial practice with depth and coffin construction determining the accessibility of the corpse to decay by invertebrates and vertebrates.

(b) Composition of the Human Corpse, Leachate, and Cremains

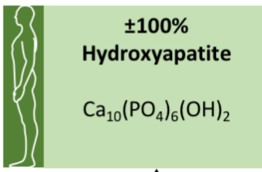
Scaled according to approximately volume (100% originally; ±50% leachate; <5% cremains)

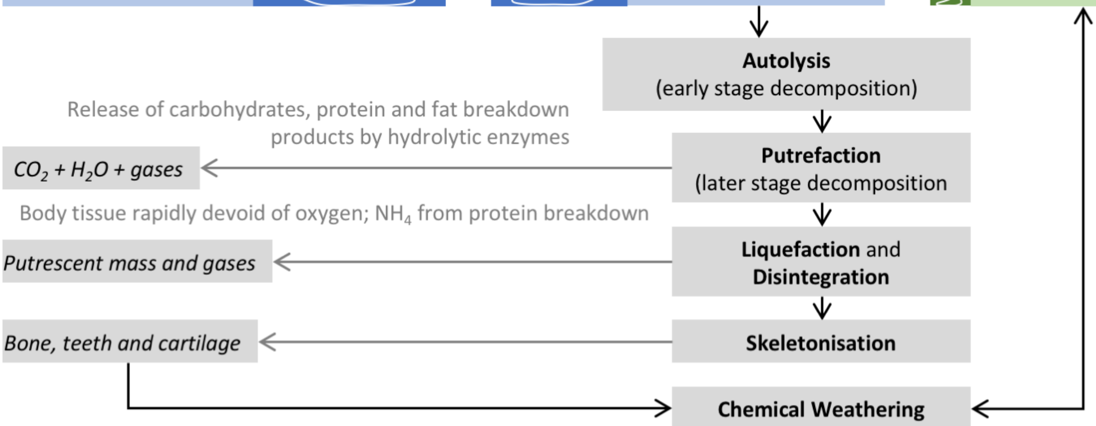
Human Body before Decomposition

Leachate formed during Decomposition



Cremains/ Skeletal remains





READ MORE: ADAPTED FROM: Żychowski and Bryndal 2015 (Fiedler et al. 2012; Matos 2001; Silva 1998; Silva and Filho 2011; Trick et al. 1999; Żychowski 2008); Dent et al. 2004; Dippenaar 2014; Dippenaar et al. 2014

With respect to the decomposition process itself, it is estimated that 0.4-0.6 litres of leachate are produced per 1 kilogram body mass. The leachate has a density of 1.23 kilograms per litre and comprises 60% water, 30% salts (N, P, Cl, HCO_3, Ca, Na and compounds of metals such as Ti, Cr, Cd, Pb, Fe, Mn and Ni), and 10% organic substances (Żychowski and Bryndal, 2015).

Spontaneous post-mortem changes (estimated within 4 minutes after death) ensue through autolysis (self-digestion), haemolysis and putrefaction of soft tissue, which has not been preserved. Putrefaction is the breakdown of soft tissue by bacteria and enzymes from the body itself or the environment of burial, resulting in the alteration of proteins, fat and carbohydrates. The process is initiated by the microorganisms present in the body (most notably the intestines and respiratory tract) with aerobic organisms using available oxygen to create suitable environments for later anaerobic organisms (from the intestinal canal and burial environment) required for the putrefaction stages. Anaerobic putrefaction results in the formation of hydrocarbons, ammonia compounds and biogenic amines, whereas the subsequent aerobic decay resulting in skeletalisation requires inorganic processes of further breakdown (Berg et al., 1975; Daldrup, 1979; Dent et al., 2004; Fiedler and Graw, 2003).

Liquefaction and disintegration follows, leaving behind resistant bone, teeth and cartilage that are further weathered through inorganic chemical processes (Dent et al., 2004).

Adipocere, also commonly referred to as grave wax, often form which preserves corpses after burial, resulting in delayed decomposition. This typically occurs at the onset of putrefaction in warm, moist, high pH environments, and is essentially the formation of soap from fat (saponification) (Fiedler and Graw, 2003; Fineza et al., 2003).

Factors enhancing the rate of desiccation (preservation without full decomposition) include (e.g. Carter et al., 2007; Dent et al., 2004; Fiedler and Graw, 2003; Turner and Wiltshire, 1999):

- Well-drained sandy soils and low moisture contents, coupled with the buried nature of the corpse resulting in limited access for insects and scavengers
- Clayey soils and high moisture contents reducing oxygen exchange rates and subsequently reducing aerobic activity
- Reducing conditions promoting the formation of adipocere.

Temperature is considered a governing parameter in skeletonization rates of corpses. For a corpse aboveground, it is roughly skeletonized or mummified in *y* days where $y = 1285/x$ where x = temperature in degrees Celsius (i.e. for a temperature of 10˚C, the period is roughly 128.5 days). Burial and submerging under water affects these rates, as well as any wounds or damage to the skin (Vass, 2001).

Remains from cremation ash (or cremains) are estimated to be roughly 3 kg (sic. 6 pounds) for an adult male with a volume in the order of 3-3.5 litres (sic. 200 cubic inches) (Lonité, 2017) or most often, for adults, in volumes exceeding those of standard urns. Cremains comprise essentially calcium and phosphorus (in the form of inorganic hydroxyapatite constituting ca. 70% of bone mass) as major elements, and essential elements including Mg, Na, Zn and Fe. Ratios of these elements mirror those in bones (Schultz et al., 2011) and all organic compounds incorporating carbon, hydrogen and oxygen are combusted at these high temperatures.

5.2.2. Metals

With very little known, especially within South African context, on the true risks posed by the decomposition process, more is available in international literature on metals from the coffin hinges and so forth. Jonker and Olivier (2012) evaluated cemetery and non-cemetery soils from the Zandfontein Cemetery in South Africa, finding that elevated metal concentrations existed within zones of dense burial.

Results from VZSA4 show that corrosion of aluminium, copper, zinc and iron is exacerbated by soils with higher water retention, acidic pH in preference to alkaline conditions, warmer temperatures, intermittent moisture regimes with alternating wetter and drier conditions, and low hardness (Box 7b). Organic content and other ionic groups such as chloride or sulphate further increase corrosivity.

Of interest in the results from VZSA4 (§13) shown in Figure 5-1 is that sands shows the highest concentrations of the different metals in the leachate, especially at early times. At later times, from week 16 to week 24, concentrations increase in clayey soils. This can very likely be ascribed to the retardation due to retention of moisture (containing the mobile metals) in fine-grained soils as compared to well-drained sandy soils. In general, it is well understood and accepted that clayey soils are generally more corrosive to metals than well-drained sandy soils. Low pH values and higher temperatures are confirmed to promote corrosion of these metals.

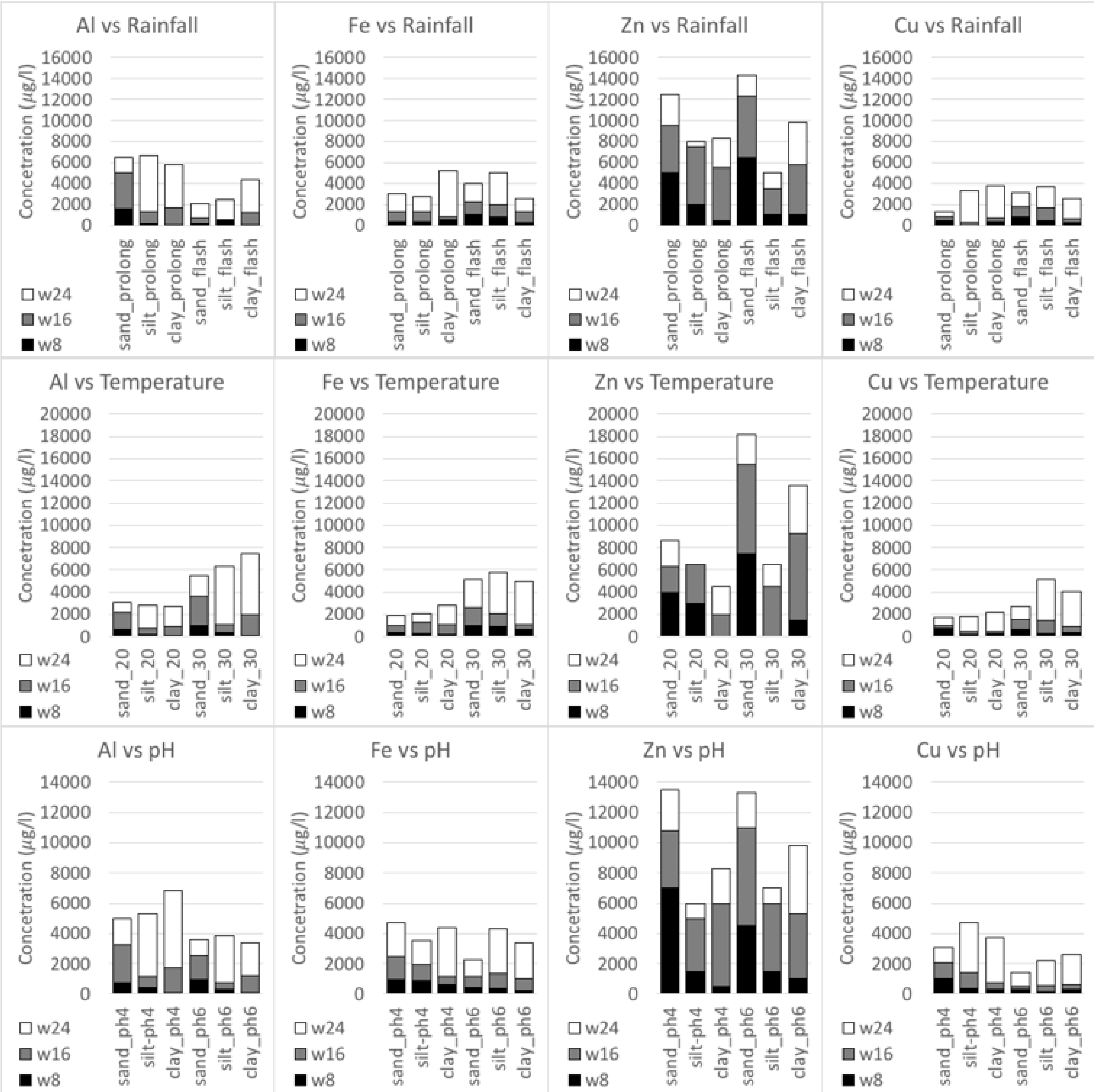


Figure 5-1. **Aluminium, iron, zinc and copper leached from the sample columns at week 8, 16 and 24 at different temperatures, rainfall intensities, and pH values (VZSA4, §13).**

5.2.3. Nutrients

Numerous studies have been conducted on nutrients in water sources, most notably with reference to agricultural land. The same principles apply to cemeteries, and major chemistry should be tested for water sources to ensure early detection of changing water quality.

5.2.4. Organics

Nowadays embalming fluids contain formaldehyde, distilled water, phenol and glycerol (Anat, 1993), of which 10 litres of the mixture (containing 1.5 litres of formaldehyde) (Karmakar, 2010) is required for a 70 kg body. Formaldehyde (CH_2O) is released during decomposition and has been shown to be carcinogenic (especially leukaemia) to living organisms (Guttman et al., 2012). According to a 2002 report, the World Health Organization (WHO, 2002) indicated that when formaldehyde comes into contact with water it breaks down into methanol, amino acids and several other chemicals and therefore does not persist in the environment. However, its persistence in a cemetery environment has not been assessed, especially given the role of the vadose (unsaturated) zone and the time for it to break down into harmless by-products.

As presented in VZSA4, formaldehyde does leach from experimental soil columns within the first 14 weeks of interment, although more than 97% was found to break down or to be immobile. However, given the health risks posed by formaldehyde, even low dosages can result in carcinogenic effects (Figure 5-2).

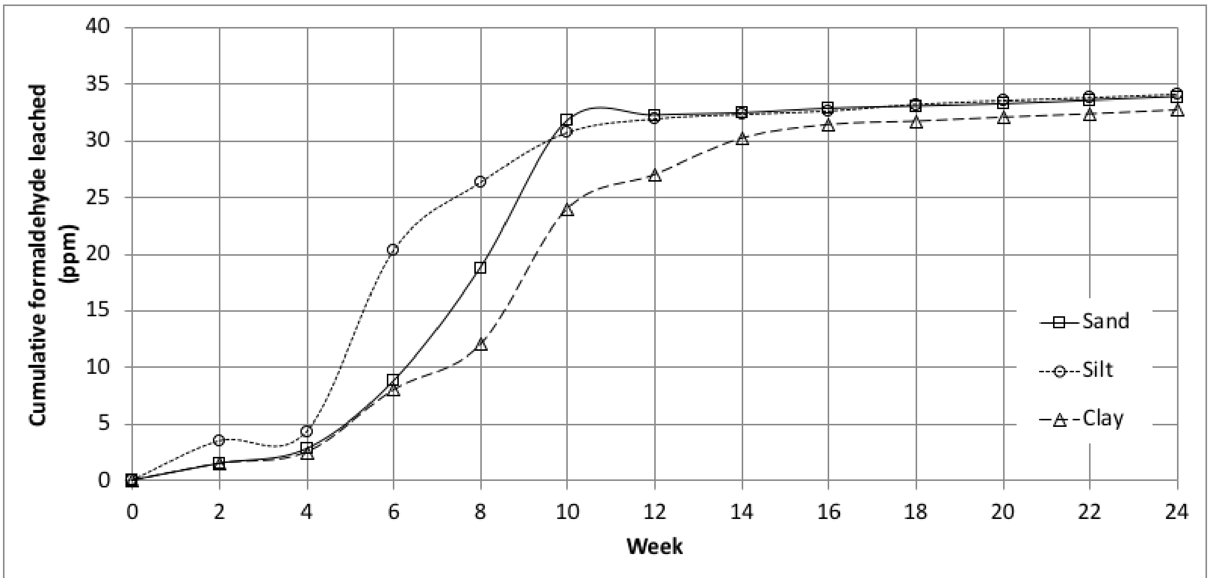


Figure 5-2. Formaldehyde leached from different soil types during the 24-week period.

5.2.5. Pathogens

Pathogens include bacteria, viruses and other microorganisms and are detailed in an extensive review by Żychowski and Bryndal (2015). *Escherichia coli* in particular is a well-known organism that has been used as an indicator of pollution in water and soils (e.g. Ashbolt et al., 2001; Harwood et al., 2005; Horman et al., 2004).

VZSA8 details microbacterial studies performed at a variety of cemeteries in South Africa. What is interesting is that, following extensive experiments conducted at VZSA6-8, certain strains of *E. coli*, for instance, can be antibiotic resistant, and that formaldehyde used in embalming does not necessarily inhibit growth of these species.

Apart from *Escherichia coli*, VZSA8 also identified the presence of, for instance, *Mycobacterium tuberculosis*, *Acinetobacter nosocomialis*, *Campylobacter ureolyticus*, *Streptococcus parasanguinis* and *Yersinia pestis*. The persistence of such pathogens suggests that (i) analyses may be required for more species than only *E. coli*, and (ii) a standard inventory for pathogens with standard mobility, persistence and toxicity cannot be formulated. Different pathogens in different cemeteries will result in different infections in different timeframes. This emphasises the importance of continuous monitoring.

SECTION D: ENGINEERING AND GEOTECHNICS

Matthys A. DIPPENAAR & Luke B. BROUWERS

6. ENGINEERING CONSIDERATIONS

Numerous engineering constraints require considerations for cemetery sites, including, for instance, shallow bedrock, excavation collapse, backfill permeability, excavatability and workability of the site materials (Box 9 and Box 10). The influence of seepage on the grave sites, as well as the influences of the excavations and backfill on the subsurface flow systems, are also addressed. These are discussed separately in detail in this section and, incorporating results from case studies VZSA3 to VZSA7, highlight contributions to the topic of cemeteries and geotechnics.

6.1. Material Properties

Soil profiles should be described according to SANS 633 (SABS 2012), whether on dolomite land or not, as based on Jennings et al. (1973) and elaborated in Dippenaar et al. (2014). This implies a six-fold classification based on moisture, colour, consistency, soil structure, soil type, and origin.

Where possible, different soil profiles should be characterised in terms of the mechanical and mineralogical properties, as these will inevitable affect the behaviour of the site soils.

Material properties to consider include the following:

- Profile description addressing field observations of the vertical soil succession, incorporating the in-situ moisture, colour, consistence, structure, soil type and origin
- Soil grading or particle size distribution analyses to infer the soil texture
- Atterberg limits to address the relationship between soil consistency and moisture content
- Soil chemical indicators such as mineralogy, pH, electrical conductivity, or as deemed appropriate
- Additional properties relevant to the site material such as problem soils.

Materials described in Cenozoic sands from VZSA7, for instance, highlighted the importance of identifying zones of periodical wetness to infer where seepage will occur and where sidewalls will collapse if graves are left open. The same knowledge of material properties also pre-empts the possible occurrence of sinkholes or difficult excavation. For areas with soluble rock, contaminated land, marshy areas, and/ or any other special site conditions, special investigations are, therefore, required.

6.2. Excavatability, Excavation Stability and Workability

Excavation should be possible to required depths of at least 1.80 m for single burials and 2.10 m for double burials. Excavation conditions should be noted as soft to hard in accordance with applicable standards, such as SANS 634 (SABS 2012), to the required depth:

- Soft: material that can be efficiently removed to the required depth, without any prior ripping, by means of a bulldozer, tract-type front-end loader (approximate mass of 22 tonne; flywheel power 145 kW) or a tractor-scraper (approximate mass 28 tonne; flywheel power 245 kW).
- Intermediate: material that can be efficiently removed to the required depth, without any prior ripping, by means of a bulldozer (approximate mass of 35 tonne; flywheel power 220 kW)
- Hard: material that cannot be efficiently ripped with the preceding; material that cannot be removed without blasting.

Box 9. Geotechnical Considerations.

BOX

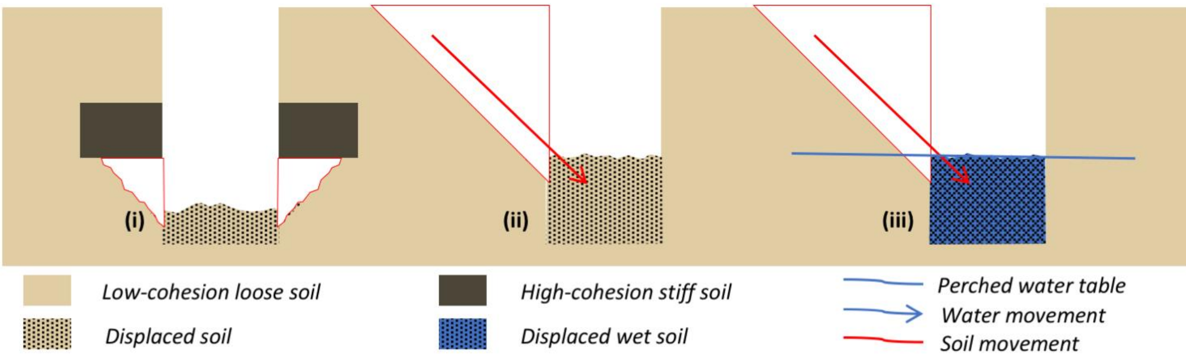
9. GEOTECHNICAL CONSIDERATIONS

(a) Excavation (In-)stability

Cenozoic sand deposits (Welmoed Western Cape 2017):

(left) Collapse of weak loose sands

(right) Orange layer: indurated by iron; possible zone of periodic wetting



(b) Karst/ Dolomite Instability

(c) Excavatability/ Backfill Materials

(left) Dolomite in the Irene Cemetery (2012): a leaking water pipe mobilised overburden into a sinkhole through the ingress scenario. Landscaping and irrigation were the anthropogenic causes of the sinkhole.

(right) Dolomite and calcrete in the vicinity of Taung (2005): difficult excavation in shallow bedrock and hard calcretes result in shallow graves and the need to create rock mounds over coffins.

(d) Perched Water and Flooded Graves

(left) Near wetland conditions and flooded grave excavations in a cemetery underlain by Hammanskraal Formation Sandstone (Pretoria, 2012). A leaking underground pipeline apparently contributed to the flooding of newly excavated graves.

READ MORE:
ADAPTED FROM: This document; Dippenaar 2014; Dippenaar et al. 2014; Dippenaar and Van Rooy 2018

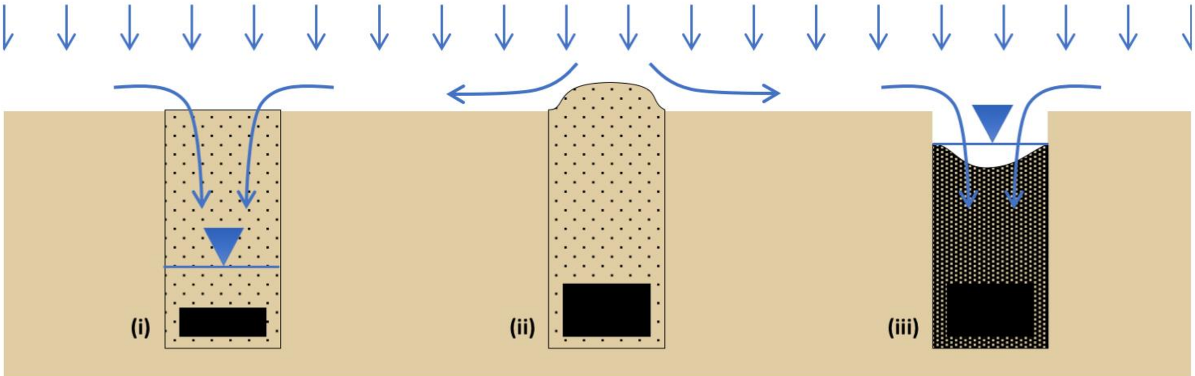
Box 10. **Engineering Hydrogeological Considerations.**

BOX 10. ENGINEERING HYDROGEOLOGICAL CONSIDERATIONS

(a) Grave Backfill and Flow

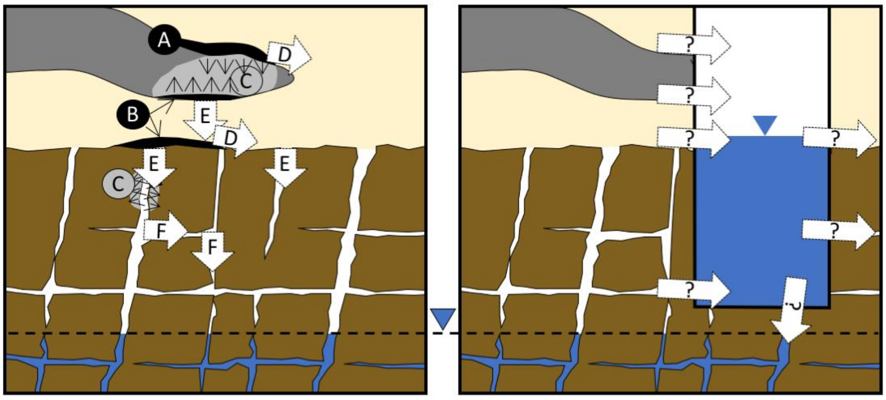
(left) Karoo Mudrocks (Middelburg Mpumalanga, 2016); mounded backfill

(right) Cenozoic Sands (Delft Western Cape, 2016); depressed backfill



(b) Complex Subsurface Flow Systems

- *Low permeability soil*
- *High permeability soil*
- *Fractured rock*
- *Excavation*
- *Free water (phreatic zone; standing water)*



Different flow scenarios co-occur in the subsurface, all contributing to the complex subsurface system. Excavation through these intercept numerous flow scenarios and affect future subsurface flow systems. Proposed scenarios include:

A) **Normal perching**: moisture can perch and disperse on lower permeability horizons due to the high suctions in small void spaces and the effort required to breach those suctions for water entry.

B) **Capillary-barriered** perching: moisture can perch and disperse on higher permeability horizons due to excessive adhesion and suction in fine-grained materials retaining moisture above larger voids or fractures, thus not allowing water entry.

C) **Imbibition**: moisture can imbibe laterally or vertically into finer-grained lower-permeability materials (soil or primary porosity of rock) due to suction, especially at fairly low moisture contents.

D) **Shallow interflow**: perched water can be mobilised as cohesion (water-water attraction) dominates and interflow ensues on lower permeability materials.

E) **Deep percolation**: perched water at high or total saturation in the vadose zone can mobilise as cohesion dominates, and gravity-driven percolation or drainage results.

F) **Unsaturated fracture flow**: seepage at partial saturation through fracture intersections and networks.

READ MORE: ADAPTED FROM: This document; (b) Dippenaar and Van Rooy 2018

Specific note should be made as to whether excavation is possible by means of pick and shovel, and whether shallow bedrock, boulders or pedocretes will influence excavatability across the site.

Material descriptions should indicate materials potentially posing difficulty, including, for instance, bedrock, boulders, pedocretes, highly organic soils, karst, wet soft clays, and very stiff dry clays.

Stability of grave excavations is important from stability and safety perspective as well as to avoid collapse of open graves during interment ceremonies. Although numerous reasons exist, sidewall failure is, for instance, due to (i) failure of cohesionless material below more competent layer; (ii) failure of loose cohesionless materials on exposure; (iii) failure of materials due to loss of shear strength of wet deeper soils or changing moisture conditions (Box 9a).

Apart from having to be readily excavatable, site materials also has to be able to adequately recompact hydrodynamically once used as backfill. The intent of backfilling graves is not to create a higher porosity and higher permeability drain for concentrated ingress of surface water, but rather to resemble natural soil consistency as near as possible. Determining some readily available moisture:density relationships through available laboratory testing will aid in this.

6.3. Backfill Compaction and Subsoil Permeability

Permeability of site soils pose geotechnical concerns as well as hydrological concerns. Backfill material is not generally compacted. The backfilled materials can either consolidate naturally, collapse under collapse of the coffin, or be mounded creating small mounds. Each of these has intrinsic consequences, mostly pertaining to the surface topography and infiltration of surface water. Examples are shown with (i) poorly compacted backfill over a collapsed coffin resulting in flooding of the grave; (ii) mounded backfill inducing runoff and erosion; and (iii) depressed backfill resulting in ponding (Box 10a).

Cemeteries may induce or limit seepage due to increased or decreased permeability of backfilled areas, mounding, collapsed coffins resulting in surface depressions, or additional water input through irrigation for landscaping.

For graves it is recommended to compact to 90 compaction effort at ±5% of optimal moisture content to minimise later consolidation of backfill, and to reduce the permeability of backfill.

6.4. Special Geotechnical Conditions

Certain conditions, apart from those addressed above, require special attention. In such instances, specialist input is required to ensure suitability of a parcel of land for development as a cemetery.

6.4.1. Soluble rock/ karst/ dolomite

If underlain by karst (any soluble rock, including, but not limited to, dolomite, limestone, marble and evaporates), a dolomite stability investigation is required as referred to in SANS 634:2012 and the SANS 1936:2012 series. Coupled with this, a suitable risk management strategy is required as graves can result in concentrated ingress of surface water, possibly resulting in surface subsidences or sinkholes. These also affect the vulnerability of the groundwater aquifer to contamination from interment activities.

6.4.2. Slopes

Land with steep gradients and slopes require investigation of the stability of the slopes, especially if the ground is to be disturbed on these slopes for the purpose of burials. Shallow interflow systems should be considered, as well as the influence of the disruption of the upper 1.80 m or more on the shear strength of site soils. Altering steep slopes in equilibrium may result in slope failure as well as extensive erosion.

Very low relief areas and flat slopes and depressions pose problems with water ponding, waterlogging and often localised infiltration into the subsurface. Disruption of ground in such areas may induce different hydrological flow regimes and may also induce erosion.

6.4.3. Wet land

Waterlogged land, marshes, wetlands and floodplains should typically not be considered at all for development as a cemetery. Special notice should be given to these conditions.

SECTION E: SITE INVESTIGATION

Matthys A. DIPPENAAR, Simon LORENTZ & Roger E. DIAMOND

7. EXISTING APPROACHES TO CEMETERY INVESTIGATION

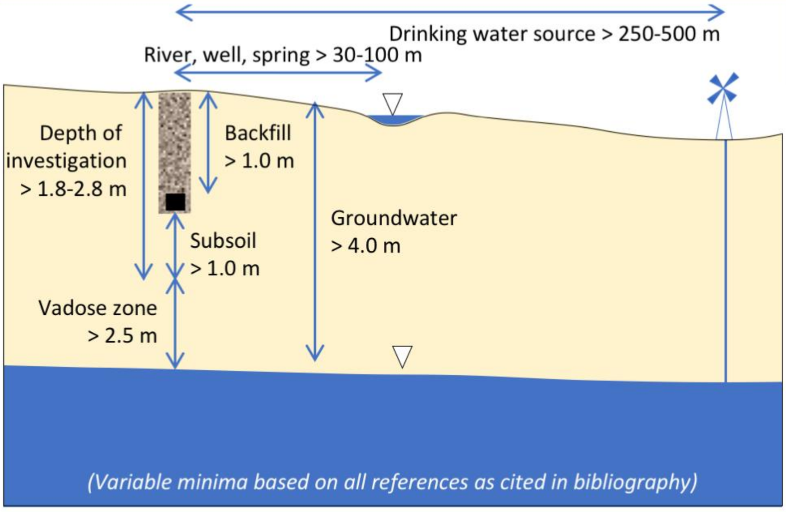
7.1. Current Best Practice for Cemetery Investigation

Existing approaches to cemetery site investigation are detailed by Dippenaar (2014) and shown in Box 11. Appropriateness and limitations of existing methods and interpretation techniques utilising data gathered and interpreted for best-case and worst-case scenario site suitability ranking scores according to Hall and Hanbury's (1990) approach are shown in Box 12. Although the method does provide a very sensible score for site suitability, it is emphasised that this does not replace the need for proper detailed field and laboratory data to validate findings.

The Vadose Zone Assessment Protocol (VZAP) by Dippenaar et al. (2014) and Dippenaar (2014) also provides a baseline for assessment of cemetery sites or any other proposed development of the vadose zone (Box 13).

Box 11. **Generic Minimum Requirements for Investigation.**

BOX 11. GENERIC MINIMUM REQUIREMENTS FOR CEMETERIES



(a) Generic Requirements for Siting and Investigations

Additional Specifications

Numerous dated other approaches require proving, by any means, the following:

- Deep water table
- Absence of perched water tables
- Soil conductivity 1 x 10^{-7} - 5 x 10^{-5} cm/s
- Thick excavatable soils
- No proximate water supply or drainage features
- Stability of sidewalls
- Surface gradient 2-6° (9° in exceptional cases)
- Space for adequate future expansion

(b) Standard Rating Scores (Hall and Hanbury 1990)

Engineering Geological/ Geotechnical	**Excavatability**	**Assessment**		**Score**
Excavatability ease to 1.80 m	Easy spade	Geological pick pushed in 50 mm with ease		15
	Pick and spade	Geological pick causes slight indentation		10
	Machine	Firm blows with pick cause 1 - 3 mm indentations		5
	Blasting	Backactor refusal		0
	Stability	**Assessment**		**Score**
Stability sidewalls stable for prolonged periods	Stable	Little overbreak with safe excavation profiling		20
	Overbreak	Overbreak between 1.3 and 1.8 m		15
	Slightly unstable	Minor falls of material		8
	Unstable	Collapse of excavation likely		1
	Workability	**Unified**	**MOD AASHTO**	**Score**
Workability material to be used as compacted backfill	Excellent to good	GW. SW, GP	> 1 800 kg/m^3	10
	Fair	SP, SM	< 1 800 kg/m^3	5
	Poor	OL, CL, ML	< 1 700 kg/m^3	2
	Very poor	OH. CH, MH	< 1 500 kg/m^3	0
Sanitary/ Environmental/ Hydrogeological	**Water Table**	**Water Table Depth (m)**		**Score**
Water table thickness of protective vadose zone	Deep water table	> 8		25
	Intermediate water table	4 - 8		5
	Possible perched water	0 - 4		5
	Waterlogged soil	0 - 4		Fail
	Subsoil Permeability	**Percolation Rate**	**Approx. Permeability**	**Score**
Subsoil permeability preventing ponding and rapid infiltration	Impermeable	Not measurable	< 10^{-7} m/s	15
	Relatively impermeable	10 - 15 mm/h	10^{-6} - 10^{-7} m/s	20
	Relatively permeable	15 - 50 mm/h	10^{-5} - 10^{-6} m/s	10
	Permeable	50 - 1 000 mm/h	< 10^{-5} m/s	0
	Backfill Permeability	**Unified Class**		**Score**
Backfill permeability preventing ponding and rapid infiltration	Impermeable	OH, CL, CH		5
	Relatively impermeable	GC, SC, MH		10
	Relatively permeable	GP, SP, GW		7
	Very permeable	SW, SP		0

Final Ranking	**Suitability**
> 90	Very good
75 - 90	Satisfactory
60 - 75	Poor
< 60	Unacceptable

READ MORE: ADAPTED FROM: (a) Croucamp and Richards 2002; Dent and Knight 1998; Dippenaar 2014; EA 2004; Engelbrecht 2000; Fisher 1992; Fisher 1994; Fisher and Croucamp 1993; Hall and Hanbury 1990; NIEA 2012; WHO 1996; Young et al. 2002; (b) Hall and Hanbury 1990

Box 12. Interpretation of Site Suitability Ranking Scores.

BOX 12. INTERPRETATION OF SITE SUITABILITY RANKING SCORES

In order to apply fairly generic ranking score systems, one has to ensure objectivity without being overly conservative, without omitting important constraining factors, and with understanding of heterogeneity and anisotropy over a single terrain.

Three examples were classified according to the well-formulated system by Hall and Hanbury (1990). Rankings are based on actual field observation, laboratory data, and technically sound interpretation.

(a) VZSA 3: Temba Cemetery

Parameter	Best-case scenario	Worst-case scenario
Excavatability	10 (pick and spade)	5 (machine)
Stability	20 (stable)	15 (overbreak >1.30m)
Workability*	10 (USC GP)	2 (USC SC)
Water table	25 (water >8m)	5 (water 4-8m)
Subsoil permeability	20 (10^{-6}-10^{-7} m/s)	10 (10^{-5}-10^{-6} m/s)
Backfill permeability*	7 (USC GP as above)	10 (USC SC as above)
FINAL SCORE	72 – POOR	40 – UNACCEPTABLE

(b) VZSA 6: Fontein Street Cemetery

Parameter	Best-case scenario	Worst-case scenario
Excavatability	10 (pick and spade)	5 (machine)
Stability	20 (stable)	15 (overbreak >1.30m)
Workability*	10 (USC GP)	5 (USC SC-SM)
Water table	25 (water >8m)	0 (water 0-4m)
Subsoil permeability	20 (10^{-6}-10^{-7} m/s)	10 (10^{-5}-10^{-6} m/s)
Backfill permeability*	7 (USC GP as above)	10 (USC SC as above)
FINAL SCORE	92 – VERY GOOD	50 – UNACCEPTABLE

(c) VZSA 7: Welmoed Cemetery

Parameter	Best-case scenario	Worst-case scenario
Excavatability	15 (easy spade)	10 (pick and spade)
Stability	15 (overbreak > 1.30 m)	1 (collapse likely)
Workability*	5-10 (USC GW, SW. GP)	5 (USC SP, SM)
Water table	10 (inferred)	0 (waterlogged)
Subsoil permeability	20 (10^{-6}-10^{-7} m/s)	10 (10^{-5}-10^{-6} m/s)
Backfill permeability*	7 (USC GW, SW, GP as above)	5 (USC CL as above)
FINAL SCORE	72-77 – POOR to SATISFACTORY	31 – UNACCEPTABLE

Best-case and worst-case scenarios were determined. The following important deductions should be noted:

i) One has to be realistic. When using, say, a Unified soil class of SC for workability, one cannot use another worse parameter for backfill permeability. These values were, therefore, kept consistent for each scenario under the realistic assumption that the same material removed when excavating the grave will also be used as backfill. This implies hypothetical worse and better case scenarios which does not make sense as different materials do not exist at the same position.

ii) Interpretations have to be truthful. The decision as to whether, for instance, the water table parameter is possibly perched (5) or waterlogged (fail), and whether this is due to external anthropogenic factors, or indeed natural conditions, need to be well formulated and motivated. Identification of seepage, especially in proximity of wetlands or other surface drainage features, require sound scientific understanding to protect the integrity of water resources.

iii) Field and laboratory data are required to validate assumptions. Although most parameters in the ranking system can be estimated with a fair amount of certainty by a competent person, results have to be verified by actual data. This is especially important for soil particle size distribution and permeability, as well as additional information not contained in this ranking system (e.g. moisture-density and compaction characteristics; shear strength; etc.)

iv) A ranking score approach should not replace well interpreted and argued scientific data.

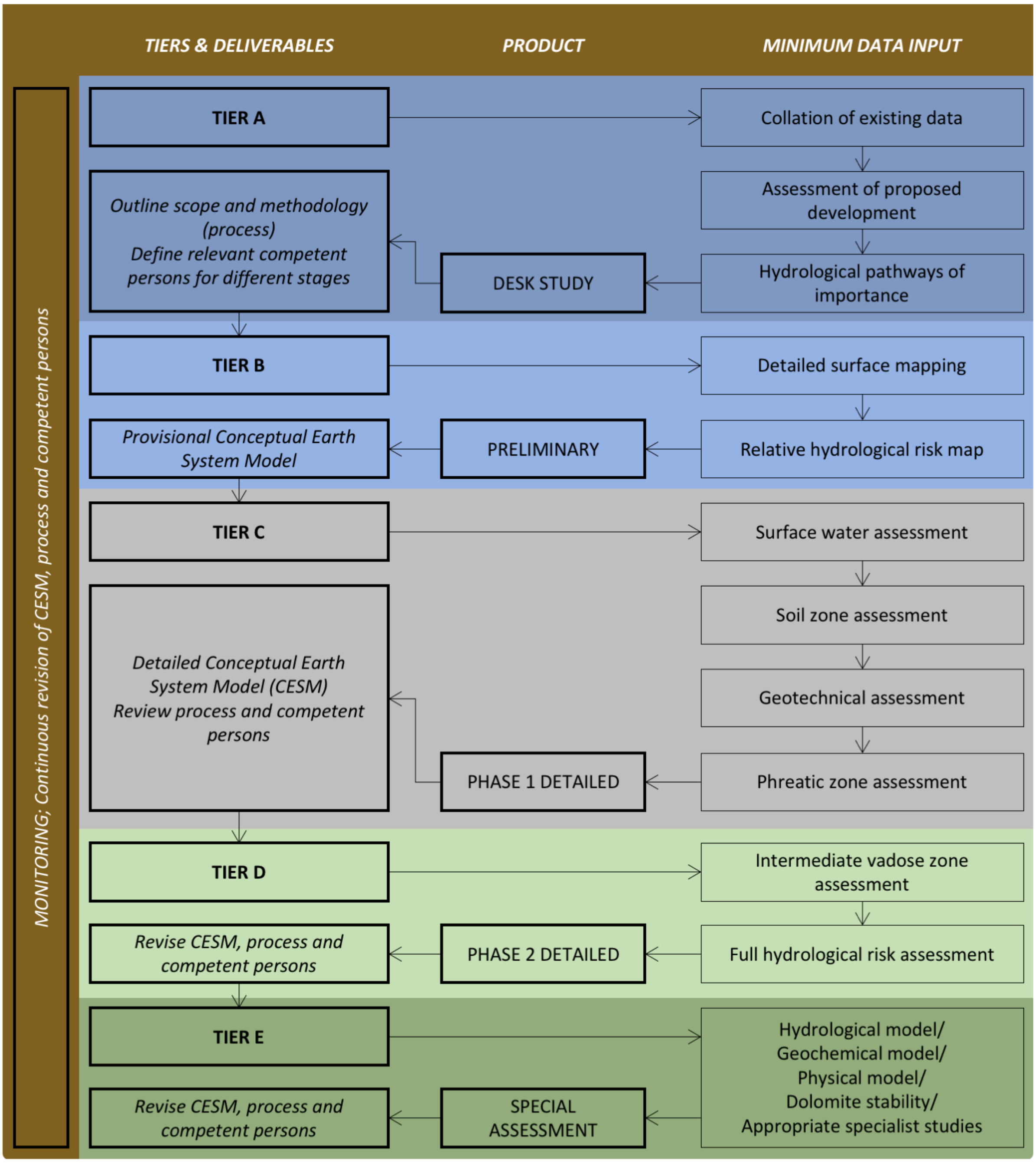
READ MORE:
ADAPTED FROM: VZSA 3: Dippenaar et al. 2014; Dippenaar2014; VZSA 6, VZSA 7: this document

Box 13. **Updated Vadose Zone Assessment Protocol (VZAP).**

BOX 13. UPDATED VADOSE ZONE ASSESSMENT PROTOCOL (VZAP)

The VZAP supplies an outline of different tiers of investigation, covering fundamental input required for proper assessment of the vadose zone for varying purposes. Within this context, specialist investigation scan be commissioned to comply with certain specified data requirements.

Collation of all information contained within the VZAP provides a detailed conceptual earth system model which can be continuously updated and validated as m ore data become available. This also ensures that the same content is addressed in technical reports, regardless of which competent persons are used. The VZAP furthermore provides opportunity for continuous updating through continuous monitoring.



READ MORE:
ADAPTED FROM: Dippenaar 2014; Dippenaar et al/ 2014

8. HYDROGEOLOGICAL/ GEOHYDROLOGICAL INVESTIGATION

The following section details a standard terms of reference for different stages of hydrogeological investigation for cemetery sites. The term "hydrogeology" is used synonymously with "geohydrology" or "groundwater". An investigation protocol is supplied in Box 14 and the extent of data requirements in the subsequent sections. With the exception of monitoring, preceding stages of investigation can be omitted, provided that the contents of those studies are incorporated into later reports. This implies, for instance, that if a Phase 1 Investigation is conducted, that the Preliminary Investigation can be excluded, etc.

8.1. General Requirements

8.1.1. Conduct

Professional conduct and competence is required, preferably using a professionally registered scientist with the South African Council of Natural Scientific Professions (SACNASP) and valid work experience as a hydrogeologist.

8.1.2. Hydraulic testing

Proposed testing required are detailed in Box 14. Standard acceptable test methods should be employed where possible, and deviation from standard methods should be document in the technical report.

Infiltration tests are conducted as per Dippenaar et al. (2014) referencing ASTM D 3385-94. Infiltration tests can be conducted as single or double ring tests. Percolation tests are conducted as per Dippenaar et al. (2014) referencing SANS 10252-2:1993. Test depths may be amended, notably to the depth below the base of the grave in open test pits or deep auger holes, based on the opinion of the specialist.

Hydraulic tests can include slug tests, bail-down tests or pumping tests. Individual tests upslope and downslope are preferred, if possible. Monitoring network boreholes identified during the hydrocensus (recommended 1-3 km diameter) can be employed for this. Hydraulic tests, notably pumping tests, are conducted as per SANS 0299-4:1998. Slug-tests and bail-down tests as alternatives can be conducted as per appropriate methods.

8.1.3. Water quality

Proposed testing required are detailed in Box 14. Standard acceptable test methods should be employed where possible, and deviation from standard methods should be document in the technical report.

Water sampling is conducted as per Weaver et al. (2007) and compared to available standards, such as SANS 241 (2001;2015) and the DWS (Department of Water and Sanitation) series of 1997. Water quality determinants should incorporate major and trace element chemistry, microbiology, physical determinants, and, if possible, selected organics such as formaldehyde.

For monitoring purposes or to possibly aid in the earlier detection of potential contamination, the following quick screen with reduced but relevant analytical parameters are recommended:

- Metals used in coffin ornaments or jewellery, or those historically used in embalming: e.g. aluminium, arsenic, cadmium, chrome, copper, iron, lead, mercury, nickel, vanadium, zinc
- Nutrients and compounds associated with both the landscaping processes as well as the breakdown of the skeleton: e.g. sodium, potassium, calcium, magnesium, chloride, fluoride, sulphate, nitrate, phosphate together
- Organics associated with embalming or daughter products of expected other organic compounds: e.g. formaldehyde
- Pathogens associated with the breakdown of biological materials; where appropriate, other pathogens expected: e.g. *E. coli*
- Other fundamental physical parameters such as pH, hardness, TDS and electrical conductivity.

Where such a condensed contaminant screen is being analysed, it should be ensured that the same parameters are incorporated into all subsequent analyses.

8.2. Preliminary Investigation (Tier A and Tier B)

The preliminary investigation relates to Tiers A and B of the Vadose Zone Assessment Protocol. The following have to be addressed:

- Collation of existing data (desk study; available maps, report and data)
- Assessment of proposed development (for cemetery sites, as detailed in this document)
- Hydrological pathways of importance (preliminary source-pathway-receptor analyses)
- Detailed surface mapping (topography; outcrops; drainage; prevailing land use)
- Relative hydrological risk (map or text addressing risks to water cycle and receptors dependent on the water cycle).

A site walkover is advised as part of the Preliminary Investigation. A preliminary hydrocensus can be included.

8.3. Hydrogeological Investigation (Tier A-D)

The Preliminary Investigation contents form part of the Phase 1 Hydrogeological Investigation. Reference should be made to preceding work completed, or the contents should be repeated in the Phase 1 Report. The Preliminary and Phase 1 Investigation contents form part of the Phase 2 Hydrogeological Investigation. Reference should be made to preceding work completed, or the contents should be repeated in the Phase 2 Report.

8.4. Additional Considerations

Water affects cemeteries in both its presence or absence as well as the effects the quality of the available water has. In the prior instance, water at partial saturation may flood the grave, resulting in waterlogging of the coffin. This results in oxidizing conditions becoming more reducing. In the latter instance, the aggressiveness of the subsurface differs based on moisture content. It is, therefore, sensible to record fundamental data such as:

- Depths at which moisture contents are very moist to wet, including waterlogged conditions on surface and the identification of the groundwater table
- Depths at which water seepage is encountered in excavation, including an estimation of the rate of flow

- Depths at which standing water occurs in open excavations, and the time required for the water level to stabilise

Minimisation of subsurface flow given the altered state of the shallow vadose zone in cemeteries should be noted:

(i) A reduction in irrigation for landscaping is proposed as a generic mitigation measure. Graves will likely cause zones of preferential infiltration if somewhat depressed, or will likely increase erosion or obstruct runoff if mounded. Optimal landscaping practices with minimal irrigation at low intensity will ensure that grass can grow without extensive mobilisation of possible contaminants.

(ii) Planting larger and indigenous trees with deeper root systems may aid in redistributing subsurface moisture and preventing waterlogging of graves and backfill. Where possible, natural vegetation and trees should not be removed, or should be replanted to aid in the natural management of subsurface waters.

(iii) Minimal accessories should be buried and coffins should preferably not contain too many artificial metals and plastics. These do, over time, mobilise, to the likely detriment of the receiving environment and groundwater and surface water users.

(iv) Hardness tends to immobilise some contaminants such as metals and reduce corrosion. If possible, small amounts of lime or dolomite may contribute to attenuating contaminants on-site.

The site should be zoned and each zone ranked according to appropriate systems such as Hall and Hanbury (1993). The final report should supply a percentage of area suitable for burial, as well as for possible future expansion. Land unsuitable for the purpose should be clearly described. If possible, the zoning of the hydrogeological and engineering geological investigations should be collated.

9. ENGINEERING GEOLOGICAL/ GEOTECHNICAL SITE INVESTIGATION

The following section details a standard terms of reference for different stages of hydrogeological investigation for cemetery sites. The term “engineering geology” is used synonymously with “geotechnics”. An investigation protocol is supplied in Box 15 and the extent of data requirements in the subsequent sections. With the exception of monitoring, preceding stages of investigation can be omitted, provided that the contents of those studies are incorporated into later reports. This implies, for instance, that if a Phase 1 Investigation is conducted, that the Preliminary Investigation can be excluded, etc.

For any infrastructure, such as crematoria, chapels, roads and so forth, the presented approach can be followed as it is based on existing standards for geotechnical investigation for single and double storey masonry structures documented in SANS 634:2012 and SANS 1936:2012 if dolomitic.

9.1. General Requirements

9.1.1. Conduct

Professional conduct and competence is required, preferably using a professionally registered scientist with the South African Council of Natural Scientific Professions (SACNASP) and valid work experience as a hydrogeologist.

9.1.2. Field investigations

For the sake of easy cross-referencing, the geotechnical investigation follows the general requirements stipulated in SANS 634:2012 (SABS 2012).

Soil profiles are described according to SANS 633:2012. Test pits should be excavated to depths of machine refusal or, if possible, to minimum depths beyond proposed grave depths of 1.80 m (single burial) to 2.20 m (double burial). The properties directly below the grave base are important in understanding possible contaminant transport processes. If excavatability allows, fewer deeper soil profiles are preferred.

9.1.3. Laboratory testing

Proposed testing required are detailed in Box 15. Standard acceptable test methods should be employed where possible, and deviation from standard methods should be document in the technical report.

Standard foundation indicator tests and soil classification supply the main mechanical properties of the site materials, as well as generic understanding of its behaviour for engineering purposes.

Moisture:density relationships are important for backfilling of graves, as well as to supply design parameters for roads and parking areas.

Soil or rock mineralogy inform about the weathering products to be expected at the site, and can also inform regarding corrosivity and baseline geogenic contaminants at the site.

9.2. Preliminary Investigation (Tier A and Tier B)

The preliminary investigation relates to Tiers A and B of the Vadose Zone Assessment Protocol. The following have to be addressed:

- Collation of existing data (desk study; available maps, report and data)
- Assessment of proposed development (for cemetery sites, as detailed in this document)
- Geological pathways of importance (preliminary indicator of anticipated geological risks)
- Detailed surface mapping (topography; outcrops; drainage; prevailing land use)
- Relative geotechnical risk (preliminary zoning map or text addressing geological such as problem soils, soluble rock, steep slopes, etc.)
- If possible, a site walkover and description of open excavations and outcrops are beneficial.

9.3. Detailed Engineering Geological/ Geotechnical Investigation (Tier A-D)

The Preliminary Investigation contents form part of the Phase 1 Engineering Geological Investigation. Reference should be made to preceding work completed, or the contents should be repeated in the Phase 1 Report. The Preliminary Investigation and the Phase 1 Investigation contents form part of the Phase 2 Investigation. Reference should be made to preceding work completed, or the contents should be repeated in the Phase 2 Report.

9.4. Additional Considerations

Additional to the methods described, specific reference should be made to the following:

- Anticipated volume change of problem soils has to be addressed with respect to mechanism of volume change (e.g. consolidation settlement, collapse, heave, etc.) as well as the thickness of the horizon prone to volume change and the anticipated vertical movement.
- Seepage constraints have to be addressed in terms of depths of notable in situ moisture content changes, as well as the likely impact of the cemetery on the subsurface hydrological conditions, and the impacts thereof on the soil properties.
- Excavatability has to be addressed at the hand of depth of excavation possible and means by which achieved (e.g. pick and shovel, machine, etc.), as well as end of hole conditions (e.g. description of materials at depth of excavation refusal).
- Special conditions have to be addressed through distinct mention of areas underlain by soluble rock, steep slopes or gradients, contaminated land, uncontrolled fill, or wet land.

Solutions should comprise a site zoning in terms of R (rock), S (settlement), C (collapse settlement), H (heave), D (dolomite), or P (problem areas, e.g. marsh land; uncontrolled fill; undermined land; etc.), as elaborated in SANS 634:2012 and SANS 1936:2012.

Importantly, each individual zone should be ranked according to appropriate systems such as Hall and Hanbury (1993). The final report should supply a percentage of area suitable for burial, as well as for possible future expansion. Land unsuitable for the purpose should be clearly described. If possible, the zoning of the hydrogeological and engineering geological investigations should be collated.

Box 14. **Hydrogeological Investigation Protocol.**

BOX 14. CHECKLIST: HYDROGEOLOGICAL INVESTIGATION

(a) Stages of Investigation and Techniques	Preliminary	Phase 1	Phase 2	Monitoring
Desk study: topography, land use, drainage, climate, vegetation, geology	1	1	1	0
Desk study: available data, reports, databases	1	1	1	1
Risk assessment: vulnerability, source-pathway-receptor, suitability ranking	1	1	1	1
Risk assessment: hydrological pathways; flow; hydrostratigraphy	2	1	1	1
Site walkover: surface mapping, outcrop description	2	1	1	0
Hydrocensus: identification of proximate water bodies, users and uses	2	1	1	0
Hydrocensus: water levels, baseline water quality	2	1	1	1
Hydraulic testing: infiltration or percolation	3	1	1	0
Hydraulic testing: pumping or slug or bail-down	3	2	1	0
Profile description: hand augering, test pits, detailed outcrop description	2	2	2	0
Water quality: proximate or on-site surface water or groundwater	3	2	1	1
Geophysical investigation: if required for understanding or siting boreholes	0	0	3	0
Drilling: if required to implement monitoring network	0	0	3	0
Reporting:	1	1	1	1

Legend			
0	Not applicable	Recommended minimum requirement	2
1	Compulsory minimum requirement	Optional minimum requirement if appropriate	3

(b) Recommended Minimum Requirements for Phase 2 Investigations

Tests and Analyses	≤ 5 ha	≤ 10 ha	≤ 20 ha	≤ 50 ha	≤100 ha	>100 ha
Infiltration/ Percolation	4 (1.25/ha)	4-8 (0.5/ha)	4-10 (0.5/ha)	8-15 (0.33/ha)	10-20 (0.20/ha)	10-40 (0.20/ha)
Water Quality (phase 1)	0 if supported by lack of monitoring points; else as for (2)					
Hydraulic Tests* (phase 1)	0 if supported by lack of monitoring points; else as for (2)					
Water Quality (phase 2)	1 upstream; 1 downstream; 1 other; as minimum within 2 km radius					
Hydraulic Tests (phase 2)	Preferably more than 1 slug, bail-down and/ or pumping tests					

* *if applicable*

(c) Additional Requirements and Best Practice

i) Consultants should be professionally registered in a category proving competence, both in terms of academic qualification and work experience, for the work to be conducted.

ii) Where available and applicable, standards and guidelines on, for instance, hydraulic testing, water sampling and analyses, and so forth, should be used to ensure transparency in methods and to ensure quality of results.

iii) Eventual site suitability can be addressed at the hand of available ranking systems (e.g. Hall and Hanbury 1990), provided that adequate data have been acquired.

iv) Phase 2 Investigations provide the minimum requirements for final Environmental Impact Assessments (EIAs) or Water Use License Applications (WULAs).

READ MORE:
ADAPTED FROM:

Box 15. Engineering Geological Investigation Protocol.

BOX 15. CHECKLIST: ENGINEERING GEOLOGIST INVESTIGATION

(a) Stages of Investigation and Techniques

(a) Stages of Investigation and Techniques	Preliminary	Phase 1	Phase 2
Desk study: topography, land use, drainage, climate, vegetation, geology	1	1	1
Desk study: available data, reports, databases	1	1	1
Risk assessment: conceptual model of geological heterogeneity and anisotropy	1	1	1
Risk assessment: site zoning based on geological constraints	1	1	1
Site walkover: surface mapping, outcrop description	2	1	1
Indicator properties: grading; Atterberg limits; soil classification	2	1	1
Moisture:density properties: compaction; CBR	3	2	1
Soil chemistry: mineralogy; and/ or pH & EC	3	2	1
Profile description: test pits (attempt > 2.5 m), detailed outcrop description	2	1	1
Specialised tests: swell; consolidation; collapse potential; etc.	3	2	2
Geophysical investigation: if required for understanding, dolomite stability, etc.	0	0	3
Drilling: if required to implement monitoring network	0	0	3
Reporting:	1	1	1

Legend

0	Not applicable	Recommended minimum requirement	2
1	Compulsory minimum requirement	Optional minimum requirement if appropriate	3

(b) Recommended Minimum Requirements for Phase 2 Investigations

Tests and Analyses	≤ 5 ha	≤ 10 ha	≤ 20 ha	≤ 50 ha	≤100 ha	>100 ha
Test Pits and Soil Profile Description	4-10 (2/ha)	4-10 (1/ha)	5-15 (0.5/ha)	10-25 (0.5/ha)	25-50 (0.5/ha)	35-70 (0.35/ha)
Foundation Indicators	4	4	6	10	15	20
Moisture-Density	4	4	4	5	6	10
Other*	2	3	4	5	6	10
pH/ EC	4	4	4	5	6	10
Mineralogy*	4	4	4	5	6	10

** if applicable*

(c) Additional Requirements and Best Practice

i) Consultants should be professionally registered in a category proving competence, both in terms of academic qualification and work experience, for the work to be conducted.

ii) Where available and applicable, standards and guidelines on, for instance, hydraulic testing, water sampling and analyses, and so forth, should be used to ensure transparency in methods and to ensure quality of results.

iii) Eventual site suitability can be addressed at the hand of available ranking systems (e.g. Hall and Hanbury 1990), provided that adequate data have been acquired.

iv) Phase 2 Investigations provide the minimum requirements for final Environmental Impact Assessments (EIAs) or Water Use License Applications (WULAs).

READ MORE:
ADAPTED FROM:

10. ADDITIONAL AND CROSS-DISCIPLINARY CONSIDERATIONS

Additional reporting contributions are detailed in this section. Often, specialist reports fail to adequate consider cross-disciplinary consequences of certain developments. Some examples that may contribute to safer development are noted here and/ or are shown in Box 16.

10.1. Life Cycle of Cemetery

10.1.1. Changes in ground properties

Backfilling results in heterogeneity and anisotropy being homogenised through mixing materials of different mechanical and hydraulic properties. Often, these materials are consolidated to lower-than-natural density, implying weaker, more porous materials (Box 16a). Note that parameters indicated are indicated as initial (i.e. prior to excavation) and relative (i.e. not indicating absolute values, but rather lower to higher relationships). For the backfilled sequence, it is likely that all these graphs will be represented by near-vertical lines, implying that parameters following backfill may be the same throughout.

Poorly compacted backfill almost always poses problems in that it tends to promote consolidation and infiltration.

10.1.2. Changes in flow

Complexity in flow systems can be identified during site investigation. Subsequently, hydrological behaviour during project life cycle can be inferred based on the understanding of the pre-developmental subsurface hydrology (Box 16c). A standard reporting format for additional understanding of the hydrological conditions and the implications thereof on infrastructure development is supplied. This incorporates data from both the engineering geological and hydrogeological investigations.

10.1.3. Climate

As climate is changing, rainfall events tend to become more intensive. Flooding and heavy rain storms are common, and effects of such Events become more catastrophic given the extremely dry periods between events. Effects of climate change on developments should acknowledge that extreme conditions will alternate, and that long-term resilience planning is required.

10.1.4. Impacts of adjacent developments

Cemeteries do not pose the only exclusive source of contamination. Agriculture, mining, industry, waste disposal, on-site sanitation and other developments all contribute to potential sources of highly variable contamination. As development inevitably encroaches on cemeteries, the impacts of these proximate developments should be considered, e.g. (i) limitations on space for the expansion of the cemetery, (ii) additional sources of contamination, and (iii) hydraulic impacts such as pipelines and other infrastructure.

Such adjacent development are also then at risk of adverse effects from the cemetery, should contamination result.

10.2. Sources of Contamination

10.2.1. Cause of death

Cause of death is not always specified on death certificates. Subsequently, very little knowledge is available about possible pathogens being interred with corpses. This makes monitoring of cemetery sites difficult and, should contamination occur, increases risk to receptors of contracting diseases not envisaged prior to interment.

10.2.2. Accessory burial and coffin materials

To minimise manageable risks, it is suggested to stay with ordinary dimensions of coffins, preferably wood or biodegradable materials, and to refrain from excessive use of ornamental metals, plastics, paints, varnishes, etc. Jewellery, dentures, pacemakers, watches, batteries, excessive cosmetics, and other such materials should preferably be removed prior to interment.

All such materials have the ability to mobilise and contaminate proximate water resources. Given the high variability of accessory burial materials, it is increasingly difficult to speculate which contaminants will mobilise, how they will be transported, and what the eventual adverse impact may be.

10.2.3. Corrosivity and mobility

Site materials affect the aggressiveness or corrosivity of the environment to different materials such as metals and cement (Box 16b). Improved understanding of the influences of different environmental factors on the corrosivity of different metals and cement can aid in better inferring which contaminants may likely mobilise, from which sources, and what rates. Of importance is that many of these parameters work in a synergetic relationship, implying that the cumulative effect of more than one may exceed the effect of the sums of the individual parameters. Similarly, certain parameters can also cancel each other out to some extent, e.g. high alkalinity which should be corrosive to steel, but $CaCO_3$ that effectively slows down corrosion.

10.2.4. Burial load

Burial loads vary temporally and spatially. Cemeteries are therefore continuous sources of potential contamination with the risk depending on the burial density. Numerous burials can occur over single weekends. Of these, some may or may not involve embalming, and metals and other contaminants are added to the subsurface continuously over time. Very large concentrations of possible contaminants can therefore be released and stored at cemeteries for later release. It is imperative that burial loads and burial densities are incorporated into risk assessments.

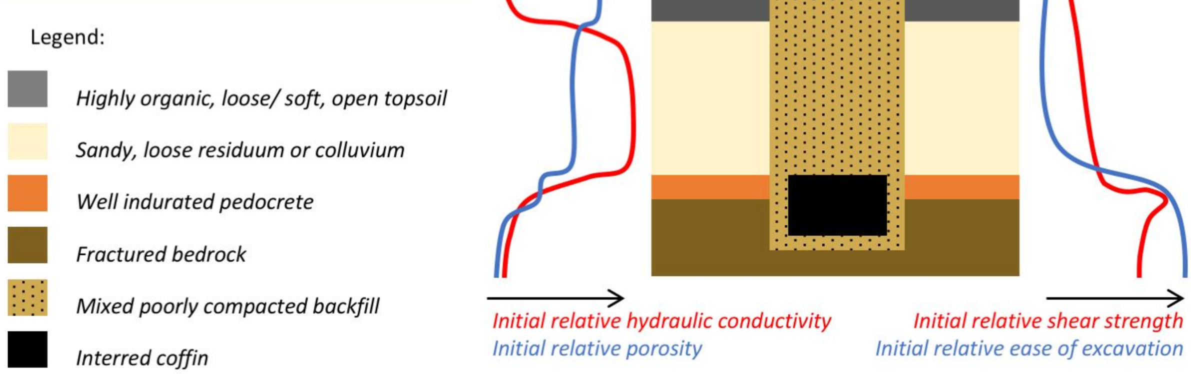
10.3. Other Specialist Investigations

Apart from anticipated project life cycle implications, other scientific specialist input such as ecology, hydropedology, surface hydrology, wetland delineation, etcetera, are not incorporated into these specifications, as these solely address the suitability for cemetery development, and do not specifically consider the very important reasons to often not develop land due to environmental importance and/ or sensitivity. Incorporation of such reports are subject to requirements for an environmental impact assessment and the required water use licenses.

Box 16. Additional and Cross-Disciplinary Considerations.

BOX 16. ADDITIONAL AND CROSS-DISCPLINARY CONSIDERATIONS

(a) Made Ground



Backfilled graves constitute made ground, also termed anthropogenic or manmade ground. This implies that the properties of the materials are highly disturbed and no longer represents the original properties. For backfilled graves, most mechanical and hydraulic properties are somewhat homogenized (depending on how backfilling occurs). Whereas important properties varied in the original soil profile, these are now harder to quantify given the randomly mixed nature of the backfill material. The figure shows some initial parameters of importance that will be affected in a backfilled scenario.

(b) Corrosivity

Parameter	→ Increasing Corrosivity or Aggressiveness of Soils →					
EC (S/m)	<0.0050: Essentially non-corrosive	<0.0100: Mildly corrosive	<0.0200: Moderately corrosive	<0.0333: Corrosive	<0.1000: Highly corrosive	>0.1000: Extremely corrosive
Soil type	Sand and gravel generally have lower EC: Generally less corrosive			Clay generally has higher EC: Generally more corrosive		
Saturation	<40% or 100%: Generally not aggressive to mildly corrosive				60-85%: Maximum expected corrosion rates	
pH	Soils with neutral pH are generally not very corrosive			Very acidic or alkaline: corrosive to steel Acidic (pH < 5.5): likely corrosive to concrete		

A number of readily available parameters can inform about the corrosivity or aggressiveness of the subsurface. Generalised corrosivity indicators are tabled above. Additional to the above, other parameters, such as contents of different ions, organic materials, etc., can also affect soil corrosivity.

(c) Complex Flow Scenarios

ID	Wetness (1)	Water Seepage (2)		Standing Water (3)		Stability (4)	
	DEPTH	DEPTH	RATE	DEPTH	TIME	(UN-)STABLE	TIME
NOTES	(1)	Depth from which moisture content is very moist to wet					
	(2)	Depth of seepage and estimation of seepage rate (slow, medium, fast, very fast)					
	(3)	Depth of standing water in pit and time taken to fill to stated level (else immediate)					
	(4)	Sidewalls stable or unstable and time since excavation until instability					

Recording data noted above can supply valuable insight into the anticipated project life cycle changes in subsurface flow. This can be collated from data acquired by the various specialists to ensure that any change in flow is pre-empted.

READ MORE:
ADAPTED FROM: Bhattaria (2013)

SECTION F: SUMMARY OF MAIN FINDINGS

Matthys A. DIPPENAAR & Jana OLIVIER

11. CONCLUSIONS AND RECOMMENDATIONS

The project deliverables are met through contributions to the environmental risk assessment, monitoring and management of cemeteries. Emphasis is on the hydrogeological and engineering geological investigations as these are of fundamental importance in environmental impact assessments and water use license applications. Additionally, these pose potential health and safety risks to people, livestock and the receiving environment.

Case studies entailed controlled laboratory and field investigations to address questions identified that are of relevance to cemeteries. Additional and cross-disciplinary contributions are highlighted in the preceding section. Apart from this and the contribution to improved understanding and improved site assessment, some novel findings are presented here.

11.1. Corrosion and mobility of metals

Environmental conditions affecting the leaching, mobility and persistence of selected metals have been addressed. Mostly, leachate from sands are more enriched, likely given that seepage is promoted in sandy materials. However, clays are more corrosive to metals, but leaching is retarded given the high retention of moisture in clayey soils. Low pH, unsaturated conditions, fine-textured soils, and warmer temperatures are some of the controls enhancing corrosion of metals. Metals tend to mobilise fairly soon on, but at highest concentrations around week 16-24 of experiments. Experiments were ceased at this time, and it should be noted that metals will remain mobile at later times.

11.2. Mobility and persistence of formaldehyde

Environmental conditions affecting the leaching, mobility and persistence of formaldehyde have been addressed. Formaldehyde did not appear to affect the plate counts of *E. coli* despite it being used as biocide in the embalming process. Formaldehyde breaks down within days in the subsurface and is therefore not extremely persistent despite its high toxicity. It does, however, keep on leaching out in the first days to weeks, with highest concentrations leaving the system around week 8 of experiments. Even though it breaks down rapidly in aerated systems, it may be more persistent in saturated systems and could, therefore, potentially pose risk if reaching groundwater or surface water.

11.3. Partially saturated flow at the soil-rock interface

Flow at partial saturation from soil into fractured bedrock is complex, but affects natural flow, as well as any cutting or excavation such as a grave. Dispersion plumes are found to exist in soils over open fractures due to capillary barriered scenarios, from where various flow mechanisms result. Saturation tends to decrease with depth in the fracture, coupled with increasing flow rates to maintain continuity. This affects whether preferential flow will occur when certain in-situ moisture contents are breached, whether interflow will be induced, or whether natural attenuation may be promoted at partial saturation in the vadose zone where contaminants are temporarily immobile.

11.4. Antibiotic resistance of *E. coli*

Some E. coli were found to be antibiotically resistant at one of the field study sites. Although this might not necessarily be a result of the cemetery itself, it does inform about the behaviour of certain microorganisms in the vadose zone. Additionally, the complexity in contaminant types are accentuated.

11.5. Isotope hydrology in the vadose zone

The use of isotopes in vadose zone systems entailing interflow, perched water tables, and interaction between the surface water and groundwater have been highlighted in adding more detailed understanding to the complex subsurface flow systems affecting and affected by cemeteries. Using isotope results together with hydraulic and laboratory data improves results and subsequently understanding of the complex flow systems.

11.6. Complexity in unsaturated zone geological models

Geological complexity is added to conceptual models through addressing a wide variation of different earth materials, climatic regimes, and land uses. This is work being continued under the auspices of the new project, K5/2826 on the complex and anthropogenically altered vadose zone.

SECTION G: SUPPORTING CASE STUDIES

Matthys A. DIPPENAAR

Individual case studies to be referenced as a chapter in a book.

12. INTRODUCTION TO SUPPORTING CASE STUDIES

The following section depicts case study descriptions, sampling, analysis, interpretation and results. The final conclusions have been collated and incorporated into the first sections of this document, typically under headings labelled Provisional Findings. The intention is not to use these case studies as discreet investigation aiming to clarify important concepts, but to use the collective dataset to understand the implications of improper investigation, lack of guidelines and oversimplification in vadose zone and, notably, intermediate vadose zone hydrology.

Main findings are incorporated into the body text of this document, continuously referring to the case study in the appendix.

For the sake of integrated readability with other case studies in other vadose zone projects, notably as initiated by Dippenaar et al. (2014), study sites are labelled as Vadose Zone Study Areas or VZSAs with numbers following on those used in Dippenaar et al. (2014). This enables the cross-reference of different study areas, with VZSA1, VZSA2 and VZSA3 being incorporated into this previous report. For the sake of easy cross-referencing, experimental studies are labelled similarly. The work contained herein also form part of a greater research focus on vadose zone hydrology and engineering hydrogeology, and subsequently future studies will conform to the numbering.

VZSA3: Peri-urban Cemetery at Temba, City of Tshwane (Dippenaar et al. 2014) applies here.

13. VZSA4: CORROSION OF ACCESSORY BURIAL MATERIALS

Sunette VAN ALLEMANN, Jana OLIVIER & Matthys A. DIPPENAAR

13.1. Motivation for Study

This section is a summary of the experimental work published by Van Allemann (2017) and Van Allemann et al. (2018).

How coffin materials corrode contributes to the possibility of contamination from cemetery sites. In addressing this, the influence of variable moisture and climate on corrosion of common metals used in the fabrication of coffins is evaluated in controlled laboratory environments with materials supplied from reputable undertakers.

13.2. Study Description

The experimental setup is illustrated in Figure 13-1:

- Typical coffin materials comprise of 65 kg chipboard or 85 kg solid wood, four hinges, six standard handles or six handles with two aluminium rods of 1.2 meter, four plastic ornaments for the corners of the coffin and screws. The ratio of each material is calculated according to the weight of an average coffin, after which the coffin samples are broken up into smaller pieces prior to interment. The materials are then buried in the soil columns with a cloth soaked in 5% formaldehyde (used as embalming fluid, which preserves the dead) and E.coli bacteria with a nutritional medium, stimulating the decomposition of a body which may influence the corrosion rate of the materials. The cloth and bacteria are placed opposite each other in order to allow the bacteria to flourish.
- Half of the columns are placed into a 30˚C chamber and the other half in an air-conditioned room which is set at 20˚C simulating hot and moderate temperatures. Interment continues for a period of six months under various simulated conditions.
- Distilled water is used in the experiments. The pH is decreased by adding small quantities of hydrochloric acid (HCl) to achieve a pH of 6 (slightly acidic) and pH 4 (acidic).
- For the samples subject to prolonged rainfall periods, 1 L of water is added over a period of 4 days. The samples exposed to flash floods are given 1 L of water once off. The samples are then left to dry for a period of two weeks to promote oxidation. The cycle is repeated for the duration of the six months.
- Cement, simulating concrete tombs, are buried in different soil type columns with 1-meter long coils of aluminium (Al), copper (Cu), zinc (Zn) and iron (Fe), all of which is weighed beforehand., representing the most common metals used for coffins.
- Three additional columns with wires, excluding the cement, are also set up in order to determine the corrosion rate of each type of wire. The columns that include the cement will therefore determine whether the cement will influence the corrosion rate of the wires. The samples are exposed to the expected "most severe" conditions such as acidic pH, 30˚C and heavy rainfall (referred to as 'flash floods') in the different types of soil. Control samples of the three different soil types are also prepared and exposed to flash floods of neutral pH water at moderate temperatures (between 20˚C and 30˚C).
- There are 36 soil columns in total that allow for differentiation between the different types of soil (sand, loam and clay), at different pH levels (slightly acidic and acidic), varying rainfall (prolonged rainfall and flash floods), different temperatures (ranging from 20˚C to 30˚C) and the addition of cement.

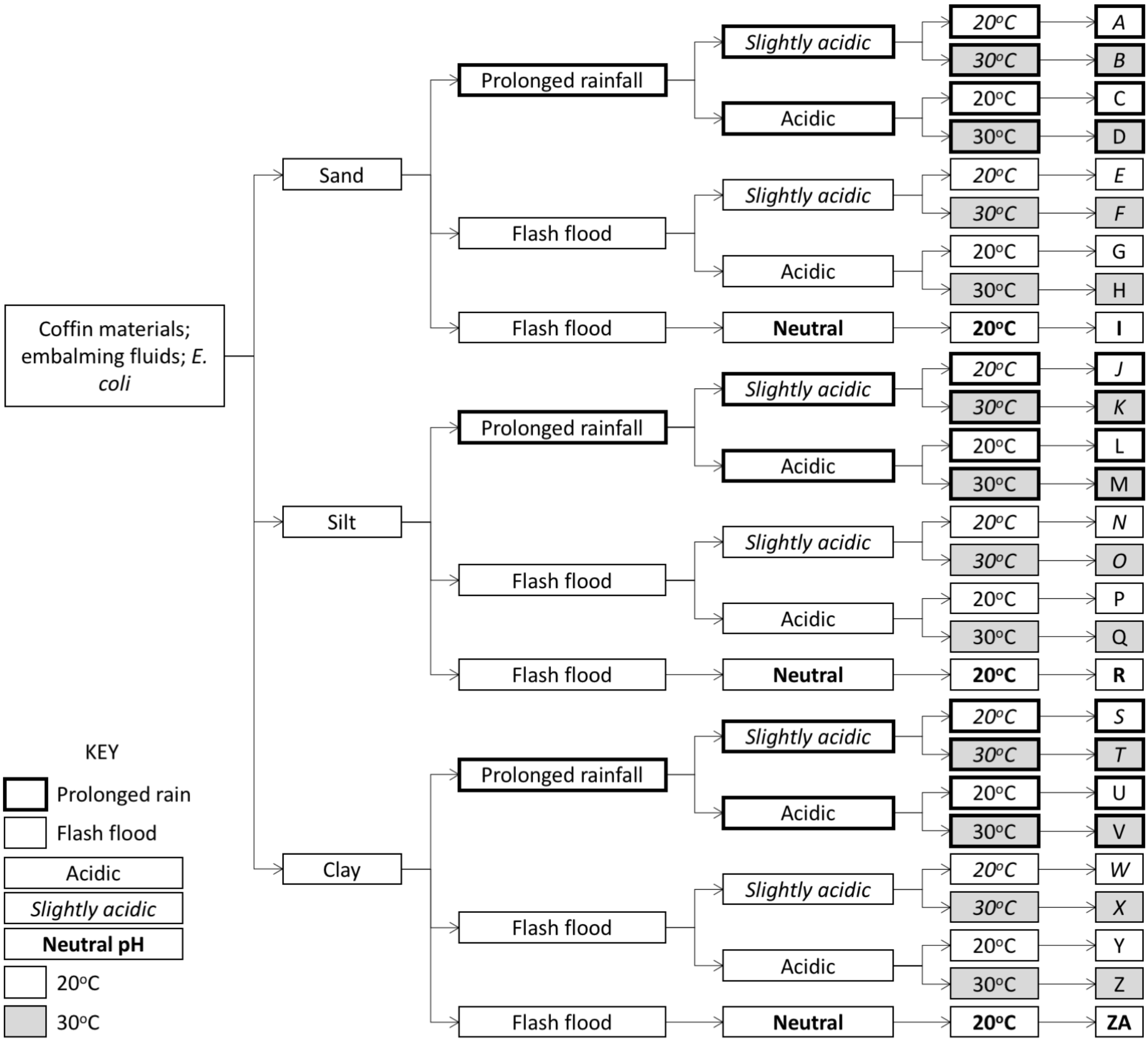


Figure 13-1. Experimental setup and variables tested.

13.3. Results

Results are detailed in Table 13-1, Figure 5-2, Box 7b and the relevant publications emanating from this study. Summaries are supplied in Table 13-1 and Figure 5-1; letters A-ZA relate to those presented in Figure 13-1.

The leachates of the various metals were found to be much lower than their individual weight-loss measurements. This suggests that either (i) significant amounts of corrosion products still remain in the soil columns, or (ii) on the metal surface itself. The latter scenario is likely to be truer since excess corroded products formed on the metal surfaces were removed by means of acid cleaning procedure in order to determine the corrosion rates.

The cumulative formaldehyde leached from different textured soil types are shown in Figure 5-2. Contrary to expectation, formaldehyde persists in soils and slowly percolates through the soil for periods of at least 14 weeks. Different environmental conditions, such as soil type, changes in temperature, rainfall amount and rainfall pH do not appear to affect the amount of leachate or the mobility rate through soils, although sand allows more effective leaching.

Table 13-1: Concentrations of aluminium, iron, zinc and copper leached from the sample columns over a period of 24 weeks.

Sample Identification	Al (µg/L)				Fe (µg/L)				Zn (µg/L)				Cu (µg/L)			
Week	8	16	24	Σ	8	16	24	Σ	8	16	24	Σ	8	16	24	Σ
COFFIN SAND																
A slightly acidic 20 prolong	370	560	100	1030	200	0	100	300	1000	1000	1300	3300	50	18	55	123
B slightly acidic 30 prolong	450	730	210	1390	100	400	500	1000	1500	2000	0	3500	47	144	86	277
C acidic 20 prolong	250	630	450	1330	30	500	450	980	1000	0	500	1500	303	0	74	377
D acidic 30 prolong	500	1580	680	2760	0	100	650	750	1500	1500	1200	4200	50	220	321	591
E slightly acidic 20 flash	50	100	300	450	50	50	100	200	500	1000	0	1500	99	5	324	428
F slightly acidic 30 flash	90	200	420	710	50	300	400	750	1500	2500	1000	5000	116	17	453	586
G acidic 20 flash	20	180	100	300	100	100	200	400	1500	300	500	2300	275	300	264	839
H sand acidic 30 flash	10	100	500	610	850	800	950	2600	3000	2000	500	5500	398	554	324	1276
I sand control	0	0	0	0	400	350	0	750	0	0	0	0	0	0	0	0
Total Sand (Σ)	1740	4080	2760	8580	1780	2600	3350	7730	11500	10300	5000	26800	1338	1258	1901	4497
COFFIN SILT																
J slightly acidic 20 prolong	0	50	320	370	150	500	650	1300	1500	1500	0	3000	6	166	327	499
K slightly acidic 30 prolong	20	380	1700	2100	100	200	750	1050	0	1500	500	2000	13	80	876	969
L acidic 20 prolong	100	370	950	1420	100	100	50	250	500	1000	0	1500	8	19	43	70
M acidic 30 prolong	100	280	2400	2780	50	100	50	200	0	1500	0	1500	0	0	1754	1754
N slightly acidic 20 flash	40	50	500	590	50	200	50	300	0	500	0	500	78	80	213	371
O slightly acidic 30 flash	200	10	600	810	50	100	1500	1650	0	1000	500	1500	41	120	235	396
P acidic 20 flash	100	50	320	470	0	150	50	200	1000	500	0	1500	111	20	785	916
Q acidic 30 flash	100	50	480	630	750	700	1400	2850	0	500	1000	1500	214	1030	756	2000
R silt control	10	0	0	10	300	300	0	600	0	0	0	0	0	0	0	0
Total Silt (Σ)	670	1240	7270	9180	1550	2350	4500	8400	3000	8000	2000	13000	471	1515	4989	6975
COFFIN CLAY																
S slightly acidic 20 prolong	50	500	430	980	50	100	650	800	0	500	1000	1500	13	18	54	85
T slightly acidic 30 prolong	20	450	670	1140	20	100	800	920	500	1500	500	2500	123	100	826	1049
U acidic 20 prolong	20	90	400	510	50	100	450	600	0	0	500	500	10	117	645	772
V acidic 30 prolong	10	560	2650	3220	400	50	2450	2900	0	3000	800	3800	187	150	1526	1863
W slightly acidic 20 flash	10	50	400	460	50	500	300	850	0	500	500	1000	156	100	321	577
X slightly acidic 30 flash	20	100	700	820	100	100	600	800	500	1800	2500	4800	15	111	754	880
Y acidic 20 flash	10	200	560	770	50	200	300	550	0	1000	500	1500	84	0	670	754
Z acidic 30 flash	30	800	1500	2330	100	200	50	350	500	1500	500	2500	15	185	111	311
ZA clay control	20	0	0	20	0	200	0	200	0	0	0	0	0	0	0	0
Total Clay (Σ)	190	2750	7310	10250	820	1550	5600	7970	1500	9800	6800	18100	603	781	4907	6291

14. VZSA5: FLOW ALONG THE SOIL-ROCK INTERFACE

Luke B. BROUWERS & Matthys A. DIPPENAAR

14.1. Motivation for Study

This section is a summary of the experimental work published by Brouwers (2017) and Brouwers and Dippenaar (2018).

In terms of hydrological risk, it is imperative to assess the movement of water from a soil material into fractured rock at partial water saturation. This is done in conjunction with other Water Research Commission projects, and addresses the very important hydrological processes occurring as water (possibly contaminated from, for instance, cemetery sites) passes from soil into fractured bedrock. Whether the coffin is placed above the soil-rock interface in the soil material, or on the contact itself (as excavation conditions will likely be too hard for placement within bedrock alone), will have fundamental implications on the possible flow mechanisms and directions in the subsurface.

14.2. Study Description

Laboratory models were constructed using pluviated sand and acrylic sheets under geotechnical centrifugal acceleration. Visual observations qualitatively represent the various flow mechanisms as functions of time, saturation and water supply.

14.3. Results

Results are shown in Box 3b, Box 5c and the relevant publications emanating from this research.

The derived conceptual model is shown in Figure 14-1, where the following were observed:

a) Formation of dispersion plume during initial saturation that encounters a capillary barrier at the soil-rock interface;
b) Combined capillary barrier and multiple flow mechanisms for variably saturated flow at the soil-rock interface;
c) Final drying phase outcome with invasion of drying plume and static droplets with extinct rivulets in the fracture;
d) Final rewetting phase outcome with the formation of a rewetting dispersion plume and larger main draining rivulets resulting in decreasing saturation with depth inside the fracture

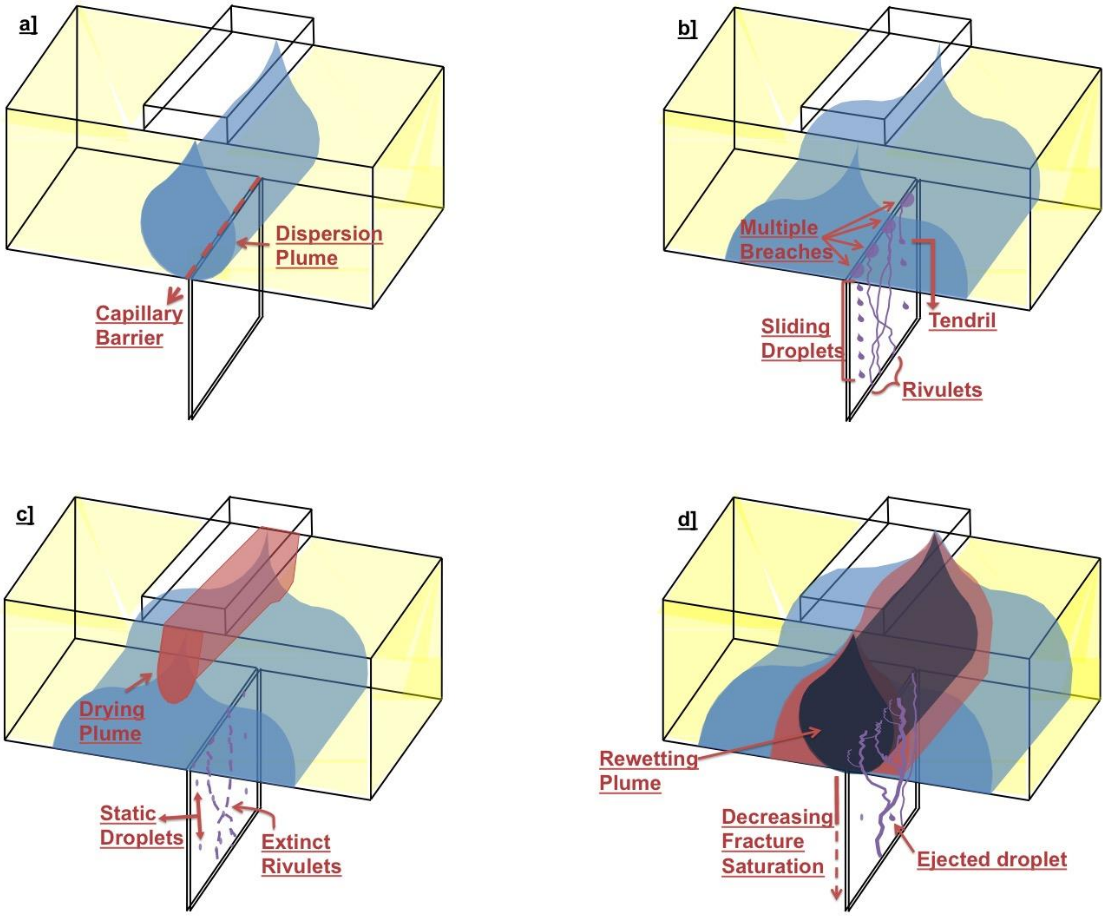


Figure 14-1. Conceptual model for variably saturated flow from soil into a discrete fracture.

15. VZSA6: FONTEIN STREET CEMETERY, STEVE TSHWETE LOCAL MUNICIPALITY

Sarah N. MAHLANGU, Lehlohonolo APHANE, Simon LORENTZ, Roger E. DIAMOND and Matthys A. DIPPENAAR

15.1. Motivation for Study

The Fontein Street Cemetery (henceforth Fontein St) management has noted issues related to flooding of graves and the close proximity of a drainage channel to the site. Coupled with a landfill on an adjacent property, the dense residential development around the site, and the need for additional land for burial in the municipality, access was granted for investigation of Fontein St. The final results are published in Aphane (2018) and Mahlangu (2018).

15.2. Study Description

15.2.1. Site locality and prevailing conditions

The site is situated on the southeastern corner of Samora Machel Street (previously Fontein Street, after which the cemetery is named) and Verdoorn Street, with access being from the latter. The site is bound to the south by a historical landfill presently used as a sports field. A drainage channel occurs at the northwestern corner of the site and residential developments occur to the east (Figure 15-1).

The first burial took place in 1959 and approximately 32 846 graves were recorded until 2015. The site is bounded by a historic landfill that is presently used as a sports ground. Residential development occurs to the east, and a drainage channel and open veldt are found to the west and north.

15.2.2. Climate

Figure 15-2 indicates the monthly rainfall at Middelburg for the period the study was conducted. The data was obtained from the South African Weather Service and was recorded from a rainfall station closest to the site. The results indicate that Middelburg received a mean precipitation (MAP) of 61 mm/month and a total volume of about 726 mm/yr. from the beginning of February 2016 to end of January 2017. Though Middelburg experienced some rainfall during winter or the dry season, most of its rainfall occurred during summer from October to March with the highest volume experienced during March and November.

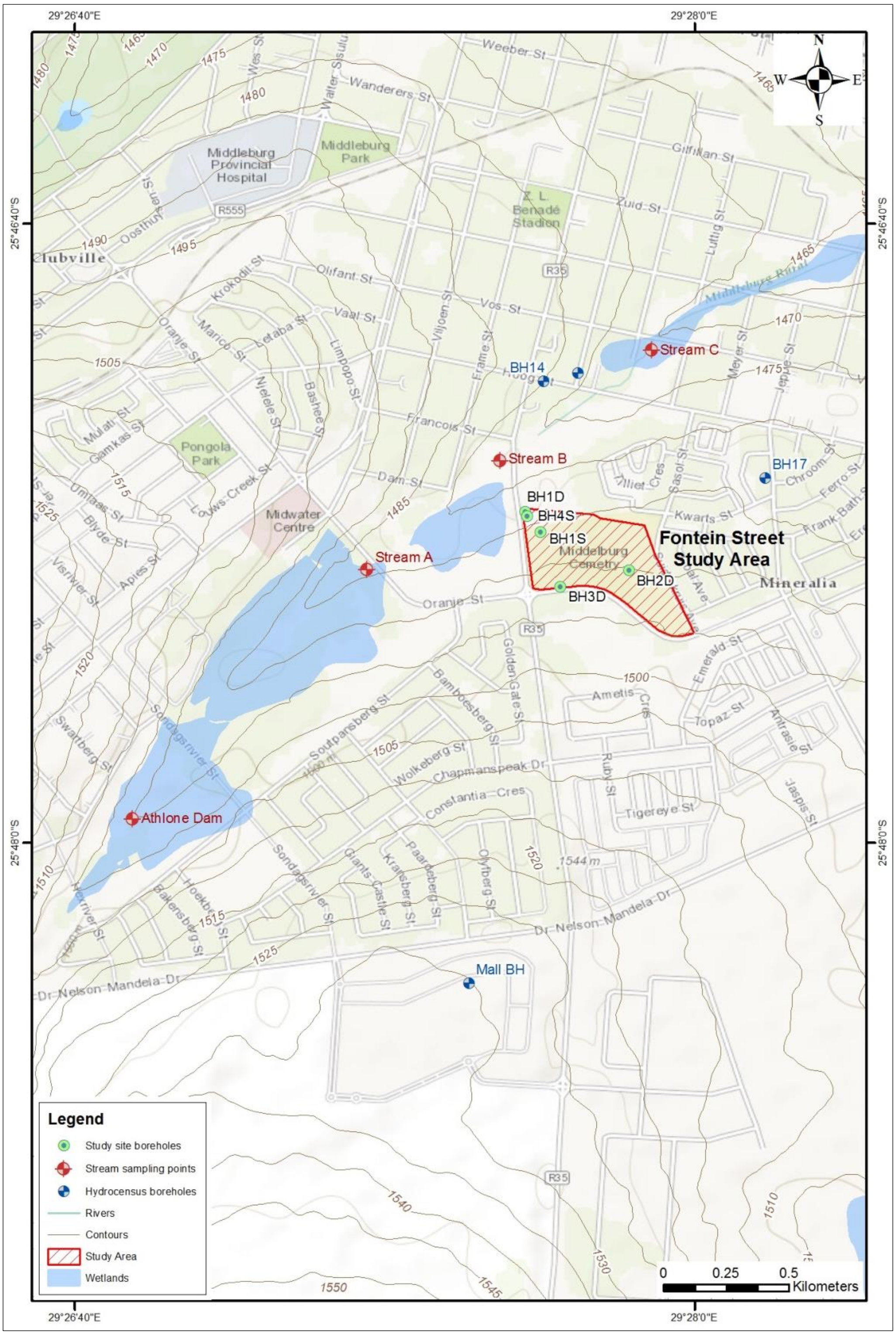


Figure 15-1: **Contour Map of the study area indicating sampling positions for the monitoring programme.**

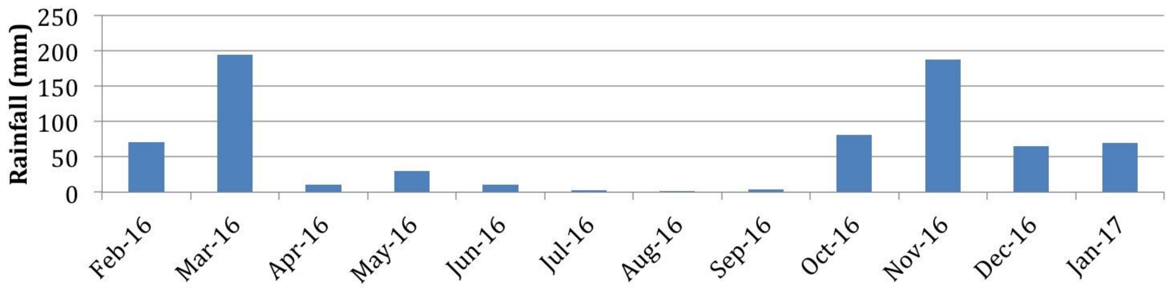


Figure 15-2: **Monthly rainfall in Middelburg obtained from a weather station closest to the study area (SAWS, 2017).**

15.2.3. Regional hydrology and geology

Regional drainage is within the B12D quaternary catchment of the Olifants Water Management Area (WMA) 4. A drainage channel is present at the northwestern boundary of the site, draining in a northeastern direction.

The site is underlain by Dwyka Group tillites and/ or shales of the Karoo Supergroup near the contact with the Loskop Formation shale, sandstone, conglomerate and lavas of the Rooiberg Group. Diabase is intruded sporadically between the Rooiberg and Dwyka Groups.

15.3. Data Acquisition

15.3.1. On-site drilling and sampling

Boreholes sampled during the study are summarised in Figure 15-2 and shown on Figure 15-1. Following drilling in April 2016, most of the boreholes were dry. This can likely be ascribed to the shallow depth of boreholes given that mudrocks expanded during drilling and deeper drilling was not possible.

Table 15-1: **Onsite borehole details (Fontein Street).**

ID	Depth (mbgl)	Static Water level (mbgl)	Location (Lat, Long, Elevation)	Borehole construction
BH1S	1.56	Dry	25°35’57.6”S 28°27’04.8”E 1388 m	Equipped with 53 mm PVC plastic casing to depth, capped at both ends
BH1D	3.74	Dry	25°47’17.0”S 29°27’38.1”E 1488 m	Equipped with 6 m long, 6.5” diameter perforated steel casing and 53 mm PVC plastic casing to depth, capped at both ends inside the steel casing
BH2D	8.10	5.13	25°47’24.75”S 29°27’51.7”E 1500 m	Equipped with 6 m long, 6.5” diameter perforated steel casing and 53 mm PVC plastic casing to depth, capped at both ends inside the steel casing
BH3D	5.42	Dry	25°47’26.6”S 29°27’42.8”E 1499 m	Equipped with 6 m long, 6.5” diameter perforated steel casing and 53 mm PVC plastic casing to depth, capped at both ends inside the steel casing
BH4S	1.60	Dry	25°47’19.4”S 29°27’40.5”E	Equipped with 53 mm PVC plastic casing to depth, capped at both ends

15.3.2. Hydrocensus

A hydrocensus was carried out, the aim being to determine other water sources within at least 1 km radius of the study area. The radius was however extended to more than 1 km with the aim of finding at least one or more boreholes upstream of the study area. A stream which runs in a northeasterly direction, situated downgradient of the study area, was also profiled during conduction of the hydrocensus (Figure 15-1).

Monitoring points were selected from upstream to downstream of the study area. A point was selected upstream of the two dams, one point just after the dams, next point adjacent to the study area and the other downstream from the study area. There are a few wetlands along the stream. These areas are completely vegetated and the grass is kept short by cutting frequently and left open, no visible infrastructure around the area

During conduction of hydrocensus, samples were collected from identified boreholes. However water levels could not be measured as the boreholes were already equipped with pumps. It was quite easy to find household with boreholes as they have signs at their gates marked “Boorgat” meaning boreholes. Table 15-2 presents a list of the hydrocensus boreholes and stream sampling positions as well as their locations relative to the study area. The hydrocensus boreholes and stream sampling positions were included in the monitoring programme. The boreholes importance became visible as one can compare deep aquifer water to shallow and they were as well used as backup for the monitoring, sampling of boreholes upstream and downstream of the study area when most of the boreholes within the cemetery were dry. Municipal water was also added to the sampling programme, water was collected from a tap located within the study area.

Table 15-2: Hydrocensus monitoring points.

Monitoring Position	Lat	Long	Elevation	Location
BH5A	-25.783151°	29.462501°	1479.91	About 1 km downgradient of study area to the south of the stream
BH14	-25.783451°	29.461277°	482.17	About 1 km downgradient of the study area and North of the stream
BH17	-25.786920°	29.469209°	1482.08	About 1 km downgradient of the study area and North of the stream
Mall BH	-25.805042°	29.458587°	1528.02	About 1.5 km Upgradient of study area
Athlone Dam	-25.799125°	29.446539°	1506.16	Upstream of Athlone and Kruger dam, upstream of all stream sampling points
Stream A	-25.790186°	29.454928°	1492.88	Upstream before the study area and just after the dams
Stream B	-25.786270°	29.459702°	1485.45	Adjacent to the study area
Stream C	-25.782308°	29.465152°	1476.01	Downstream After the study area
Mun1				Municipal Tap at study area

15.4. Results

15.4.1. Groundwater levels

Monitoring of the borehole water levels started in April 2016 and was done during every site visit using a dip metre. Figure 15-3 indicates the boreholes water level changes throughout the monitoring programme. Note that BH2D shows a clear pattern of changing water level with changing season as it never went dry and was drilled well below the water table. Most of the boreholes were dry as they were very shallow and drilled to a depth above the water table.

The groundwater levels are plotted together with the daily rainfall in to show the area's water table's response to rainfall or no rainfall. The recorded rainfall data is as expected for the area, with more rainfall in summer and less in winter.

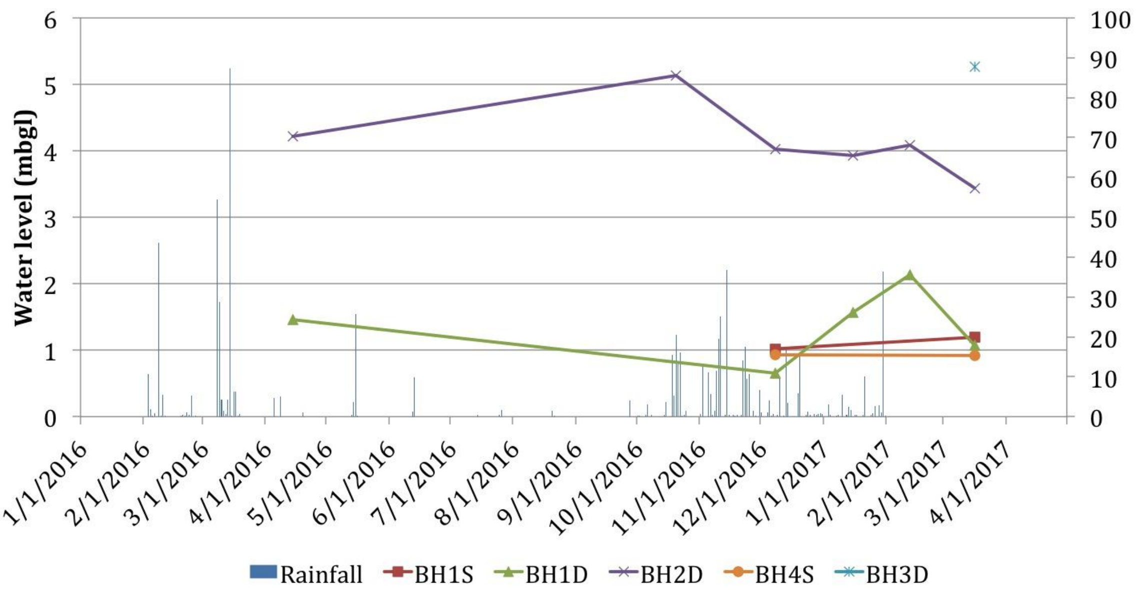


Figure 15-3: **Borehole water levels versus rainfall.**

15.4.2. Stream Water Depths

During sampling of the stream, the stream dimensions were measured at each sampling position and this included the depth to the riverbed. Figure 15-4 indicates the water depths measured for the three stream sampling positions. Note that the monitoring programme for the stream was only started during the rainy season in November; hence the data is presented from November 2016.

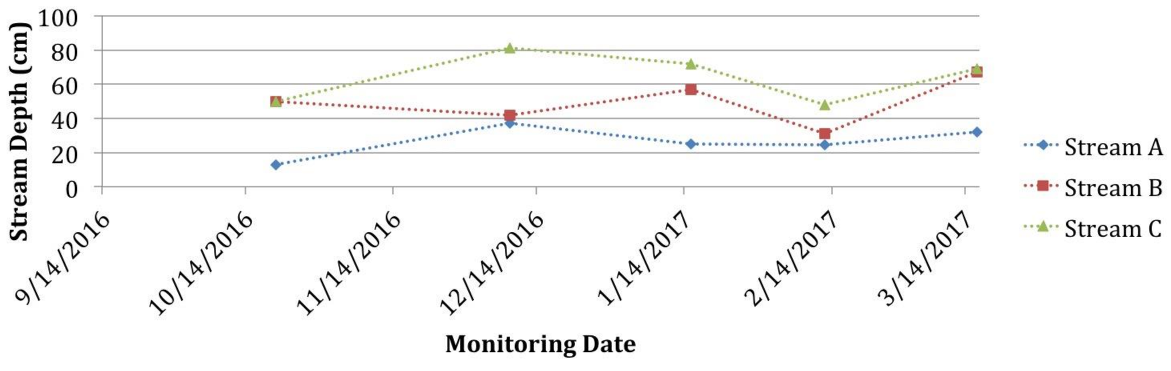


Figure 15-4: **Stream water depths.**

Figure 15-5 indicates a plot of stream water depths with rainfall. Note that the sampling points were downstream of two dams which are indicated as wetland areas. Thus the water quantity in the stream is controlled by both rainfall events and also what was coming from upstream, from the dams. Though there is a significant change in gradient from the cemetery area to the stream, the stream does not receive much runoff from upstream as the area is completely vegetated thus much highly induced infiltration which might slightly be hindered by the clayey soil in the area. There is however roads near the streams which induce runoff, with drains ending at the streams.

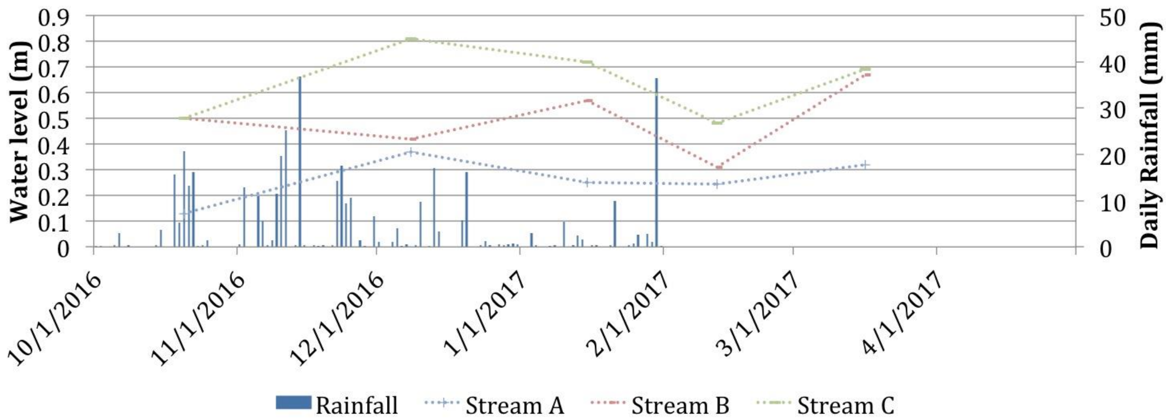


Figure 15-5: **Stream water quantity response to rainfall events and changing season**

15.4.3. Isotope Data – Deuterium and Oxygen-18

Water samples collected were analysed for general chemical parameters as well as isotope. This report will mainly highlight on results obtained from isotope analysis.

The following explains how the analyses of samples for deuterium and Oxygen-18 were carried out by the UKZN Centre for Water and Resources Research; the preparation and measurements are explained and the results obtained are presented;

Sample Preparation

Samples were shaken to equilibrate and 1.5 ml of each sample was pipetted into marked autosampler vials with a fresh pipette tip. The samples were then capped with septa and stacked into the autosampler tray. A set of three standards was placed in the autosampler tray before every 5 samples to be analysed as well as after the last 5-sample set. The six samples supplied were analysed in triplicate to assess the consistency of the analysis.

The standards used have been prepared by calibration against the following known standards: LGR2 (δ2H -117.00, δ18O -15.55), VSMOW2 (IAEA) (δ2H 0.0, δ18O 0.0) and IA-RO53 (IAD) (δ2H -61.97, δ18O -10.18). The accuracy of the standards calibration is presented in Figure 15-6.

Sample Measurements

The spectrum of the analyzer was verified and the sub-sampling of the autosampler programmed. Each sample and standard was sub-sampled and analysed 6 times using a Los Gatos Research (LGR) DT-100 Liquid Water Isotope Laser Analyser.

Sample Analysis

The LGR DT-100 analyser does not report δ values on a V-SMOW scale, but as 2H/H and 18O/16O ratios. Post processing therefore requires determining these ratios for the standards, developing a relationship between the known V-SMOW δ values and the measured ratios of the standards (Table 1-3) and then applying the relationship to the sub-sample measured ratios. Post processing checks included:

Temperature variation (rate of change was less than 0.3°C/hour and standard deviation for each measurement less than 0.004°C),

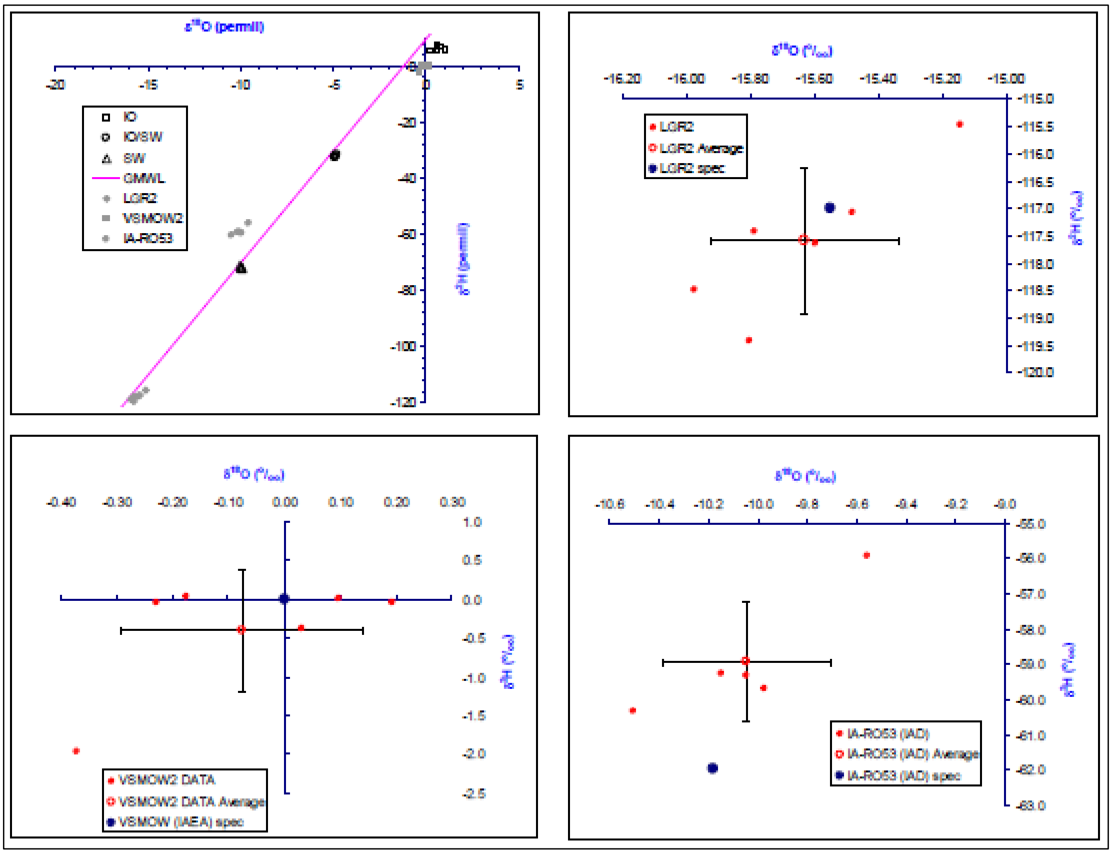


Figure 15-6: LGR – 100 Accuracy of standard preparations.

Sub-sample density (the density was between 2 to 4x1016 molecules/cm3 and standard deviation between measurements less than 1000 times smaller than the injected density),

Deviation of the 2H/H and 18O/16O ratios (Standard deviation of 2H/H ratio was less than 1000x smaller than measured ratio; 18O/16O was less than 3000x smaller than measured ratio).

Each sub-sample result is reported as the average and standard deviation of injections 3-6 of the 6 sub-sample determinations. The standard deviation of the 2H results was less than 1 (‰) and for the 18O samples, less than 0.25 (‰).

The data for deuterium and oxygen-18 analyses is presented in Table 15-3, showing the reported values and standard deviations. The results are also plotted in Figure 15-7 against the global meteoric water line.

Table 15-3: Water Samples: δ^2H and $\delta^{18}O$ analysis

Sample	Sample Name	Sampling Date	Analysis Date	δ^2H Reportable Value (‰)	δ^2H Standard Deviation (‰)	$\delta^{18}O$ Reportable Value (‰)	$\delta^{18}O$ Standard Deviation (‰)
1	BH14A	08/11/2016	18/11/2016	-9.26	0.58	-1.72	0.23
2	StreamB	20/10/2016	18/11/2016	11.80	0.31	1.74	0.12
3	Mall BH	08/11/2016	18/11/2016	-21.41	0.63	-3.61	0.07
4	StreamA	20/10/2016	18/11/2016	12.86	0.61	3.23	0.10
5	BH5A	08/11/2016	18/11/2016	-14.13	0.77	-2.25	0.19
6	BH2D	20/10/2016	18/11/2016	-14.51	0.73	-3.07	0.22
7	BH17	08/11/2016	18/11/2016	-10.35	0.20	-2.92	0.24
8	StreamC	20/10/2016	18/11/2016	11.33	0.78	0.79	0.22

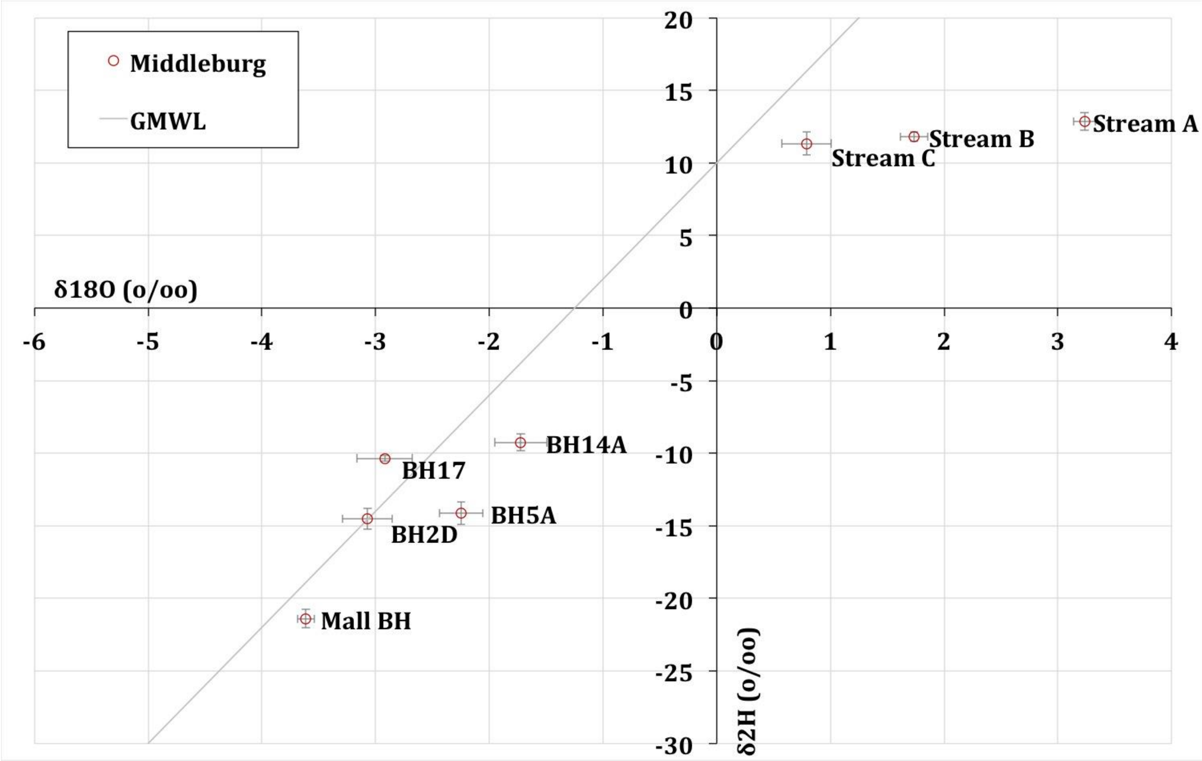


Figure 15-7: **Sample values vs. the global meteoric water line.**

Data quality control

The quality and accuracy of the obtained isotope data was checked and is presented in Table 15-4 and Figure 15-8.

Table 15-4: **LGR DT – 100 Standard checks.**

SBEEH STANDARD	Calibrated δ2H (‰)	Current run δ2H (‰)	Std Dev Current run δ2H (‰)	Calibrated 18O(‰)	Current run δ18O(‰)	Std Dev Current run δ18O(‰)
IO	-8.63	-8.30	0.50	-1.50	-1.53	0.11
IO/SW	-36.08	-39.74	1.00	-5.80	-5.75	0.18
SW	-72.58	-72.25	0.67	-9.93	-9.95	0.14

15.4.4. Results

When it rains, water hits the ground with a certain isotope composition of oxygen-18 and deuterium (δ18O and δ2H), some water infiltrates the ground, and some of it eventually recharges the groundwater while some evaporates from the surface and vadose zone. Some is transported to the nearest water bodies as runoff, through interflow or through groundwater-surface water interaction. During recharge to groundwater, mixing of old water and recently recharged water occurs, the same happens when groundwater feeds surface water or the other way around. A simple water cycle conceptual model of the study area is indicated by Figure 15-8. All these processes bring about changes in isotopic composition.

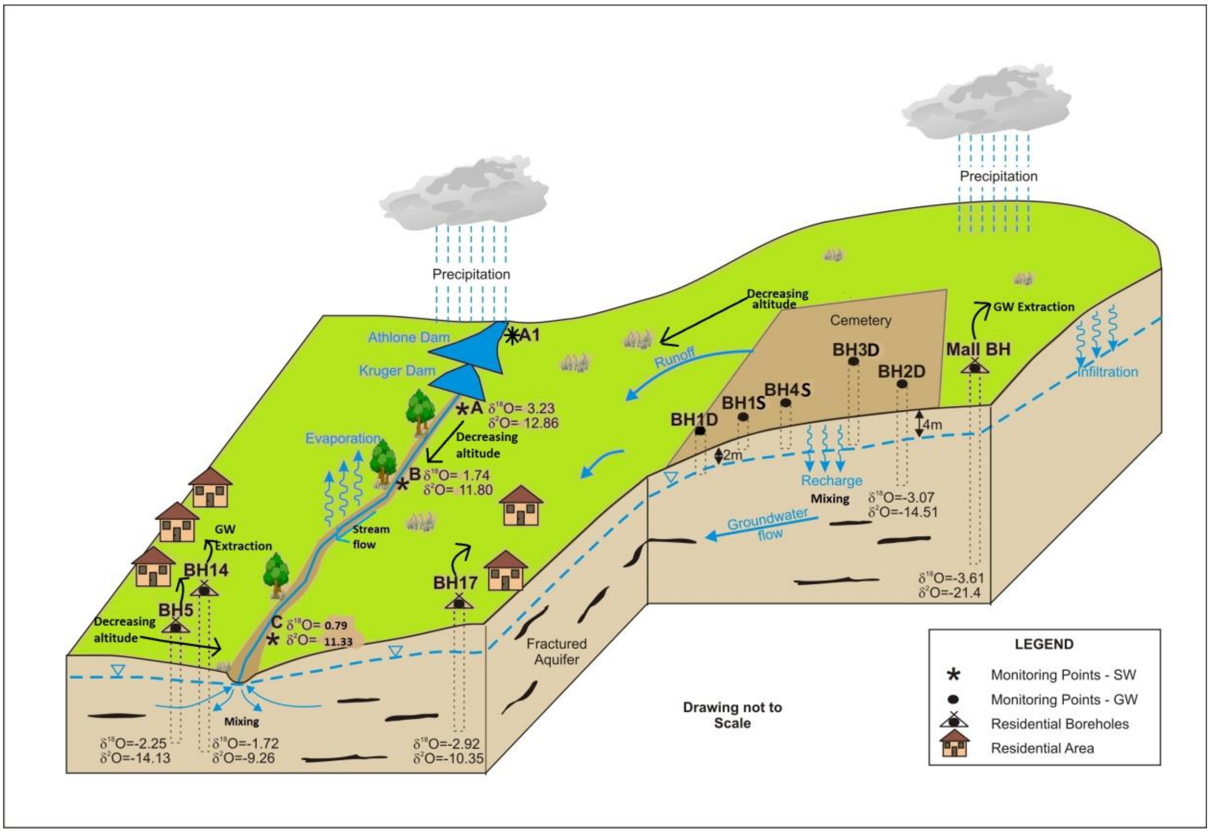


Figure 15-8: **Conceptual model of Fontein Street Cemetery indicating the changes in isotopic ratios within the water cycle (not to scale).**

Figure 15-9 indicates results obtained from the analysis of the stable water isotopes (deuterium and Oxygen-18). The results are explained as below.

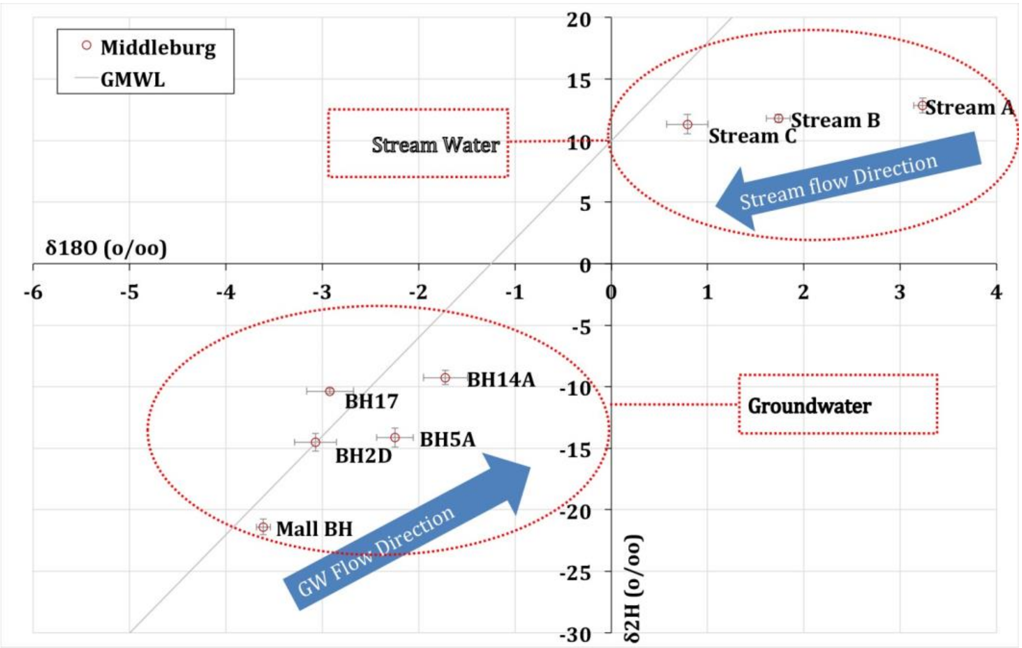


Figure 15-9: **Sample values vs. the global meteoric water line, also showing groundwater and stream flow directions.**

Removing of water from the system

Other processes that may usually result in isotopic changes are usually human induced, and one perfect example is pumping or removing water from the aquifer. From the hydrocensus that was carried out, it was found out that some people that have boreholes in their households are pumping water out of the aquifer. As mentioned in the above section, evaporation always occurs and this also is an example of removing water from the system, resulting in fractionation and thus isotope composition

Groundwater vs Surface water

The results in Figure 15-9 are clearly grouped as either groundwater or surface water. All results obtained from surface water samples plot in the 1st quadrant where both δ18O and δ2H are positive whereas results obtained from the analysis of groundwater samples plot in the 3rd quadrant where δ18O and δ2H are both negative.

This simply indicates that surface water is enriched with heavy isotopes while groundwater is depleted with heavy isotopes, reason being that the stream water is exposed to air and will continuously evaporate resulting in depletion in lighter isotope and increased concentration of heavy isotopes. The opposite is true for groundwater which is less exposed to the atmosphere and thus less prone to evaporation resulting in depleted concentration of heavy isotopes. This kind of arrangement is expected.

Figure 15-9 indicates the surface water flow direction and the changes in isotopic composition. Take note of how δ18O and δ2H isotopic composition changes as one moves from upstream where the sample indicates water enriched with heavy δ18O and δ2H isotopes to downstream where the water is depleted with δ18O and δ2H. This may either be depicting less evaporation due to trees around the sampling points or old groundwater feeding into the stream as one move downstream. The groundwater-surface water interaction may be confirmed by the fact that the depth to water table decreases as one moves downgradient towards the stream from the cemetery area. Note that the area itself is characterised by wetlands around the stream which gives high confidence that groundwater might be feeding into the stream.

The Global Meteoric Water Line

The Global Meteoric Water line (GMWL) is a line derived from precipitation data around the globe. Thus any sample that plots on or very close to this line may depict rainwater.

Precipitation is an ultimate source of groundwater. This enables the use of δ18O and δ2H a useful tool that can be used to trace water sources. Note that the boreholes sampled are of different depth as indicated in the data section. BH2D is the shallowest borehole which is about 8 metres deep while the depths of other hydrocensus boreholes are unknown, but expected to be deeper than 8 m. When rain hits the ground, its travel time to reach groundwater determines the changes in isotopic composition. Shallow water tables will more likely result in isotopic composition similar to that of rain. However, mixing with old water with a certain isotopic composition also occurs when rainwater recharges the groundwater, the amount of rain recharging will determine if the rain's isotopic composition will have a significant change in the groundwater isotopic composition.

The fact that BH2D is shallow and plots exactly on the GMWL makes sense as this borehole is very shallow, and water samples are collected at a very shallow depth as compared to other boreholes sampled. This thus indicates recently recharged water, which is more likely possibly dissolved with highly soluble components of the soil. This will however be confirmed by the chemical composition of the water sample collected.

Results for other boreholes indicate old water; that has been recharged a while ago.

More results will be provided in order to ensure statistically meaningful data and a better interpretation of changing isotopic composition due to processes involved in water transport and changing season.

15.5. Site Suitability Ranking

Using absolute best-case and worst-case scenario data acquired during the site investigation, the site can be ranked as unacceptable (mostly due to engineering or mechanical constraints) to very good for development as a cemetery (Box 12).

Shallow interflow and a proximate drainage channel contribute to possible water-related issues at the site. Proximate residential and commercial developments and the old municipal landfill upslope of the site may contribute to water quality issues.

Likely the biggest constraint on the suitability of the cemetery site is the development constraining possible future expansion of the site. Although very likely suitable for a cemetery in greenfields state, the site cannot expand further without infringing on the flood plains of the proximate drainage channel.

16. VZSA7: CAPE TOWN CENOZOIC SAND CEMETERIES CASE STUDY

Chantelle SCHMIDT, Elsie MPYE, Jana OLIVIER and Matthys A. DIPPENAAR

16.1. Motivation for Study

The Cape Town Cenozoic Sand Cemeteries is facing special issues with respect to drainage and stability of graves excavated in Cenozoic sand deposits. The Maitland, Welmoed and Delft cemeteries form part of this combined study, looking at the flow and contaminant transport through the unconsolidated sands.

The purpose of the study is to investigate the fate and transport of various contaminates within the Cape Flats Aquifer. Welmoed Cemetery was as contaminants are potentially not solely derived from the cemetery, but also possibly from proximate agricultural, industrial and animal-related industries.

Welmoed Cemetery is approximately 94 hectares in spatial extent and is located in Eerste Rivier (Western Cape) approximately 30 km east of Cape Town. A small piggery is situated directly to the north, and informal settlements are found further to the north. Agricultural land, predominantly vineyards, is found to the east, and the residential area Penhill Estate is located to the south. To the east of Welmoed Cemetery, along Van Riebeeck Road, is an industrial area comprising liquid petroleum gas storage and distribution and a vehicle transport and storage facility.

The final results are published in Mpye (2018) and Schmidt (2018).

16.2. Study Description

The topography is characterised by low relief, and the site slopes in a south-western direction with the eastern site boundary rising to approximately 55 mamsl and the south-western side dipping slightly to 35 mamsl.

The climate in Cape Town is described as Mediterranean, with wet winters and warm, dry summers. Climate is classified as Csa (warm temperature with hot, dry summers) by the Koppen-Geiger classification system (Peel et al., 2007). Temperatures average 10°C in winter to 27°C in summer. According to the quaternary catchments dataset for South Africa, the study area falls within the G22E Quaternary Catchment of the Water Management Area 19 (Berg). The mean annual precipitation (MAP) for the G22E Quaternary Catchment is approximately 563 mm (with most rainfall occurring during June, July and August) and the Simons Pan Mean Annual Evaporation is estimated as 1410 mm (WRC, 2012). Humidity in Cape Town averages at about 70% (DWA, 1996).

Collectively the accumulation of Cenozoic Sands, extending from the Cape Peninsula along False Bay inland towards Bellville and along Table Bay to Elands Bay, is known as the Cape Flats. These Cenozoic Sediments, deposited in fluvial, aeolian and shallow marine environments, form the Sandveld Formation and unconformably overlie the Malmesbury Group, Cape Granite Suite and Table Mountain Group basement rocks (Theron et al., 1992). The Cape Flats is an area of low relief, and at its boundaries where the Cenozoic sedimentary deposits are absent and the Table Mountain Group unconformably overlies the basement rocks (Seyler et al., 2016).

The unconsolidated Cenozoic sediments of the Sandveld group form what is known as the Cape Flats Aquifer. The Cape Flats Aquifer is a primary intergranular aquifer which is almost wholly saturated as groundwater levels are within a few metres of the ground level. In certain cases the water table intersects the ground surface forming wetlands or marsh/vlei areas (DWAF, 2008).

The Elandsfontyn, Springfontyn and Witzand Formations form the major aquifer within the Cape Flats Aquifer and the hydraulic nature of these aquifers depend on scale. The Elandsfontyn Formation may be confined or semi confined by the clayey deposits above it; whereas the Varswater Formation may be confined to semi-confined by the calcrete of the Langebaan Formation. The Springfontyn Formation may be semi confined by local clay/peat lenses within it and the Witzand Formation is considered as an unconfined aquifer (DWAF, 2008). The unconfined nature of these aquifers makes them more susceptible to surface pollution (Browning and Roberts, 2015). The distinction of separate hydraulic units at a regional scale depends on the lateral continuity of the particular confining beds (peats, clays, calcretes layers) (Seyler et al., 2016). During soil profiling done on the study area it was confirmed that the clay lens is not continuous and occurs at different depths within the soil profile resulting in a heterogeneous character within the aquifer. Essentially the aquifer is made up of two portions: the upper perched aquifer above the clay lens and beneath this the main aquifer. Water samples collected will thus represent only the perched water system.

16.3. Data Acquisition

Characterisation of Welmoed Cemetery entailed the following (further elaboration in Schmidt, 2018 and Mpye, 2018):

- Site walkover, followed by soil profiling and soil sampling from hand auger holes
- X-Ray Fluorescence Spectroscopy (XRF) and X-Ray Diffraction analyses
- Double Ring Infiltration and Soil Percolation testing
- Hydrocensus for proximate baseline water quality and levels
- Frequent sampling of an on-site monitoring network established during the field work phases.
- Hydrocensus positions are shown and described in Figure 16-1 and Table 16-1.

Welmoed Cemetery is shown in Figure 16-2 and Table 16-2. A number of sampling sites were identified for sampling and field hydraulic testing. As the cemetery is still being developed, access to all portions was not possible.

Table 16-1. Hydrocensus results around Welmoed Cemetery (City of Cape Town).

Locality ID	Co-ordinates	Collar Height (m)	Groundwater Level (mbCH)	Groundwater Level (mbsl)	Surface Elevation (mamsl)	Additional Information
Onze Rust	33° 58' 15.92"S 18° 44' 43.12"E	0	0.6	0.6	96	Wetland and spring on farm. Very shallow groundwater level.
Onze Rust-Spring	33° 58' 16.46"S 18° 44' 43.12"E	n/a	0		95	
Reyneke Wines	33° 57' 17.56"S 18° 45' 4.91"E	0	25.65	25.65	195	One borehole on farm.
59 Herbert Penny Rd	33° 59' 44.27"S 18° 44' 5.83"E	0.2	7.25	7.05	50	
Palm Parks Primary School	33° 59' 44.51"S 18° 43' 10.17"E	0	5.98	5.98	29	Two boreholes on school property, access to one.
Malibu High School	33° 59' 41.88"S 18° 41' 43.25"E				60	Borehole on school ground but no access as borehole is sealed off.
Stratford Primary School	34° 0' 24.6"S 18° 43' 41.05"E				24	Borehole on school ground but no access as borehole is sealed.
Delmonte Hall	33° 58' 5.53"S 18° 42' 19.33"E				60	No access.
Begonia Road	33° 57' 46.25"S	0	1.5	1.5	61	Hand dug pit/ well

	18° 42' 6.7"E					

Figure 16-1. **Hydrocensus positions at the Welmoed Cemetery (City of Cape Town).**

Figure 16-2. **Locality and sampling positions at the Welmoed Cemetery (City of Cape Town).**

Table 16-2. Sampling positions at the Welmoed Cemetery (City of Cape Town).

Locality	Co-ordinates	Description
		Downstream Piggery
WWP8	33° 59’ 08.34” S 18° 43’ 17.18” E	Located on the northern border of Welmoed cemetery, south-west downstream of the piggery.
WC4	33° 59’ 05.31” S 18° 43’ 26.17” E	Located on the northern border of Welmoed cemetery, downstream on the piggery.
DSP	33° 59’ 02.42” S 18° 43’ 31.04” E	Located on the northern border of Welmoed cemetery, downstream on the piggery.
		Downstream Agricultural Land
WWP6	33° 58’ 55.63” S 18° 43’ 47.57” E	Located on the top northern corner of Welmoed Cemetery downstream of agricultural land.
DSA	33° 59’ 4.05” S 18° 43’ 44.93” E	Located on the northern end of Welmoed Cemetery south of locality WWP6, downstream of agricultural land.
		Central Cemetery and Downstream Burial Ground
EM1	33° 59’ 17.81” S 18° 43’ 22.79” E	On the western boarder of Welmoed Cemetery, downstream of the first portion of burial ground currently at capacity.
EM2	33° 59’ 16.71” S 18° 43’ 21.33” E	On the western boarder of Welmoed Cemetery, downstream of the first portion of burial ground currently at capacity.
CCPW2	33° 59’ 11.00” S 18° 43’ 28.30” E	Downstream of sampling locality WD4 and DSP and upstream of EM1 and EM2.
		Downstream Welmoed Cemetery
DSC	33° 59’ 21.05” S 18° 43’ 28.47” E	Located on the western end of Welmoed Cemetery and represents water exciting the cemetery.
PHW	33° 59’ 29.45” S 18° 43’ 31.75” E	Located downstream of Welmoed Cemetery within Penhill Estate.
DDD	33° 59' 22.15" S 18° 43' 8.63" E	Located to the southwest of Welmoed Cemetery, downstream of the industrial area.

During each quarterly sampling excursion, field parameters pH, EC, TDS and temperature were recorded using a multi-parameter meter. The existing boreholes, WWP8 and WWP6, were dry during the April 2017 to January 2018 sample runs. During April 2017, localities CCPW2 and DSC were dry. Locality DDD was installed in July 2017 but was destroyed in October 2017. The remaining localities were all successfully sampled.

16.4. Results

16.4.1. Field observations

An initial three hand auger holes were excavated prior to installation of the monitoring network. Field observations are detailed in Table 16-3. Water levels, if encountered, are at very shallow levels, although it is not possible at this stage to infer whether it represents a shallow phreatic system or a shallow perched system.

Table 16-3. Field observations at W1, W2 and W3 (Welmoed Cemetery).

	Site W1	Site W2	Site W3
Borehole depth (m)	2.3	1.76	2.37
Stabilized water level (m)	-	0.9	1.15
Comment	Water table was not reached. Auger hole collapsed below the casing at 2.3 m.		

16.4.2. Soil profile descriptions

Soil profiles as described on-site are shown in Figure 16-3 to Figure 16-5. Materials were generally described as sands with shallow water levels (1-2 m depth) encountered in profiles B and C.

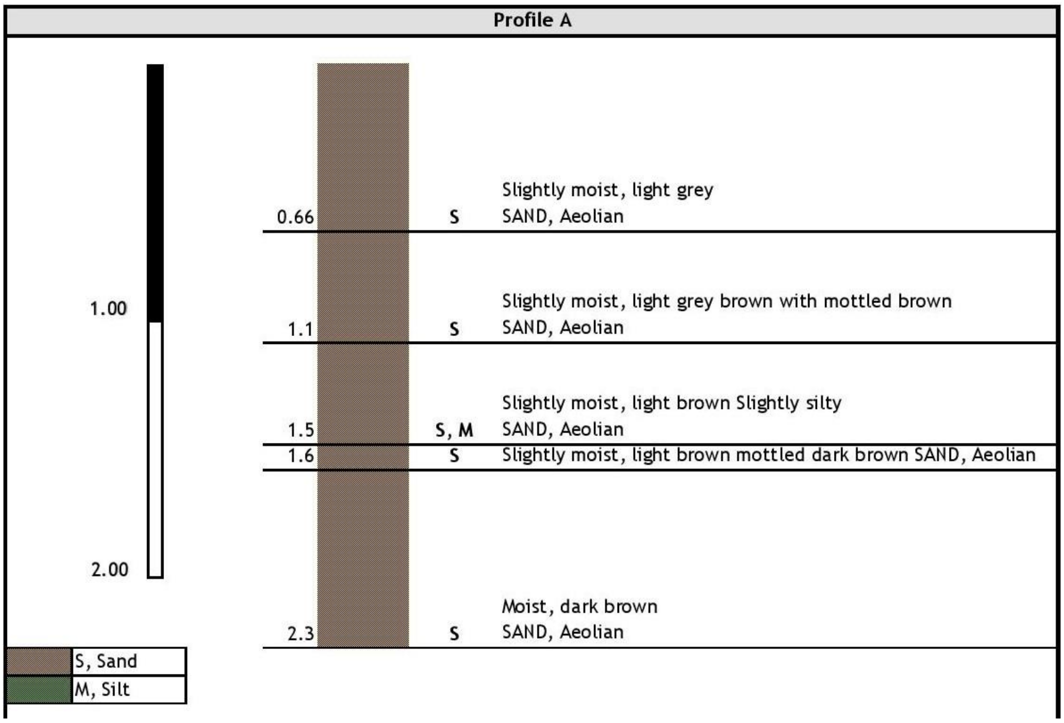


Figure 16-3. **Welmoed soil profile A.**

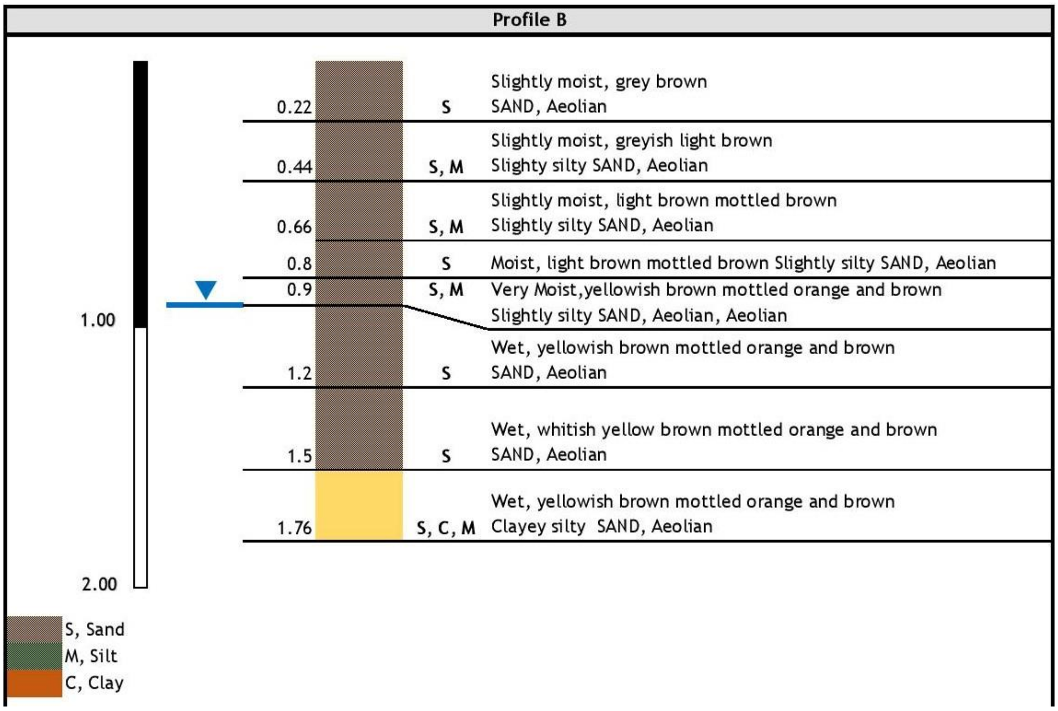


Figure 16-4. **Welmoed soil profile B.**

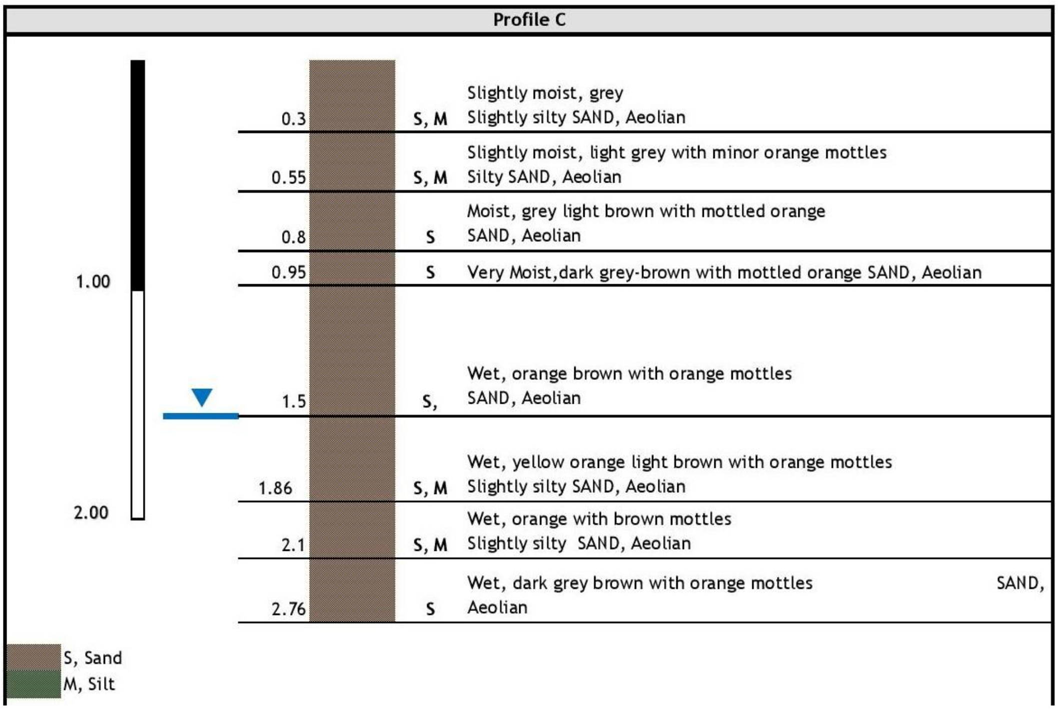


Figure 16-5. **Welmoed soil profile C.**

16.4.3. Analytical results: field hydraulic

Results of percolation tests conducted until steady-state conditions are shown in Table 16-4 and Figure 16-6. Infiltration rates are roughly in the order of 3 x 10-7 to 1 x 10-7 m/s. Under the assumption that tests have reached saturation, and that flow is solely in a vertical direction under a hydraulic gradient of one, this implies a hydraulic conductivity of roughly 1 x 10-7 m/s. As it is understood that tests never truly reach full saturation, especially in sandy soils, this is taken as a lower-than-maximum possible hydraulic conductivity, and is understood to be relevant as a percolation rate, but not as a saturated hydraulic conductivity.

Table 16-4. **Double ring infiltration test results: Welmoed Cemetery.**

	dh (mm)	**10**	**20**	**30**	**40**	**50**
Test 0	Time per interval (s)	36.64	42.57	41.38	42.5	49.32
	Cumulative time (s)	36.64	79.21	120.59	163.09	212.41
	Infiltration Rate (m/s)	2.35E-07				
Test 1	Time per interval (s)	38.47	51.36	52.46	56.18	61.04
	Cumulative time (s)	38.47	89.83	142.29	198.47	259.51
	Infiltration Rate (m/s)	1.93E-07				
Test 2	Time per interval (s)	85.26	84.42	88.66	99.53	105.99
	Cumulative time (s)	85.26	169.68	258.34	357.87	463.86
	Infiltration Rate (m/s)	1.08E-07				

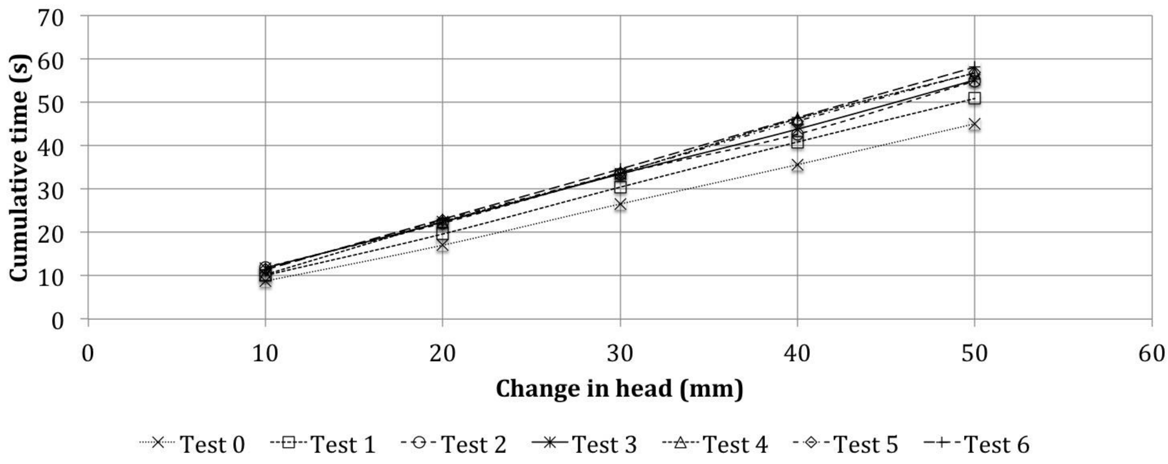


Figure 16-6. Double ring infiltration test results: Welmoed Cemetery.

Results of percolation tests conducted until steady-state conditions are shown in Table 16-5 and Figure 16-7. Percolation rates are roughly in the order of 8 x 10-7 to 1 x 10-6 m/s. Under the assumption that tests have reached saturation, and that flow is solely in a vertical direction under a hydraulic gradient of one, this implies a hydraulic conductivity of roughly 1 x 10-6 m/s. As it is understood that tests never truly reach full saturation, especially in sandy soils, this is taken as a lower-than-maximum possible hydraulic conductivity, and is understood to be relevant as a percolation rate, but not as a saturated hydraulic conductivity.

Table 16-5. Percolation test results: Welmoed Cemetery.

	dh (mm)	10	20	30	40	50
Test 0	Time per interval (s)	8.71	8.32	9.49	9.08	9.41
	Cumulative time (s)	8.71	17.03	26.52	35.6	45.01
	Percolation rate (m/s)	1.11E-6				
Test 1	Time per interval (s)	10.06	9.55	10.79	10.41	10.03
	Cumulative time (s)	10.06	19.61	30.4	40.81	50.84
	Percolation rate (m/s)	9.83E-7				
Test 2	Time per interval (s)	11.94	10.17	11.34	9.16	12.26
	Cumulative time (s)	11.94	22.11	33.45	42.61	54.87
	Percolation rate (m/s)	9.11E-7				
Test 3	Time per interval (s)	11.79	10.59	11.06	10.34	11.31
	Cumulative time (s)	11.79	22.38	33.44	43.78	55.09
	Percolation rate (m/s)	9.08E-7				
Test 4	Time per interval (s)	10.27	12.18	11.26	12.46	10.57
	Cumulative time (s)	10.27	22.45	33.71	46.17	56.74
	Percolation rate (m/s)	8.81E-7				
Test 5	Time per interval (s)	11.47	11.33	10.96	11.87	11.14
	Cumulative time (s)	11.47	22.8	33.76	45.63	56.77
	Percolation rate (m/s)	8.81E-7				
Test 6	Time per interval (s)	11.37	11.68	11.53	11.86	11.64
	Cumulative time (s)	11.37	23.05	34.58	46.44	58.08
	Percolation rate (m/s)	8.61E-7				

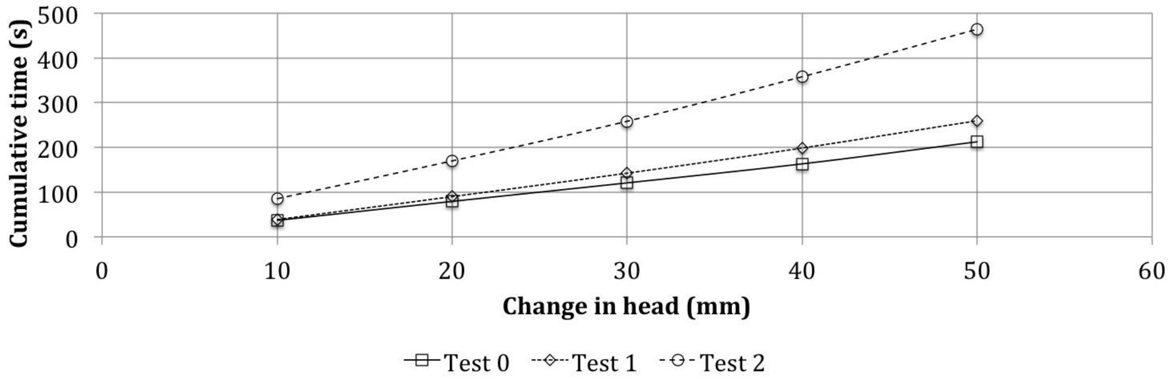


Figure 16-7. **Percolation test results: Welmoed Cemetery.**

16.5. Site suitability ranking

Using absolute best-case and worst-case scenario data acquired during the site investigation, the site can be ranked as unacceptable (mostly due to shallow water seepage and expected excavation instabilities) to satisfactory for development as a cemetery (Box 12).

Shallow interflow and a proximate drainage channel contribute to possible water-related issues at the site. Proximate residential and commercial developments and the old municipal landfill upslope of the site may contribute to water quality issues.

Likely the biggest constraint on the suitability of the cemetery site is the development constraining possible future expansion of the site. Although very likely suitable for a cemetery in greenfields state, the site cannot expand further without infringing on the flood plains of the proximate drainage channel.

17. VZSA8: MICROBIOLOGICAL STUDIES OF SELECTED STUDY SITES

Eunice UBOMBA-JASWA and Akebe L. K. ABIA

17.1. Motivation for Study

Monitoring the changes in microbial communities as well as the presence or absence of pathogens in soil samples from cemeteries, can serve as an early warning system of the possible negative impacts of cemeteries on the environment, groundwater, grave diggers and cemetery workers. The microbial content of soil is a reflection of a number of parameters including land use activity, which cause subtle changes over time in microbial populations. High through put screening provides an opportunity to conduct detailed microbial community analysis of cemetery soil samples and associated water bodies to determine if the same organisms are identified in both water and soil as well as if there are relationships between sampling depth (surface and burial) and microbial composition.

17.2. Study Description

The microbiological component of this work consisted in investigating if cemeteries could contribute to the pollution of groundwater. The experiments in this section consisted of culture and molecular (metagenomics). Study sites included those previously discussed, viz. Fontein Street Cemetery the Cape Town Cenozoic Sands Cemeteries study.

17.3. Data Acquisition

17.3.1. Sample collection

Water and soil samples were collected from four cemeteries. The Fontein Street Cemetery located in Middelburg (Mpumalanga) and three cemeteries in Cape Town (Western Cape), namely, Delft, Maitland and Welmoed.

Soil Sampling

Soil samples were collected at the surface and at a depth of 2 m. At the Middelburg Cemetery, samples were collected from three points – uphill from the cemetery (UP), around the centre of the cemetery (MID) and downhill from the cemetery (LOW). Here, soil was extracted using an industrial drill. At the Maitland Cemetery, the soil was extracted using a hand augur. A borehole was drilled using the augur until the water table was met. The auger was emptied of soil at different depths of the boreholes. For microbial analysis the auger was emptied at the surface and at 2 m from six points – MS1, MS2, MS3, MS5, MS6 and MS7. The samples were aseptically collected, placed in sterile zip lock bags and transported to the laboratory for processing and analysis.

Water sampling

Water samples were only collected from the cemeteries located in Cape Town. Samples were collected in triplicate from hand augured boreholes as well as from wetlands (labelled as W Dam) located in the cemeteries. Once the boreholes were augured and the water level was consistent in the hole, a bailer was used to bail water out of the borehole and water was then collected in sterile 500 mL plastic bottles and transported to the laboratory in cooler boxes for analysis.

17.3.2. Enumeration of Escherichia coli from water samples

Escherichia coli was enumerated using the colilert® 18 Quanti-Tray® 2000 system (IDEXX, SA) following the manufacturer's instruction. Prior to analysis, the sampling bottle was inverted several times to allow proper mixing of the water sample. Each water sample (100 mL) was mixed with the Colilert® 18 reagent, allowed to stand until complete dissolution of the reagent and was then transferred into a Quanti-Tray® 2000. The trays were sealed using the Quanti-Tray® sealer and then incubated at 37˚C for 18-24 h. Plates were examined under UV and wells that fluoresced were recorded and the Most Probable Number (MPN) of E. coli in the sample inferred from the statistical table provided with the Colilert® 18 reagent and recorded as the Most Probable Number per 100 mL (MPN/100 mL).

17.3.3. DNA extraction and Metagenomic analysis of soil samples

Only soil samples were analysed for microbial diversity using metagenomics. Total DNA was extracted from the soil samples using the ZR Soil Microbe DNA MicroPrep™ (Zymo Research Corp., Irvine, U.S.A.) following the manufacturer's instructions. The pure DNA was then sent to Inqaba Biotechnology, Pretoria, for next generation sequencing.

17.4. Results

17.4.1. Enumeration of E. coli

The results obtained for the E. coli data are shown in Table 17-1. All E. coli counts <1 were considered as 0. Less than half of the sample sites (7/16; 43.75%) were positive for E. coli. The highest mean E. coli count (2419.6 MPN/100 mL) was recorded in water samples from Maitland (MD3 and MD4).

17.4.2. Metagenomic analysis of soil samples

Fontein Street Cemetery (Mpumalanga)

The various taxonomic groups were not equally distributed amongst the various sample sites. Figure 17-1 shows the distribution of the most detected group in each taxon.

Table 17-1. Mean *E. coli* count for water samples collected at the Cape Town Cemeteries.

Cemetery	Sample Site	Depth (m)	Replicate samples (MPN/100 mL) 1	2	3	Geometric mean (MPN/100 mL)	Standard Deviation
Delft	DM1	3.1	0	0	0	0.0	0.0
	DW1	na	0	0	0	0.0	0.0
Maitland Wetlands	MD1	na	1	1	4.1	1.6	1.8
	MD2	na	1	4.1	1	1.6	1.8
	MD3	na	2419.6	2419.6	2419.6	2419.6	0.0
	MD4	na	2419.6	2419.6	2419.6	2419.6	0.0
Maitland Boreholes	MM1	1.7	0	0	0	0.0	0.0
	MM2	2.8	0	0	0	0.0	0.0
	MM4	3.9	0	0	0	0.0	0.0
	MM5	2.5	0	0	0	0.0	0.0
	MM6	2	9.7	18.7	8.4	11.5	5.6
	MM7	2.7	0	0	0	0.0	0.0
	MM8	2.3	8.6	3.1	5.2	5.2	2.8
Welmoed	WD1	2.3	65.7	86.5	42	62.0	22.3
	WM2	1.8	0	0	0	0.0	0.0
	WM3	2.4	0	0	0	0.0	0.0

Maitland Cemetery (Cape Town)

Like the Fontein Street Cemetery, the various taxonomic groups in the Maitland samples were not equally distributed amongst the various sample sites (Figure 4).

17.5. Discussion

The overall aim of the microbial component of this work was to investigate the possible impact that cemeteries could have on the microbial quality of groundwater and to infer the possible health threats this may pose to humans.

17.5.1. Enumeration of E. coli

Escherichia coli is a well-known organism that has been used as an indicator of pollution in water and soils (Ashbolt, et al., 2001; Harwood et al., 2005; Horman et al., 2004). Also, E. coli is said to be an index (indicative of the presence) for Salmonella (Ashbolt et al., 2001). Similarly, Abia et al., found that there was a correlation between the abundance of E. coli and the presence of other pathogens like Salmonella sp., Shigella sp. and Vibrio cholerae in riverbed sediments (Abia et al., 2016). Although high levels of E. coli were detected at some of the sites in the present study (Table 1), conclusions could not be drawn regarding the possible presence of other pathogens because sampling was done only on a single day. Nevertheless, it is interesting to realise that E. coli was detected in water samples collected at depths of 2.3 m which is deeper than the burial depth of 1.8 m. This could imply the possible movement of microorganisms from decaying bodies down into surrounding groundwater bodies especially in areas like Maitland where water was detected at depths of 1.7 m (< 1.8 m). This hypothesis was not tested in the present study but could however be achieve by carrying out tracer studies.

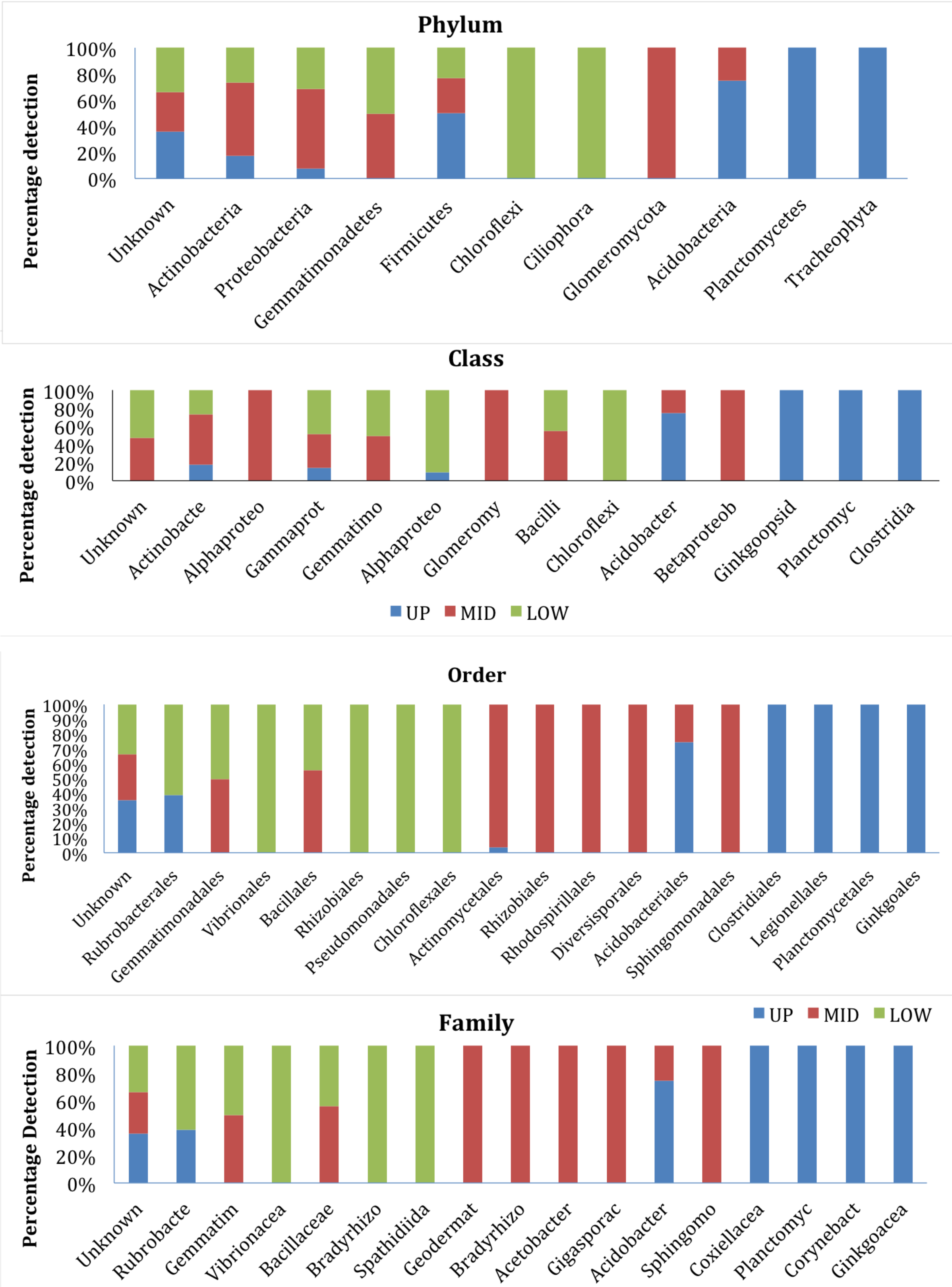


Figure 17-1. **Distribution of the most detected members in each taxon (up to the Family level) for the Middelburg cemetery samples.**

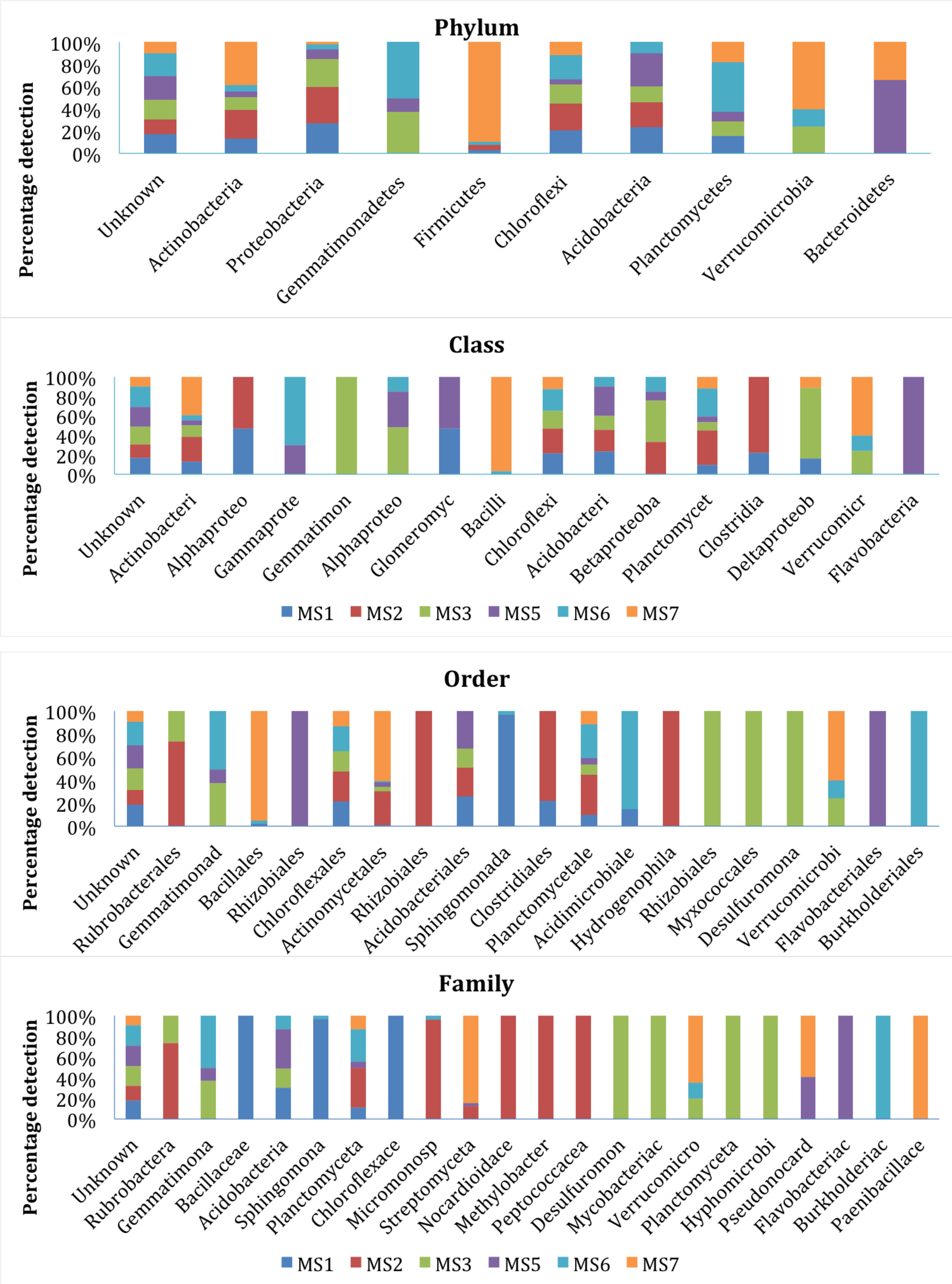


Figure 17-2. **Distribution of the most detected members in each taxon (up to the Family level) for the Maitland cemetery samples.**

17.5.2. Metagenomic analysis of soil samples

Metagenomics has been used in many fields of science including medicine (Padmanabhan et al., 2013). It is a culture-independent approach to determine the microbial diversity of microorganisms within a given system, something that would not be otherwise achieved through culture and conventional molecular techniques (Daniel, 2005). In the current study, we used metagenomics to check for the presence of potentially pathogenic microorganisms (bacteria) in cemetery soils.

Results obtained in the current study revealed that the microorganisms in the samples collected were very diverse (Figure 17-1 and Figure 17-2). Also, at the surface, there was an increase in microbial population with a decrease in altitude. This could be due to surface runoff during rainfall, which results in the accumulation of more organisms and nutrients at the lower points.

Microorganisms have been found at depths going up to 3800 m below soil surface levels (Das, 2011; Murugesan et al., 2012). A rich microbial diversity was also found at a depth of 2 m for both cemeteries. This depth is approximately the burial depth of 1.8 m. Of importance is the fact that some of the microorganisms isolated have also been found to be of clinical importance.

Mycobacterium tuberculosis, the causative agent of tuberculosis in humans was identified in samples collected at 2 m depth especially in the Maitland Cemetery (Cape Town). Other organisms found to cause human infections that were identified in these samples include (but not limited to): Acinetobacter nosocomialis, Campylobacter ureolyticus, Streptococcus parasanguinis, Yersinia pesti. The presence of these organisms at burial depth could signify the possibility of these organisms finding themselves in groundwater sources (although this was not tested in this study). Further analysis on the data will include phylogenetic relationships between the organisms detected at the various sites and at the various depths.

SECTION G: BIBLIOGRAPHY

18. BIBLIOGRAPHY

18.1. Formal Bibliography

Aller, L., Bennett, T., Lehr, J.H., Petty, R.J. & Hackett, G. (1987). DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeological settings. US Environmental Protection Agency. EPA/600/2–87/036. 622 pp.

Anat, J. (1993). An improved composition for embalming fluid to preserve cadavers for anatomy. 182:295-297.

Ashton, P.J. & Ramasha, V. (2002). Water and HIV/AIDS: Some strategic considerations in South Africa. In: Turton AR & Henwood R. (eds.) Hydropolitics in the Developing World: A Southern African Perspective. African Water Issues Research Unit (AWIRU). Pretoria: 217-235.

Bartley, A. (2009). A Lucian for our Times. England. Cambridge Scholars Publishing.

Berg, S., Mueller, B. & Schleyer, F. (1975). Leichenveränderungen, Todeszeitbestimmung im frühpostmortalen Intervall: Leichen-zersetzung und -zerstörung. In: Mueller, B. (ed.) Gerichtliche Medizin. Springer, Berlin Heidelberg New York. pp 45-106 (cited from Fiedler and Graw 2003)

Bern-Klug, M., Ekerdt, D. & Wilkinson, D.S. (1999). What Families Know about Funeral-Related Costs: Implications for Social Workers. Health and Social Work. 24(2):128-137.

Best Available Science. (2004). Critical aquifer recharge areas. Executive report. Vol. 1 Chapter 6.

Bhattaria, J. (2013). Study on the corrosive nature of soil towards the buried-structures. Scientific World. 11(11): 43-47.

Bitton, G., Farrah, S.R., Ruskin, R.H., Butner, J. & Chou, Y.J. (1983). Survival of pathogenic and indicator organisms in groundwater. 21(4):405-410.

Brouwers, L.B. (2017). Geotechnical Centrifuge Modelling of Variably Saturated Flow at The Soil-Rock Interface. MSc dissertation (unpublished). University of Pretoria, South Africa.

Brouwers, L.B. & Dippenaar, M.A. (2018). Partially saturated flow from sand into a discrete smooth open vertical fracture at the soil-rock interface: experimental studies. Bulletin of Engineering Geology and the Environment. DOI 10.1007/s10064-018-1258-x

Carter, D.O., Yellowlees, D. & Tibbett, M. (2007). Cadaver decomposition in terrestrial ecosystems. Naturwissenchaften. 94:12-24.

Cooney, K.M. (2013). The functional materialism of death in ancient Egypt: A case study of funerary materials from the Ramesside period. IBAES VII Das Heilige und die Ware. 273-299.

Cottle, R.K. (1997). Cemetery siting in the bluestone reservation area. Unpublished Master's Thesis, Virginia Tech, United States of America. scholar.lib.vt.edu/theses/available/etd-61497-121752/unrestricted/Etd.pdf

Croucamp, L. & Richards, N. (2002). Guidelines for Cemetery Site Selection. Council for Geoscience. Pretoria.

Daldrup, T. (1979). Postmortaler Eiweisszerfall in menschlichen Organen: Reaktionen und zeitliche Zusammenhänge. PhD thesis, Rheinisch-Westfälische, Aachen. (cited from Fiedler and Graw 2003).

Dent, B.B. (n.d). Vulnerability and the unsaturated zone – The Case for Cemeteries. www.science.uts.edu.au/des/StaffPages/BoydDent/anchor_story.html) [Accessed 11 December 2007]

Dent, B.B. & Knight, M.J. (1998). Cemeteries: a Special Kind of Landfill. The Context of their Sustainable Management. Proceedings: Groundwater: Sustainable Solutions (International Association of Hydrogeologists, Melbourne, February 1998):451-456.

Dent, B.B., Forbes, S.L. & Stuart, B.H. (2004). Review of human decomposition processes in soil. Environmental Geology. 45:576-585.

Development Works. (2005). Spatial planning, land development and land use management in context of HIV and AIDS. Prepared for the South African Cities Network.

Deviese, T., Ribechini, E., Baraldi, P., Farago-Szekeres, B., Duday, H., Regert, M. & Colombini, M. (2011). First chemical evidence of royal purple as a material used for funeral treatment discovered in Gallo-Roman burial (Niantré France, third century AD). Anal Bioanal Chem. 401:1739-1748.

Dippenaar, M.A. (2014). Towards a multi-faceted vadose zone assessment protocol: cemetery guidelines and application to a burial site located near a seasonal wetland (Pretoria, South Africa). Bulletin of Engineering Geology and the Environment. 73(4):1105-1115.

Dippenaar, M.A. & Van Rooy, J.L. (2018). Vadose zone characterization for hydrogeological and geotechnical applications. Proceedings: AEG (Association of Environmental and Engineering Geologists) Annual Meeting/ XIII IAEG (International Association of Engineering and Environmental Geologists) Congress. Volume 2: Geotechnical and Environmental Site Characterization. 17-21 September 2018. San Francisco.

Dippenaar, M.A, Van Rooy, J.L., Breedt, N., Huisamen, A., Muravha, S.E., Mahlangu, S. & Mulders, J.A. (2014). Vadose Zone Hydrology: Concepts and Techniques. WRC Report No. TT 584/13. Water Research Commission. Pretoria. 174pp.

Dixon, B. (2005). Groundwater vulnerability mapping: A GIS and fuzzy rule based integrated tool. Applied Geography. 25(4):327-347.

Edwards, H., Villar, S., David, R. & De Faria, D. (2004). Nondestructive analysis of ancient Egyptian funerary relics by Raman spectroscopic techniques. Analytica Chemica Acta. 503:223-233.

Engelbrecht, J. (2000). Groundwater Pollution from Cemeteries. CSIR. Pretoria.

Engelbrecht, J.F.P. (1998). Groundwater pollution from cemeteries. In: Proceedings of the Water Institute of South Africa (WISA) Biennial Conference. Vol 1. Session 1C-3. Cape Town, 4-7 May 1998.

Fiedler, S., Breuer, J., Pusch, C.M, Holley, S., Wahl, J., Ingwersen, J. & Graw, M. (2012). Graveyards – special landfills. Sci. Total Environ. 419:90-97.

Fiedler, S., Dame, T. & Graw, M. (2018). Do cemeteries emit drugs? A case study from southern Germany. Environmental Science and Pollution Research. 25(6): 5393-5400.

Fiedler, S. & Graw, M. (2003). Decomposition of buried corpses, with special reference to the formation of adipocere. Naturwissenschaften. 90:291-300.

Fineza, A.G., Marques, E.A.G., Bastos, R.K.X. & Betim, L.S. (2014). Impacts on the groundwater quality within a cemetery area in southeast Brazil. Soils and Rocks. 37(2):161-169.

Fisher, G. (1992). Selection Criteria for the Placing of Cemetery Sites. Geological Survey of South Africa. Johannesburg.

Fisher, G. (1994). The Selection of Cemetery Sites in South Africa. Proceedings: 4th Terrain Evaluation and Data Storage Symposium. Midrand.

Fisher, G. & Croucamp, L. (1993). Groundwater Contamination and its Consequences resulting from the Indiscriminate Placing of Cemeteries in Third World Context. Vol 1: Africa needs Groundwater Convention. (Vol. 1). Johannesburg.

Fisher, J.J. (2001). The selection of cemetery sites in South Africa. Council for Geoscience Report No. 2001-0040. Council for Geoscience, Port Elizabeth.

Forbes, G.B. (1987). Human body composition; growth, aging, nutrition, and activity. Springer-Verlag. New York. 380pp.

Ford, T.E. (1999). Microbiological Safety of Drinking Water: United States and Global Perspectives. Environmental Health Perspectives. 107(Supplement 1).

Fraust, D.G. (2008). This Republic of Suffering: Death and the American Civil War. New York: Alfred A. Knopf.

Gondal, M., Nasr, M., Ahmed, M., Yamania, Z. & Alsalhid, S. (2011). Detection of lead in paint samples synthesized locally using laser-induced breakdown spectroscopy. 46, 42-49.

Goodman, J. (2006). Arsenic and old graves. Water and Waste Water Products. 6 (5) www.motherjones.com/news/outfront/1990/01/cook.htm

Grover, S. (2014, July 7). Leave a lighter footprint: green funeral and burial tips. Olney, United Kingdom: Treehugger.

Guttman, S., Watson, J. & Miller, V. (2012). Til Death Do We Pollute, and Beyond: The Potential Pollution of Cemeteries and Crematoriums. UK: Trent University.

Hall, B.H. and Hanbury, R. (1990). Some Geotechnical Considerations in the Selection of Cemetery Sites. IMIESA March 1990: 2125

Harris, M. (2007, June). Grave Matters: A Journey Through the Modern Funeral Industry to a Natural Way of Burial. New York: Scribner.

Janin, A., Coudert, L., Riche, P., Mercier, G., Cooper, P. & Blais, J-F. (2011). Application of a CCA-treated wood waste decontamination process to other copper-based preservative-treated wood after disposal. Journal of Hazardous Materials, 186(2), 1880-1887.

Jennings J.E., Brink, A.B.A. & Williams, A.A.B. (1973). Revised guide to soil profiling for civil engineering purposes in Southern Africa. The Civil Engineer in South Africa. 15:1.

Johnson, E.C. (1995). A History of the Art and Science of Embalming. Casket and Sunnyside.

Johnson, S. (2013). May 14). The Rise of the Green Burial. Texas, United States: Pacific Stand.

Jones, J. (2004). New perspectives on the development of mummification and funerary practices during the Pre-and Early Dynasty Periods. (pp. 982-989). Proceedings of Ninth International Congress of Egyptologists Grenoble.

Jones, J., Higham, T.F., Oldfield, R., O'Çonnor, T. P. & Buckley, S.A. (2014). Evidence for Prehistoric Origins of Egyptian Mummification in Late Neolithic Burials. PLoS ONE, 9(8).

Jones, P. (2008, March). The Discovery of Tutankhamun's Tomb. Niagara Falls, New York: History Magazine.

Jonker, C.Z. (2012). Environmental and health impacts of heavy metal contamination from the Zandfontein cemetery, Tshwane. Unpub. MSc, Dept Environmental Sciences, UNISA.

Jonker, C. & Olivier, J. (2012). Mineral contamination from cemetery soils: case study of Zandfontein Cemetery, South Africa. Int. J. Environ. Res. Public Health. 9:511-520.

Kampassakali, E., Pavlidou, E. & Varella, E.A. (2003). Purple and purple adulterations – an interesting case study. Archaeometry studies in the Aegean: reviews and recent developments, 28-31.

Karmakar, R.N. (2010) Forensic Medicine and Toxicology. 3rd ed. India: Academic Publishers.

Kastenbaum, S.A. (1994). Cryogenic Suspension: An Interview with R. C. W. Ettinger. Omega 30, 3, 159-171.

Kearnes, M. and Rickards, L. (2017). Earthly graves for environmental futures: Techno-burial practices. Futures. 92: 48-58.

Knight, M.J. & Dent B.B. (1996) A Watery Grave – The Role of Hydrogeology in Cemetery Practice. Australian Cemeteries and Crematoria Association 1995, National Conference in Sydney. Reproduced in: Institute of burial & Cremation Administration, Summary 1996. 19-22.

Konefes, J.L. & McGee, M.K. (2001). Old Cemeteries, Arsenic, and Health Safety. In D.A. Poirier & K.L. Feder, Dangerous Places: Health, Safety and Archaeology (pp. 129-134). Westport, United States: Greenwood Publishing Group Inc. Retrieved from Water Industry.

Lee, S. (2003). Evaluation of waste disposal site using the DRASTIC system in South Korea. Environmental Geology, 44, 654-664.

Lerner, D.N. (2002). Identifying and quantifying urban recharge: a review. Hydrogeology Journal. 10:143-152.

Matos, B.A. (2001). Avaliação da Ocorrência e do Transporte de Microrganismos no Aqüífero Freático do Cemitério de Vila Nova Cachoeirinha, Município de São Paulo. [Occurrence and Transport of Microorganisms in Groundwater Aquifer of Vila Nova Cachoeirinha cemetery, Município de São Paulo]. Dissertation, Instituto de Geociências da Universidade de São Paulo.

Mook, W. (2000). Environmental Isotopes in the Hydrological Cycle: Principles and Applications, Vol. 1, Centre of Isotope Research, Free University: Amsterdam.

Mpye, E. (2018/in progress). The effect of age and burial load on the chemistry of cemetery soils: A Cape Town study of three cemeteries. Unpublished MSc dissertation. University of Pretoria.

NIEA [Northern Ireland Environment Agency]. (Downloaded 2012). Cemeteries, Burials & the Water Environment: Guidance Notes. Available on the Internet at www.ni-environment.gov.uk. 12 pages.

Pacheco, A., Mendes, J.M.B., Martins, T., Hassuda, S. & Kimmelmann, A.A. (1991). Cemeteries – a potential risk to groundwater. Water Science and Technology. 24(11), 97-104.

Papageorgopoulou, C., Xirotiris, N.I., Iten, P.X., Baumgartner, M.R., Schmid, M. & Ruhli, F. (2009). Indications of embalming in Roman Greece by physical, chemical and historical analysis. Journal of Archaeological Science, 36, 35-42.

Pearson, M.P. (1999). The archaeology of death and burial. Texas: Texas A&M University Press College Station.

Richards, N.P & Croukamp, L. (2004). Guidelines for cemetery site selection. Preliminary Report. Council for Geoscience, Pretoria, South Africa.

Rogers, R.N. (2004). State of human decomposition. What are the products? http://www.shroudstory.com/faq/tarin.

Schmidt, C. (2018/in progress). Subsurface flow and urban contamination in Cenozoic Sands (City of Cape Town, South Africa). Unpublished MSc dissertation. University of Pretoria.

Schultz, J.J., Warren, M.W. and Krigbaum, J.S. (2011). Analysis of Human Cremains: Gross and Chemical Methods. In: Schmidt, C.W. and Symes, S.A. (eds.). The Analysis of Burned Human Remains. Academic Press. 296pp.

Silva, L.M. (1998). Cemitérios: fonte potencial de contaminação dos aqüíferos livres. [Cemeteries: potential source of contamination of superficial aquifers]. In IV Congresso Latino-Americano de Hidrologia Subterrânea. [IV Latin American Congress of the Hydrology of the Groundwater], ALHSUD, Montevideo, pp. 667-681.

Silva, R.W.C. and Filho, W.M. (2011). Geoelectrical mapping of contamination in the cemeteries: the case study in Piracicaba, São Paulo/Brazil. Environ. Earth Sci. 66 (5), 1371-1383.

Singh, R., Gautam, N., Mishra, A., & Gupta, R. (2011). Heavy metals and living systems: An overview. Indian Journal of Pharmacology, 43(3), 246-253.

Spongberg, A.L. & Becks, P.M. (1999). Inorganic soil contamination from cemetery leachate. Toledo, Ohio: Department of Geology, University of Toledo.

Spongberg, A.L. & Becks, P. (2000). Organic contamination in soils associated with cemeteries. Soil and Sediment Contamination, 9(2), 87-97.

Tarlow, S. (2000). Landscapes of memory; the nineteenth-century garden cemetery. European Journal of Archaeology, 3(2), 217-239.

Tredoux, G., Cavé, L. & Engelbrecht, P. (2004). Groundwater pollution: Are we monitoring appropriate parameters?

Trick, J.K., Williams, G.M., Noy, D.J., Moore, Y. & Reeder, S. (1999). Pollution Potential of Cemeteries: Impact of the 19th century Carter Gate Cemetery, Nottingham. Technical Report WE/99/4. British Geological Survey, Keyworth, Nottingham, pp. 1-34.

Tumagole, K.B. (2005). Geotechnical survey of underground water pollution at Ditengteng. Unpublished MSc thesis, University of Johannesburg.

Turner, B.D., Wiltshire, P.E.J. (1999). Experimental validation of forensic evidence: a study of the decomposition of buried pigs in a heavy clay soil. Forensic Sci Int 101:113-122

Van Allemann, S.T. (2017). Laboratory Simulation of the Corrosion of Coffin Materials in Cemeteries (South Africa). MSc dissertation (unpublished). University of Pretoria, South Africa.

Van Allemann, S.T., Olivier, J. and Dippenaar, M.A. (in print). A laboratory study of the pollution of formaldehyde in cemeteries (South Africa). Environmental Earth Science. Accepted manuscript number ENGE-D-17-01523R1.

Van Haaren, F.W.J. (1951). Churchyards as sources for water pollution. Moorman's Periodieke Pers 35(16):167-172 (in Dutch).

Vásquez-Suñé, E., Sánchez-Vila, X. and Carrera, J. (2005). Introductory review of specific factors influencing urban groundwater, an emerging branch of hydrogeology, with reference to Barcelona, Spain. Hydrogeology Journal. 13:522-533.

Vass, A.A. (2001). Beyond the grave – understanding human decomposition. Microbiology today, 28, 190-192.

Weaver, J.M.C., Cavé, L. and Talma, A.S. (2007). Groundwater Sampling. 2nd Ed. Water Research Commission. Report No. TT 303/07. Pretoria.

WHO [World Health Organisation]: Regional Office for Europe. (1996). The Impact of Cemeteries on the Environment and Public Health: an Introductory Briefing. Document EUR/HFA target 23. World Health Organisation. Copenhagen.

WHO [World Health Organization]. (1998). The impact of cemeteries on the environment and public health. WHO Regional Office for Europe, Copenhagen.

World Health Organization. (2002). Formaldehyde: Concise International Chemical Assessment Document 40, Geneva: WHO.

Young, C.P., Blackmore K.M., Reynolds P.J. & Leavens, A. (1999). Pollution Potential of Cemeteries, R & D Technical Report P223, Environment Agency. ISBN 1857050215, 61pp.

Young, C.P., Blackmore, K.M., Reynolds, P. & Leavens, A. (2002). Pollution Potential of Cemeteries: Draft Guidance. R&D Technical Report P223. Environmental Agency. Bristol. 71 pages.

Żychowski, J. (2008). Impact of WW 1 and 2 mass graves on the natural environment. Pedagogical University of Cracow, Cracow.

Żychowski, J. & Bryndal, T. (2015). Impact of cemeteries on groundwater contamination by bacteria and viruses – a review. Journal of Water and Health. 13.2:285-301.

18.2. Legislation and Standards

Animal Health Act (AHA) No. 7 of 2002. Government Printer. Pretoria.

ASTM [American Society for Testing and Materials]. (1994). Standard test method for infiltration rate of soils in field using double-ring infiltrometer. Designation D 3385-94. USA. 6pp.

Department of Health. (2014). Regulations relating to health care waste management in health establishments. Government Gazette, 23 May 2014. Government Printer. Pretoria.

DWA [Department of Water Affairs]. (Retrieved 2010). Water Quality Management Policy with regard to the Management of and Control over Cemeteries as a Source of Water Pollution. Document number: GraveR. Available on the Internet at http://www.dwaf.gov.za/Documents/Policies/WDD/Cemetery.pdf. 2 pages.

DWAF [Department of Water Affairs and Forestry]. (2000). Policy and Strategy for Groundwater Quality Management in South Africa. Number W.1.0.

DWAF [Department of Water Affairs and Forestry]. 2004: Protecting Groundwater from Contamination by Burial Sites. In: Guidelines on Protecting Groundwater from Contamination. DWAF, Pretoria.

EA [Environmental Agency]: Science Group Air, Land & Water. (2004). Assessing the Groundwater Pollution Potential of Cemetery Developments. Product Code SCHO0404BGLA-E-P. Environmental Agency. Bristol. 24 pages.

ECA [Environmental Conservation Act]. (1989). No. 73. Government Printer. Pretoria.

Environmental Conservation Act No 73 of 1989. Government Printer. Pretoria.

MOSA [Machinery and Occupational Safety Act]. (1983). GN1031 of 30 May 1986 as amended including inter alia amendment GN 433 (20 June 1986 Section 13). Government Printer. Pretoria.

National Environmental Management: Waste Act No. 59 of 2008.

National Environmental Management: Waste Amendment Act No. 26 of 2014. Government Printer. Pretoria.

National Health Act No. 61 of 2003. Government Printer. Pretoria.

National Water Act No. 36 of 1998. Government Printer. Pretoria.

SABS [South African Bureau of Standards]. (1993). Code of Practice: Water Supply and Drainage for Buildings. Part 2: Drainage Installations for Buildings. SANS 10252-2. South African Bureau of Standards. Pretoria.

SABS [South African Bureau of Standards]. (1998). Development, maintenance and management of ground water resources. Part 4: Test-pumping of water boreholes. . SANS 0299-4. South African Bureau of Standards. Pretoria.

SABS [South African Bureau of Standards]. (2001). Specification. Drinking Water. SANS 241. Pretoria.

SABS [South African Bureau of Standards]. (2012). Geotechnical Investigations for Township Development. SANS 634. Pretoria.

SABS [South African Bureau of Standards]. (2012). Soil profiling and rotary percussion borehole logging on dolomite land in Southern Africa for engineering purposes. SANS 633. Pretoria.

SABS [South African Bureau of Standards]. (2015). Drinking Water. Part 1: Microbiological, physical, aesthetic and chemical determinands. SANS 241-1. Pretoria.

SPLUMA [Spatial Planning and Land Use Management Act]. (2013). No. 16. Government Printer. Pretoria.

18.3. Informal and Popular Bibliography

Adams, C. (2006). Are people living near to graveyards at increased risk of exposure to biohazards? In: The straight dope. www.straightdope.com/columns/060324.html [Accessed 13 December 2007]

Alibaba. (2008). Coffin assembly brackets. www.alibaba.com (Accessed 27 Aug 2008).

Ann's Studio. n.d: Conditions in 19th Century London.

Bloemnuus. 07/09/2007: Cemeteries nearing full capacity. p6.

Bothma, B. (2015, September 10). Homo naledi: New human ancestor buried its dead. Retrieved from eNCA: https://www.enca.com/south-africa/new-human-ancestor-species-buried-its-dead

Cape Argus. 20/08/2007: Cemeteries out of burial room – again. p4. Makoba N.

Cape Times. 20/02/2008: Burial crisis looms as cemeteries almost full. p4. Powel A.

Carter, H. (2014). The Tomb of Tutankhamun: The Burial Chamber (Vol. 2). New York: Bloomsbury Publishing.

Cemeteries and cemetery reform forum. n.d: http:www.deathreference.com/Bl-Ce/Cemeteries-and-Cemetery-Reform.html [Accessed 02/04/2008].

Cemetery and cemetery reform forum. n.d. www.deathreference.com/Bl-Ce/Cemeteried-andCemetery-Reform.htlm [Accessed 2 April 2008].

Clarke, L. (2002). Aids deaths fill South African cemeteries. The Sunday Independent IOL.

Cork City Council. n.d: Cork in the 19th Century.

Falck, S. M. & Wettengel, W. (2008). The discovery of King Tut. Berlin: Facts & Files Historisches Forschungsinstitut.

Gagnon, A. (2015, October 1). Death and Mourning in the Civil War Era. Retrieved from Connecticut History: http://connecticuthistory.org/death-and-mourning-in-the-civil-war-era/

http://anngs.co.uk/index2.php?option=com_content&do_pdf=1&id=38. [Accessed 12 March 2008].

http://www.corkcorp.ie/aboutcork/historyofcork/19thcenturycork) [Accessed12 March 2008].

Ikram, S. & Dodson, A. (1998). The Mummy in Ancient Egypt: Equipping the Dead for Eternity. 108.

Lonité. (Accessed 6 December 2017). Available at https://www.lonite.com/education/cremation-ashes.html

Lotz K. Personal communication. 2007

Mass Media and Personal Communications:

Mercedes, B. (2015, October 6). Funeral and Memorial Practices. Retrieved from Encyclopedia: http://www.encyclopedia.com/doc/1G2-3402200154.html

Moore, B. & Lundell, M. (2012). Mound Builders of the Ancient World. Phoenix: Pueblo Grande Museu.

Niven, J. (1965). Connecticut for the Union the Role of the State in the Civil War. New Haven, CT: Yale University Press.

Noble, R. (n.d.). South African HIV & AIDS Statistics, 2006: www.avert.org/safricastats.html

Order of Christian Funerals. (1990). Christian Study Edition. Chicago: Liturgy Training Publications.

Perkins, S. (2014, August 2014). Mummifying-balm recipe is older than the pharaohs. Retrieved from Nature: International weekly journal of science: http://www.nature.com/news/mummifying-balm-recipe-is-older-than-the-pharaohs-1.15717

Phillips, N. (2015, September 11). New species of extinct human 'Homo naledi' found in South African cave. Retrieved from The Sydney Morning Herald: http://www.smh.com.au/technology/sci-tech/new-species-of-extinct-human-homo-naledi-found-in-south-african-cave-20150910-gjjypf.html

Pienaar H. & Xu Y. (2007). Protecting what's Underneath the Tap. Ground Protection. The Water Wheel, 6(4), 24-27.

Rawood, L. (2015, September 18). A new addition to the family. Roodepoort Record, p. 6.

researchspace.csir.co.za/dspace/bitstream/10204/534/1/tredoux_2004.pdf [Accessed 3 July 2007].

Rose-Innes, O. (2013, August 7). A greener way to go. Cape Town, South Africa: Health24.

SA News. 18/05/2004: Grave concern over full cemeteries. www.iafrica.com [Accessed 23 February 2008].

Sibongakonesi, M. (2011, August 18). Now your final goodbyes can leave a green legacy. Cape Town, South Africa: Cape Argus.

Statistics South Africa. 2007: Mid-year population estimates, South Africa: 2007. www.statssa.gov.za [Accessed 20 January 2008].

Sunday Independent. 02/02/2003: KZN cemeteries run out of burial space. p 5. Clarke L.

The Cremation Society of Great Britain, International Cremation Statistics 2004.

The Herald. 31/07/2006: Bold new proposals to relieve crowded cemeteries. p 1. Capazorio B.

The Herald (EP Herald). 29/06/2007: Parts of cemeteries due to be reused due to shortage of burial space. p 5.

This Day. 18/05/2004: Aids deaths cause crisis as cemeteries fill up. p 1. Hofstatter S.

Trochu, A.F. (2015, September 11). About Incorruptibles – The Catholic Heart. Retrieved from The Catholic Heart: www.thecatholicheart.org/pdf/AboutIncorruptibles.pdf

UEIG, 2003: On line GIS Dictionary. University of Edinburgh, Institute of Geography.