Use of tritium and stable water isotopes to assess contaminant transport at a burial site in Middelburg, Mpumalanga

by

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Declaration

I, Sarah Ndazi Mahlangu declare that the thesis/ dissertation, which I hereby submit for the degree MSc. Hydrogeology at the University of Pretoria is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE:

DATE: 12 February 2020

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Abstract

When different water resource components coexist in nature, they usually have an impact on each other. Studies of how they impact each other in terms of water quantities, flow dynamics, quality and contamination are therefore necessary to ensure an appropriate water and environmental management is conducted. A study in Middleburg comprised a literature review and field investigations at and around a cemetery, as part of a Water Research Commission project on impacts on the water resource from large-scale burials. A literature review conducted has enabled familiarisation with similar studies that have been conducted around the subject. Reliable methodologies have therefore been adopted from the published literature and applied on the current research. A seasonal wetland is located downgradient of the cemetery, between the cemetery and a stream that flows past the cemetery. In order to assess possible flow pathways of near-surface and groundwater from the cemetery to the stream, monthly monitoring of surface and groundwater quality and level fluctuations was carried out on the stream, as well as existing and newly installed boreholes at the cemetery. Water samples collected were analysed for inorganic constituents, tritium, and stable water isotopes. The tritium and stable water isotope results – revealed the comparative influence of rainfall and shallow groundwater contributions to streamflow, while groundwater provides base-flows as the stream levels recede. The depth to groundwater reduced with increasing rainfall, indicating direct recharge. The difference in concentrations of some inorganic parameters in the stream compared to the groundwater at the cemetery revealed the effect of natural attenuation in the vadose zone due to reduced conditions and the wetland acting as a filter to improve the water quality of the shallow interflow on reaching the stream. Since isotope data indicated to be a useful tool in studying water resource interactions, the methodology should form part of site investigations for cemetery development or on existing cemeteries to study the current impact and/or predict future impacts that the cemetery may have on the water resources. The methodology best applies in areas with multiple water resources, where there may be an interconnection between them. The isotope studies can also be used to estimate recharge and thus contaminant transport rate of the cemetery leachate.

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Acronyms

BH	Borehole
CGS	Council for Geoscience
Deuterium (D)	Hydrogen-2 Isotope
DO	Dissolved Oxygen
DRI	Double Ring Infiltration Test
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
GMWL	Global Meteoric Water Line
GSSA	Geological Society of South Africa
Ha	Hectares
IAEA	International Atomic Energy Agency
IRMS	Isotope Ratio Mass Spectrometry
iThemba	Isotope Laboratory located at the University of Witwatersrand
K	Hydraulic Conductivity (units commonly used; m/d – meters per day)
Ksat	Saturated hydraulic conductivity
l/s	Litres per second
LGR	Los Gatos Research
LS	Laser Spectroscopy
mamsl	Metres above mean sea level
mbgl	Metres below ground level
Mmbgl	Millimetres below ground level

NGA	National Groundwater Archives
SA	South Africa
SABS	South African Bureau of Standards
SANS	South African National Standards
SANS 241 (2015)	The South African Drinking Water Standard
SAWS	South African Weather Services
SRK	SRK Consulting (South Africa) (Pty) Ltd
STLM	Steve Tshwete Local Municipality
SWL	Surface Water Level
TDS	Total Dissolved Solids
TU	Tritium Units
UKZN	University of KwaZulu-Natal
UP	University of Pretoria
uPVC	un-plasticised Polyvinyl Chloride pipe
US EPA	United States Environmental Protection Agency
V	Volts
WL	Water Level
WRC	Water Research Commission

1 Chapter I: Introduction and literature review

With the increasing population, development of the country and the changing climate, an increasing demand of fresh water is observed in some cities in South Africa (SA). These cities are already experiencing water shortages due to climate change, i.e. less rainfall and more evaporation (Mussá, et al., 2015). Unfortunately, most of our natural resources are negatively impacted by human activities, resulting in their quality being compromised. One impacted water resource may influence the next water resource, since there exists an interconnection between different water resources within the water cycle. Understanding the interaction between water resources is vital in contamination studies, as they can reveal information regarding transport and the fate of the contaminant (Du, et al., 2018).

Groundwater was seen to change from an undervalued water resource to a basic human need, with more than 50% of communities in villages and small towns relying on it to meet their domestic and general livelihood needs (DWS, 2017). Groundwater is still a reliable source of fresh water as surface water is more exposed to contamination. Groundwater is not only important for human consumption but also maintains flows and water levels in rivers, lakes and wetlands (Le Maitre and Colvin, 2008). Protection of groundwater from the risk of potential pollution is thus necessary to ensure its suitability for use and its sustainability. The study of water quantities, flow dynamics and its quality, contamination, as well as sources thereof, is getting more and more attention as we continue experiencing fresh-water availability problems. Most risk assessment and monitoring studies around water resources involve conducting geochemical studies. However, it becomes challenging when there is more than one suspected source of contamination when trying to quantify each source’s contribution and delineate the plume. The need to predict future impacts of an identified pollution plume is also triggered in order to manage it and plan for remediation thereof. Stable water isotopes are used as a tool combined with chemical analysis to determine sources or contributors to contamination, as well as the transport behaviour and extent of such contaminant plume (Miljevic and Golobocanin, 2007). The isotope study is thus used to substantiate findings from a chemical study.

A case study was conducted at a cemetery that is classified as a landfill to apply biogeochemical and isotope studies, to study the impact the landfill has on the receiving water resources quality, as well as the interconnection of the local water resources and their impacts on each other. The primary aim of the study is to contribute to the improvement of the existing cemetery guidelines to assist researchers in selection of suitable practice sites (cemeteries). The secondary aim is the application of most reliable methods during the research and to familiarise with information that have already been published from previous studies that focus on the same subject and apply similar methodology in a form of a review and a case study. Groundwater monitoring points were installed within the cemetery with additional private boreholes added to the monitoring programme that involved sampling and analysis for inorganic, biological parameters, metals, tritium, and stable water isotopes. The study focused mainly on isotopes and some inorganic parameters which are cemetery contamination indicators and only formed the background of the study.

The literature review focused on a compilation of different studies carried out in relation to isotope application in hydrogeological studies, as well as findings from studies conducted at cemeteries. The review is presented in such a way that some of the findings are applied in methodologies and interpretation parts of a case study, which is presented from section 5.

Findings from studies previously conducted at cemeteries (which is the background study location) with the aim of determining the impacts cemeteries have on the water resources within a particular area, as well as controlling factors of the severity of the impact were reviewed. The most common studies conducted at sites suspected to be contaminated are chemical studies, with the aim of identifying the source of contamination, processes involved during movement of the suspected contaminant and affected receptors. Chemical studies, however, have their limitations, and this research describes how stable and tritium isotopes can be used to support findings from chemical studies.

1.1 Cemeteries

Rainwater is introduced into water resources as runoff from streams or as directly recharged water into both surface water and groundwater. Recharged water will contain different dissolved constituents and so will water leaching through cemeteries. Cemeteries are considered as part of the environment; therefore, it is important to understand their position and impact within the water cycle (Knight and Dent, 1995). According to Spongber and Becks (2000), cemeteries have been overlooked as possible sources of contamination and are often only used as background locations for various investigations. They are considered landfills with a low negative impact on the ground and/or surface water quality (Dippenaar, 2014). In that case there are no local monitoring requirements for cemeteries. Cemeteries are still, however considered a pollution source (Tredoux, et al., 2005). They comprise of degradable substances, which form part of burial by-products, as well as land (Knight and Dent, 1995). The characteristics of their leachate compositions are described and summarised in this section.

1.1.1 The human body other cemetery constituents decomposition

When life stops, the human body starts decomposing. The decomposition process (manner, rate, and by-products) is determined by physicochemical and bacterial environmental conditions. It is important to understand the decomposition process as it assists with the cemetery and environmental management, as well as application in other studies (Dent, et al., 2004).

According to Yusmartini et al. (2013) a landfill is not only defined by solid waste, but also liquid waste (leachate) that is composed of organic and inorganic substances, as well as some pathogenic bacteria. This all depends on where the leachate is derived. When absorbed in the soil, the leachate can be potentially harmful to the environment and to the water resources, it comes into contact with. The severity of the impact is determined in mg/l by comparison to certain parameter concentration limits in published water quality standards like the South African National Standards (SANS) for drinking water (SANS 241) (SANS, 2015).

Leachate from cemeteries is derived from decomposing buried human bodies, as well as associated burial material (da Cunha Kemerich, et al., 2012). The major human body tissues include protein, carbohydrate, fat and bone (Dent, et al., 2004). According to Van Haaren (1951) (as cited in Rodrigues & Pacheco, 2010), an average human body is composed of 64% water, 10% lipids, 6.4% proteins, 5% mineral salts and only 1% carbohydrates by volume. During the process of decomposition, about 0.4 – 0.6 litres of leachate is produced per 1kg of body weight.

The leachate is characterised by a fishy odour and is usually composed of 60% water and 30% salts. The salt components may include nitrogen, phosphorus, Cl^-, HCO_3^-, Ca^{2+}, Na^+ and compounds of various metals that can be derived from the buried corpses, the coffin material and from the material used for graves construction. High conductivity, pH and BOD are also common (Matos, 2001). Other compositions of leachate depend on the substances used for embalming and burial practices, such as arsenic and mercury, formaldehyde and preservatives for wooden coffins, as well as metal constituents derived from coffins, such as zinc and copper (Spongber and Becks, 2000).

According to Dent and Knight, (1998, as cited in Zychowski, 2011) calcium and phosphorus are some of the most abundant elements that form part of the human body composition. Thus, water samples under study should be analysed for these parameters when investigating the effects of cemeteries on water resource quality. Phosphorus was found to be highly concentrated below burial sites at a research site in Cracow (Zychowski, 2011).

Elevated Fe and Cr were also measured from samples collected during a study conducted at Botany Cemetery in Sydney. Fe is an indicator of soil redox processes that have taken place in the soil. It is also an adsorbent to some anions. If concentrations of Fe are elevated in the vadose zone, this will limit the influx of burial material into the groundwater. Fe also tends to adsorb decomposition products, as some organic substance fragments were found to be surrounded by Fe, limiting their migration out of the soil underlying the burial zone, for example, the underlying groundwater (Zychowski, 2011). Though Fe is a by-product of burial material decomposition. Its presence is also controlled by microbes (Thomas, et al., 2016). Microbes are also by-products of decompositions at cemeteries (Vaezihir and Mohammadi, 2016), their presence in the soil result in oxygen depletion and thereby reducing Fe and other compounds, like manganese oxides. These will then dissolve in soil water and result in elevated Fe in soil water. The resultant soils will be grey in colour. Such conditions usually occur where water permeability is restricted for a long time, thus giving microbes enough time to reduce Fe and Mn oxides. Once they encounter oxygen again, they will precipitate and form Fe (red, yellowish orange) and Mn (black) concretions (Thomas, et al., 2016). Cr is also a common constituent of material associated with burial. The composition of cemetery substrates was determined by analysing soil samples from the depth of 0.3 to about 1.6 meters below the surface at cemetery sites in Poland. Other findings included elevated concentrations of ammonia and nitrate in groundwater below newly developed cemeteries. These concentrations decreased with distance from the graves, as well as with increasing age of the cemetery (Zychowski, 2011).

A study at the Zandfontein cemetery in the Tshwane Municipality in South Africa was conducted to determine whether cemeteries can be classified as anthropogenic pollution sources to the environment. The study was mainly focused on metals derived from cemeteries, where metal scans were conducted on soil samples collected around the cemetery. The results obtained from this study indicated that many of the metals associated with burial material were concentrated at the cemetery sites as compared to other areas offsite the cemetery (Jonker and Olivier, 2012).

1.1.2 Contaminant transport at cemeteries – determining factors

The position of cemeteries may or may not pose a risk to nearby water resources, more especially the underlying groundwater. Various factors may determine the impact cemeteries may have on groundwater, and that includes the depth of groundwater below the cemetery area, permeability of the aquifer, the burial rate, and age of cemetery (Vaezihir and Mohammadi, 2016).

Hydraulic conductivity – a determining factor for water residence time

Most contaminants, especially those soluble in water, tend to migrate with water. Water tends to flow preferentially through porous media and rock structures like voids and fractures. Therefore, it is crucial to understand the aquifer characteristics in a study area, how it is recharged, and the possible water pathways through it (Tredoux, et al., 2005). Hydraulic conductivity (denoted by the capital letter K with commonly used units m/d) is related to water flow mechanism. Hydraulic conductivity is defined as the rate at which water flows through a unit cross-sectional area of a porous medium at a given amount of time under a hydraulic gradient of 1 (US EPA, 2009). Knowing the hydraulic conductivity helps in managing groundwater that includes protection of it and managing contamination where necessary (Shevnin, et al., 2006).

Different methods can be used to determine hydraulic conductivity of a medium through which water passes. In-situ methods that can be conducted to estimate hydraulic conductivity in the unsaturated zone include, double ring surface infiltration and falling head tests inside boreholes. There are uncertainties and accuracy limitations to be taken into consideration when applying the in-situ methods to estimate the vertical hydraulic conductivity in the unsaturated zone. The hydraulic gradient, in this case, cannot be estimated due to variable saturation conditions. Additionally, results obtained from both tests are biased as tests are conducted at specific areas, which are convenient for the field technician, i.e. in an area where it is easy to install the test rings for a double ring test, and where it is accessible to conduct a falling head test in a borehole (Dippenaar et al., 2014). The tests are, thus carried out until the obtained hydraulic conductivity is at its maximum, termed saturated hydraulic conductivity (Ksat). The results can be interpreted as a prediction of the time it will take for precipitation to flow through the soil for an extended period (Thomas, et al., 2016). Once calculated, hydraulic conductivities of material in the study can be compared to published hydraulic conductivity of different material (Figure 1-1) (Shevnin, et al., 2006).

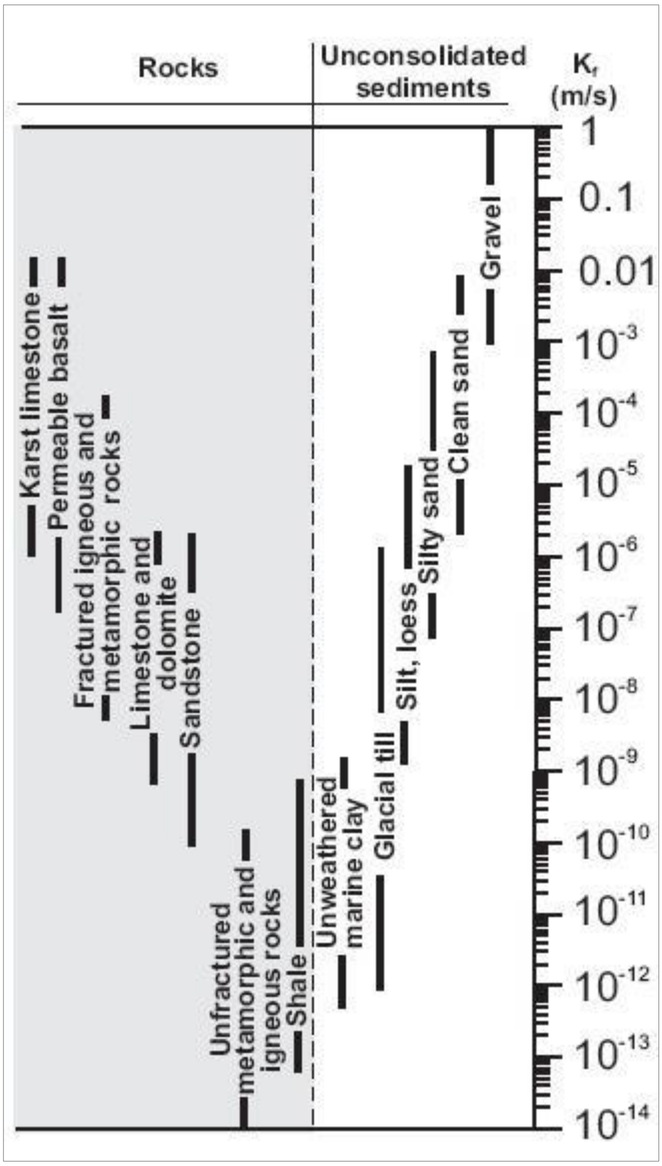

Figure 1-1. Distribution of filtration coefficient values for hard rocks and unconsolidated sediments (Shevnin, et al., 2006).

Double Ring Infiltration (DRI) Tests

DRI tests are conducted to estimate water infiltration rate into the subsurface to depict rainfall (Ruggenthaler, et al., 2010). Results from the DRI tests are also used to measure the saturated hydraulic conductivity of the material. The outcomes of the DRI test is dependent on several factors and that includes, the initial soil moisture, the soil properties, and the land-use/cover. Wetter soils like wetlands have less pore volumes and conducting a test on them will result in those pores getting filled-in seconds, thus resulting in less infiltration and more runoff of the water added, and therefore, precipitation (Ruggenthaler, et al., 2016). The presence of trees (root activity) and the application of some activities like excavation will alter the soil's hydraulic properties and result in higher infiltration rates and less runoff. In that case, a large amount of precipitation in forest areas is stored in the soil, and less contributes to runoff (Falkenmark and Rockström, 2004). However, in areas covered by lots of vegetation like grass, high evapotranspiration is common and therefore, low field capacity will result in fast drying of soil water and less water stored in the soil (Fohrer, et al., 2001).

During setting up to conduct a DRI, both rings are driven into the ground to about 5cm. However, there are various ways of installing the rings (Figure 1-2) (Ruggenthaler, et al., 2016). One can decide on whether to do a constant head or a falling head infiltration test. Water is added into both rings and the water level in the outer ring is kept constant for both the constant and falling head tests (Gregory, et al., 2005). The water will infiltrate into the ground but will first move laterally. However, the aim of keeping the outer ring filled with water is to ensure that the soil on the sides remains saturated, thus forcing the water in the inner ring to move vertically down. During the constant head test, the water in the inner ring is also kept constant, and the volume of water added per time is noted and recorded, while during the falling head test, the time it takes for the water level to drop to a particular depth is recorded. A volumetric flow rate is calculated. Darcy's law is used to calculate the vertical saturated hydraulic conductivity, generally assuming a constant hydraulic gradient (Dippenaar, et al., 2014).

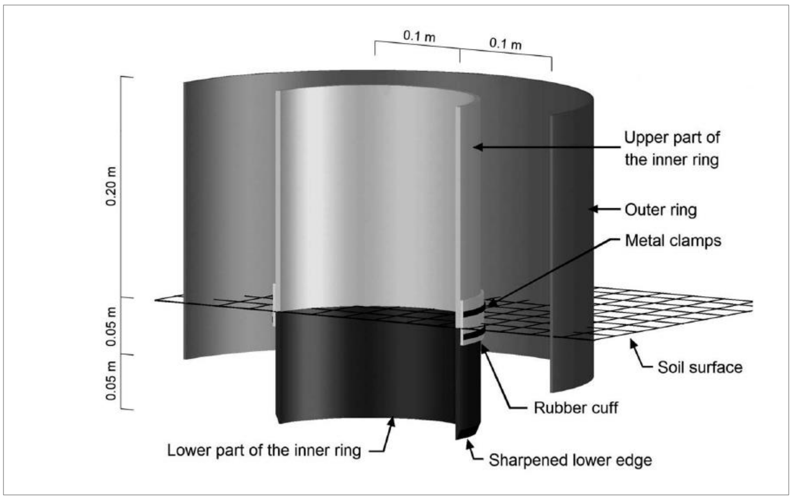

Figure 1-2. Cross-section of a double ring infiltration test setup (Ruggenthaler, et al., 2016).

Falling Head Tests in the unsaturated zone

One of the more common and simple methods used to determine hydraulic conductivity in porous media is the slug test. The slug test involves either instantly lowering (by withdrawal) the water level in a borehole and observing and recording the rate at which it rises back to its initial static level or by introducing a solid slug of known volume or a known volume of water into a borehole to raise the water level in the borehole followed by observation and recording of the rate at which the water drops back to its initial static level (Bouwer, 1989). Slug tests are not only simple and cheap to conduct, compared to pumping tests, but are also the recommended tests to conduct on sites related to contamination studies, as they involve no or minimal addition or removal of water that might mobilise the contaminant (US EPA, 2009).

Slug tests were designed to measure borehole yields or hydraulic conductivity in the vicinity of a borehole (also known as near-well aquifer properties (Wang, et al., 2015) where the test is being carried (Van Tonder and Vermeulen, 2005). Therefore, it is expected that results obtained from these tests are an overestimation or underestimation of the hydraulic conductivity of the main aquifer or the major unsaturated zone of the study area.

Slug tests results can be interpreted using different methods, e.g. the Hvorslev or the time lag method and Bouwer and Rice method (Glenn, et al., 2018). A mathematical solution by Bouwer and Rice (1976, as cited in Glenn, et al., 2018) can be used to determine the hydraulic conductivity from slug test data. The results are plotted on a scatter, and a curve and best-fit line are drawn. Different material will produce different scatter plots. Material with low hydraulic conductivity will more likely produce scattered velocity plots, thus resulting in high uncertainty of hydraulic conductivity estimates (Chiasson, 2005). The calculations can be done either manually or by using available software like Aquifer Test.

There are certain factors that influence results and level of confidence in the hydraulic conductivity value obtained from the slug testing, and they include borehole construction manner and depth to the water table in relation to casing perforations. Removal or raising water level during a slug test will result in a large hydraulic gradient (Wang, et al., 2015), i.e. for boreholes whose annulus are filled with gravel or not, hydraulic conductivity will be higher initially (non-Darcian flow process). Also, note that material in the immediate vicinity of the borehole is disturbed during drilling and therefore, its hydraulic conductivity is not representative of the in-situ material. This effect is indicated by Figure 1-3, i.e. the double straight-line effect. Line AB reflects the gravel and disturbed material hydraulic conductivity, while line BC represents the true aquifer’s hydraulic conductivity, and is used to interpret falling head test results (Bouwer, 1989). During the calculation of the hydraulic conductivity, the gravel pack thickness and its porosity are usually taken into consideration. In cases where they are not taken into consideration, reasonable hydraulic conductivity values might be obtained, provided that the well is appropriately developed and the BC section in Figure 1-3 is used to interpret the data (Buttler, 2014).

The depth to the water table in relation to the casing perforations is bound to change naturally, even after borehole construction, due to rising or dropping of the water level. In cases where water is added to raise the water level from its initial static level, it is ideal that the initial equilibrium water level is above the top of the screened section of the hole, or above the open part of the hole, for a hole that is cased off (Bouwer, 1989). In many contamination related studies, most of the monitoring boreholes are constructed in such a way that the casing screens extend across the water table. Performing slug tests in such boreholes may result in a lot of noise in the data obtained and reduced confidence level in the hydraulic conductivity value estimated. Therefore, it is important that knowledge of the well construction be distributed among the parties involved prior to conducting of slug tests so that they can be taken into consideration (Buttler, 2014). If this is not the case, the hydraulic conductivity value obtained from the test will be over- or underestimated. Figure 1-4 indicates a situation where the top part of the casing’s screened section is above the water table. The arrows indicate that the water will first move laterally in the unsaturated zone through the screens or open hole above the water table causing the water level to drop quite quickly. Note that the greater the ratio y/l (see labelled Figure 1-4), the higher the overestimation of K. To overcome this, the borehole needs to be saturated repeatedly, by filling it with water until the effect from the unsaturated zone is less significant (Bouwer, 1989).

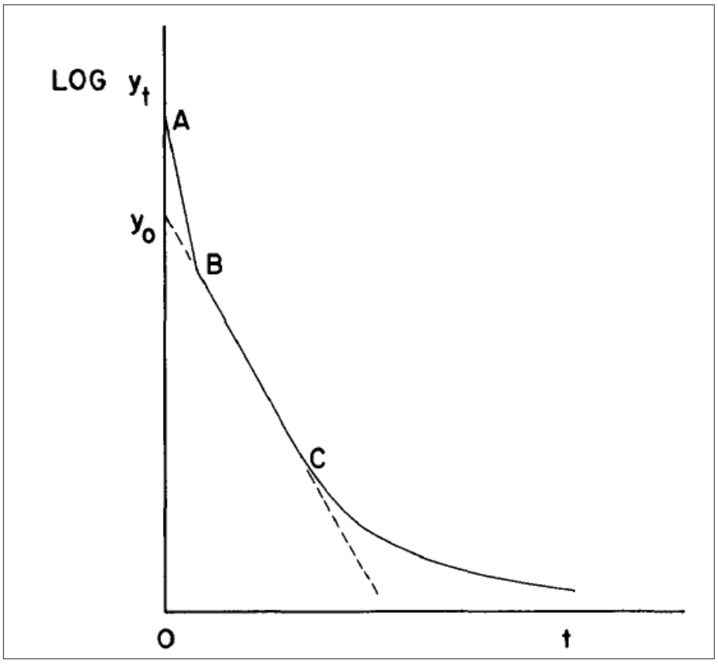

Figure 1-3. Schematic of the double straight-line effect (Bouwer, 1989).

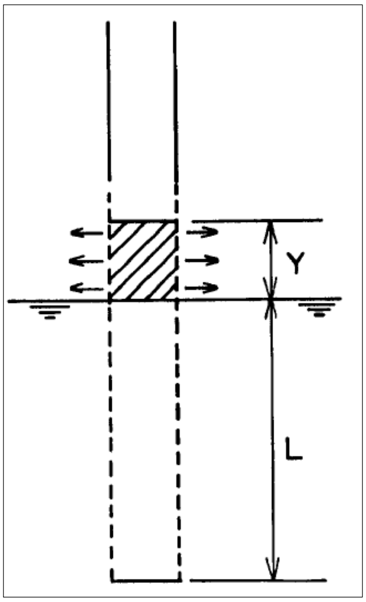

Figure 1-4. Schematic illustrating conduction of a falling head test with the equilibrium water level below the top of the casing screens or open hole (Bouwer, 1989).

Groundwater flow direction – estimation of

Understanding the groundwater flow direction is another important part of a contaminant transport study, as it plays a role in the migration of contaminants. The outcomes can also be used to assess groundwater dynamics, like the interaction of it with surface water (Kabede, et al, 2017). In cases where a stream exists nearby, and it is discovered that groundwater discharges into it, the groundwater flow pattern will usually follow that of the stream and the stream usually acts as a divider for the underlying compartments (Girmay, et al., 2015).

Groundwater flow directions can be estimated by using groundwater levels that are usually obtained from measuring water levels in existing boreholes and surface water bodies at a site. This method is however, not always applicable as sometimes, there are no accessible or available points where water levels can be measured. This usually occurs in cases where no boreholes are available or where private boreholes are equipped with pumps.

It is possible to estimate groundwater flow direction with no knowledge of the groundwater levels in an area. This could be achieved by using a non-destructive method, which has some assumptions; one of them being that groundwater flow mimics topography, i.e. will move from high potential to low potential (elevation and pressure in this case). The method involves the use of the geo-electric survey to estimate groundwater depth. An expected flow net map is then generated from the survey findings and used to study groundwater flow dynamics. Contaminant migration information can be generated from this method. In this way, one can use it to design a monitoring network, which includes deciding where to install groundwater monitoring boreholes (Moustafa, 2017). This method can further be used as part of an initial step in determining hydraulic connections, water resource interactions, and to estimate recharge/discharge zones. However, most of the time it is not applied in monitoring studies, due to cost implications.

The role played by grave construction manner and material

There are various materials used to construct graves and tombstones. Most of the commonly used materials include rubble of limestone, which is used to form some embankments of graves. The method is not only applied in Poland but also in SA. This is expected to contribute to elevated concentrations of calcium found below cemeteries (Zychowski, 2011).

Maintenance work and construction at cemetery sites also play a role in limiting or promoting movement of decomposition products. Construction of impermeable tombstones, gutters, storm water sewers, and sealed vaults inhibits infiltration of water through the bodies. This water usually joins surface water sources as storm water through storm water drains. The type of tombstones used also determines the infiltration rate of water from the surface, some tombstones (depending on how they are constructed) are very porous and thus accelerate infiltration of water through the buried decomposing corpses (if laid over a grave) (Zychowski, 2011).

Grave diggers always opt for areas, which are easy to excavate, while back fillers will opt for material, which is easy to move with shovels. Compaction after backfilling will not be the same as the in-situ material and thereby promoting rainwater infiltration through this zone. The open pores will also allow aeration and promote oxidation processes to take place. These processes may play a role in naturally attenuating any contamination (Dippenaar, 2014) and the decomposition rate (Fineza, et al., 2014).

The role played by climate and other environmental factors

The impact cemeteries have on the environment (specifically on water resources), is largely determined by their position relative to water resources. Previous studies have indicated the selection of study areas based on different environmental conditions and location of cemeteries being investigated in relation to water resources to represent a diverse location of different cemeteries and their impacts on nearby or underlying water resources.

When bodies are buried, they start decomposing, and the rate at which they decompose is determined by, among other factors, certain environmental factors. Environmental factors affecting the rate of decomposition are considered extrinsic factors, and these include temperature and pH around the grave, depth of burial, precipitation amount and frequency, soil oxygen, the access of insects, etc. These processes can either accelerate decomposition or stop it (Rodrigues and Pacheco, 2010).

At highly vegetated areas covered by grass, there is less runoff, and therefore more water can infiltrate into the ground and recharge groundwater. High vegetation may also promote more evapotranspiration, and thus less infiltration during warmer days. The more water infiltrating the ground the more of will recharge into groundwater, carrying with any soluble substances picked up as it infiltrated (Zychowski, 2011).

The geology of the area also has an impact on the change in the chemical composition of water in contact with it. Geological structures contribute to the rate at which water moves through the media. The more porous or fractured the lithology the more quickly the water in which a contaminant is dissolved in will be transported and will reach the nearest water resource. The presence of clay minerals in a medium through which water passes will result in promoted ion exchange. The advantage of clayey soils below cemeteries is that they are less permeable, and thus limit movement of contamination with filtrating water into the groundwater (Zychowski and Bryndal, 2015), hence giving enough time for natural attenuation.

When rain falls, it recharges the underlying aquifers, and this causes water tables to rise. In areas with low rainfall and low recharge, water tables will drop due to evapotranspiration or sometimes due to groundwater abstractions, if any is happening around an area. The shallower the water table, the more prone to pollution the associated groundwater would be. The depth of the water table is associated with the thickness of the vadose zone. Deep water tables have thick vadose zones. The thicker the vadose zone, the more time available to allow for natural attenuation to play a role in limiting movement of contaminants to groundwater and also for some processes to take place to eliminate that particular substance from the soil before it is introduced to the nearest water source (Dippenaar, et al., 2014). Some decomposition products can be stored for a certain period in the vadose zone, and depending on environmental conditions, they can be transported further into the groundwater. The role of climate in contaminant transport below cemeteries is thus mainly influenced and determined by the amount of rain, its intensity, and transport paths to water resources. The more it rains, the more the water table will rise and the more the groundwater is exposed to recharge of leachate from cemeteries (Zychowski, 2011). According to Zychowski and Bryndal (2015), higher contamination is recorded in areas characterised by warmer and moister climates, mostly with an average annual rainfall exceeding 1500mm.

During a study conducted at the Zandfontein cemetery in the Tshwane Municipality in Gauteng, South Africa, topography was listed as one of the contributing factors to the movement of the metals. It was concluded that water quality monitoring, especially at boreholes near the cemetery sites, need to be carried out as recharge may move these constituents to the nearest water sources (Jonker and Olivier, 2012). Zychowski, (2011) also indicated how topography can accelerate the transport of leachate from cemeteries to the nearest water resource. The methodology for the study conducted in Poland involved the collection of soil samples downslope of the cemeteries where the study was carried out and conducting chemical analyses on them. Since water moves downslope under the influence of gravity, it will carry with any soluble substances.

Zychowski and Bryndal, (2015); Jonker and Olivier, (2012), concluded that contamination at poorly sited cemeteries is dependent on the number of burials, chemicals, physical and biological characteristics of the environment, the fluctuation of the water table, groundwater circulation, organic matter content, as well as, the ability to create binding between decomposition products and the substrate, inappropriate management and practices and natural disasters like floods and landslides.

Wetlands and their roles in the ecosystem

According to (DWA, 1998) a wetland is defined in South Africa as “land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soils.” They usually occur in the upstream parts of a river catchment (Bullock and Acreman, 2003) (Figure 1-5). They are waterlogged and will usually be defined by reeds, which are adapted to waterlogged conditions (Dippenaar, 2014). The fact that they are waterlogged means they can act as barriers to recharge, since the pores in the soils are fully recharged. This means they can promote flooding since most of the received precipitation will become runoff (Bullock and Acreman, 2003).

Since wetlands act as a connection between the terrestrial and aquatic environments, they play very important roles in delivering valuable service to the two ecosystems one of which involves improving water quality (Macfarlane, et al., 2016). Therefore, it is crucial that these terrestrial areas are preserved. According to DWS (2018), 50% of South African wetlands have been destroyed, and one-third of the remaining 3.2 million hectares are already in poor condition.

These ecosystems thus need to be protected. According to the Department of Water Affairs DWA, (2019) graveyards should not be located near wetlands, as part of adequate planning and therefore, local authorities need to take appropriate responsibilities when planning on developing graveyards.

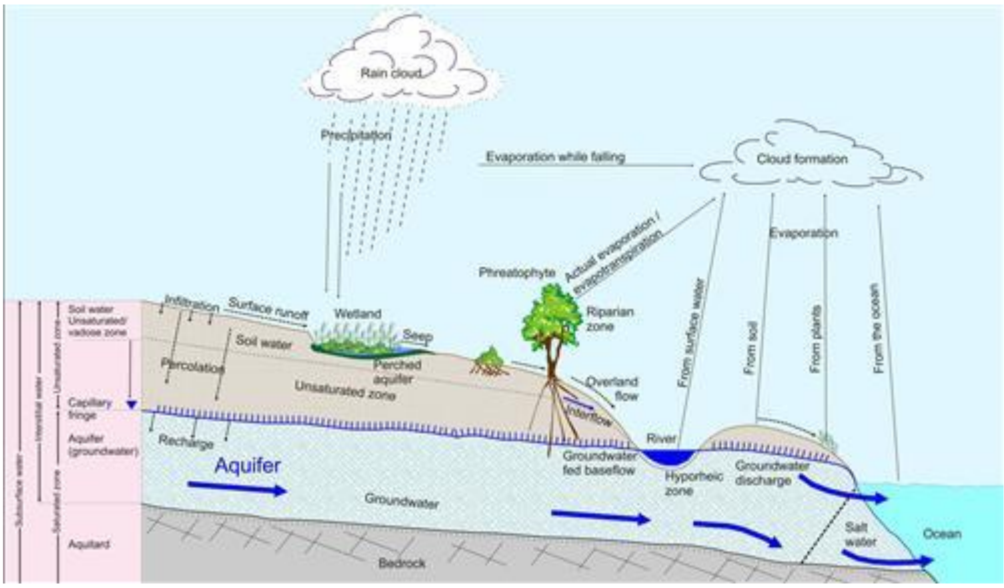

Figure 1-5. Common wetland location in the ecosystem (CSIR, 2003).

Cemeteries should be treated as any other contaminant source. Studies of pollution plumes below cemeteries are increasing, and remediation measures are planned. However, in order to plan for remediation, one needs to know all possible sources of contamination for that particular plume.

If there is more than one possible source, how would we know which source contributes to the plume and by how much? The next section explains how stable isotope studies can be used as a powerful tool to determine the sources of contaminants and environmental processes associated with the contaminants during their transport.

1.2 Environmental isotopes

Isotopes are used in various studies, and this research is mainly focused on the hydrology and hydrogeology field of the study where isotopes are applied. They undergo fractionation due to chemical and kinetic process. This makes them useful to study the processes water undergoes in the water cycle, such as recharge, evaporation, and mixing of waters from different sources. This is further used in the tracking of contaminants most particularly the soluble ones that can easily be transported with water from one water resource to the next, i.e. contaminant transport. A literature review is presented in this section to present how isotopes are used in hydrological studies. The methods are further used to interpret results from the case study in later sections. The isotopes focused on are the stable water and tritium isotopes.

1.2.1 Definitions

Isotopes are atoms of the same element that have the same number of protons but different numbers of neutrons, which results in a different atomic mass. They are represented by a notation which makes it clear to distinguish heavier isotopes from lighter ones, for example, $^{12}_{6}C$ is the most common carbon isotope, also called carbon-12. The atomic mass of this isotope is 12 atomic mass units, and the number of protons is six, meaning that this atom has six neutrons. Isotopes of the same element are chemically identical but physically different. This means all isotopes have similar chemical reactions, but different behaviour in certain physical processes, such as evaporation (Fitts, 2002).

Isotope hydrology is a study whereby either or both stable and unstable isotopes are applied to determine sources of water that recharge the groundwater, to determine if the groundwater is vulnerable to contamination, the source of contaminants and their transport medium and behaviour, as well as the suitability of that water to be used for a particular proposed purpose (IAEA, 2015).

The following definitions are useful in understanding isotopes and their applications:

Environmental Isotopes – Isotopes of light elements both stable and radioactive that are present in the natural environment, as a result of human input or naturally occurring due to natural processes (the most common being; hydrogen, carbon, oxygen, nitrogen, sulfur, chlorine).

Stable isotopes – Isotopes that are energetically stable and do not decay over the geological timescale. They have an equal number of protons and neutrons, or their ratio is not more than 1.5 or less than the normal atom. Their ratio is only changed by evaporation and mixing hence, they are used for hydrology studies. They are, therefore, suitable to be used to trace sources of solutes or contaminants in water (Michener and Lajtha, 2007).

Radioactive isotopes – isotopes that decay through the geological time scale.

Light isotopes – atoms of the same element but with fewer neutrons, i.e. lower mass number than the corresponding atom, e.g. ^{15}O is the lighter isotope of oxygen of the more common ^{16}O.

Heavy isotopes – atoms of the same element but with a greater number of neutrons than the corresponding atom, e.g. ^{18}O is the heavier isotope of the more common ^{16}O.

Fractionation reactions - Isotope fractionation is the main reason why isotopes are studied. They are described as reactions, which give rise to a difference in isotope distribution between chemical substances (reactants to products) or phases. Fractionation can be defined by the ratio of the two isotope ratios (lighter and heavier). There are multiple effects that cause fractionation, and that is equilibrium effects, physical effects (e.g. evaporation) and kinetic effects. Temperature is the main effect of isotope equilibrium, whereby fractionation is proportional to temperature at equilibrium. Large fractionations usually happen in low-temperature environments. In that case, stable isotope ratios of coexisting substances can be used as geothermometers.

Kinetic Isotope effect– reactions whereby the products of the reaction are quickly removed from the system before equilibrium occurs. In cases where the compound is composed of lighter and heavier isotopes, the lighter isotopes will react faster than the heavier ones, the lighter isotope will be removed from the system, and the product will be comprised of heavier isotopes. These will then be regarded as depleted of lighter isotopes.

Figure 1-6 indicates where and when each of the common environmental isotopes are applied in hydrology studies. However, note that the application of the indicated isotopes is not restricted to the study areas or to the associated hydrology processes (Mook, 2000).

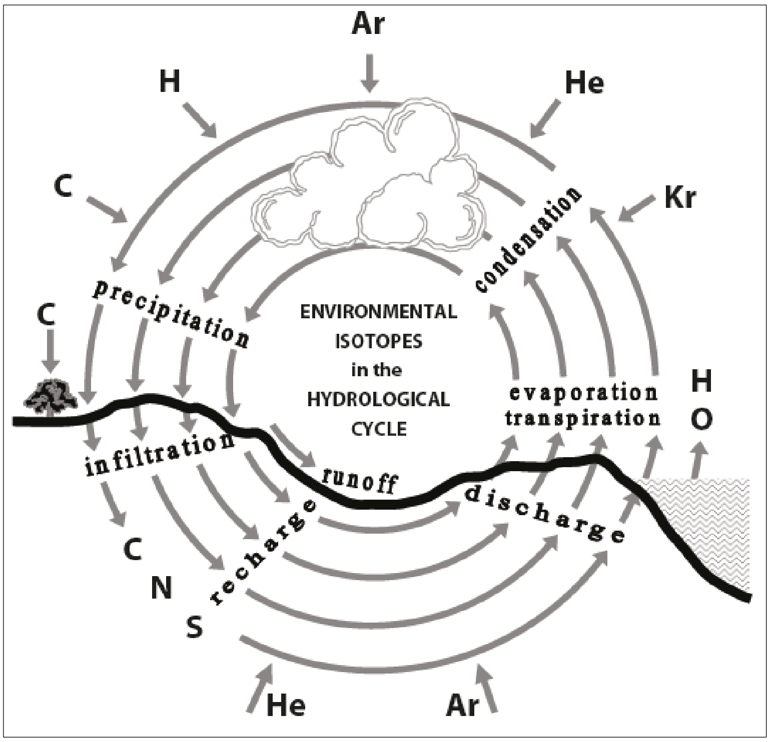

Figure 1-6. Environmental Isotopes in the Hydrological cycle (Mook, 2000).

Most of the common studies involve identifying sources of contaminants to both surface and groundwater, studying of processes involved during contaminant transport, estimation of residence time of both water and solutes in water, determining how much of a particular substance is added into a water system, as well as support or criticise other findings from other methods. One of the advantages of using isotopes in contamination studies is that they can give early warning of any contaminants found, even if they are not yet a threat (Miljevic and Golobocanin, 2007).

Isotope concentrations are determined in water samples relative to standards of known concentrations. The next section describes the planning of a sampling monitoring programme.

1.2.2 Sampling and analyses for isotopes

Methods for sampling and preparation for isotopes vary according to isotopes to be analysed for, and so do the types of samples to collect depending on the aim of the study.

For the Kettle River Basin study, both surface water and groundwater samples were collected for isotope analysis. Precipitation samples were also collected, and the samples were analysed for the two stable water isotopes ^{2}H (deuterium) and ^{18}O (Oxygen-18) (Hacker, et al., 2015).

Sampling of water from water resources suspected to be affected by contamination should be done upgradient near the suspected contamination source, and downgradient of the suspected source of contamination.

Sampling procedure

Containers to be used for collecting water samples can either be plastic or glass bottles. However, their caps should fit tightly so no air can enter or escape the container, as this might result in certain processes (like evaporation) to occur and a change in isotopic composition of the sample as compared to the original water. In that case, one will not have a representative sample. To ensure no air in the samples, sampling bottles must be filled to the top, so no air bubbles are observed. During the sampling of surface water, one should immerse the bottle or an open-mouthed sampling vessel below the water surface and replace the cap while the bottle is still below the water surface. The amount to be sampled is usually as per agreement with the laboratory (Weaver, et al., 2007).

Surface water samples must be collected where water is flowing to allow for proper mixing. During the sampling of surface water, to avoid contamination of the water being sampled, the sampler must stand downstream facing upstream of the sampling point. The sampling bottle and cap should be rinsed three times with the water to be sampled and discarded downstream of the sampling point (WRC, 2000).

Precipitation samples are collected when it is raining where the sampling bottles are left open and removed after it stops raining. Precipitation samples are mostly important for $\delta^{18}O$, $\delta^{2}H$ and tritium analyses, since they are the isotope constituents of the water molecules (Hacker, et al. 2015). Rainfall samples are used to estimate the rain contribution to groundwater recharge and river flows (Rai, et al., 2009).

Preservation of samples is important to avoid any processes occurring during the transport of samples to the laboratory that may result in a change in isotopic or chemical composition of the sample. Samples are kept in a cooler container from site and refrigerated until analysis (Weaver, et al., 2007).

Advanced laboratory analysis for isotopes

Analysis for isotopes refers to the high-precision determination of the ratio of heavy to light isotopes relative to an agreed standard (Weaver, et al., 2007). During the analysis of stable isotopes, the sample collected is converted into a purified gas before it can be analysed by a spectrometer (Michener and Lajtha, 2007). The precision and accuracy of isotopic results are increasing with increasing advance of technical methods used for analysis of isotopic signatures. This allows for measurements of even small isotopic signatures (Oulhote, et al., 2011). The Isotope Ratio Mass Spectrometry (IRMS) has relied on conventional method for measuring isotope ratios for over 40 years. However, the Laser Spectrometry (LS) is now highly recognised as an alternative to the IRMS. This is due to its more advanced high sensitivity and precision for isotope ratio analyses. The IRMS requires chemical preparation of some samples before the analysis is performed (e.g. conversion of a water sample to a water molecule), which is time-consuming. IRMS instruments do not only require specific skills users but are also heavy and take up a lot of space in the laboratory, while LS instruments users can learn the techniques quite quickly. The laser-based instruments are now widely used by isotope researchers in different research fields (Kerstel and Gianfrani, 2008).

1.2.3 Presentation of results obtained from an isotope analysis

Isotope fractionation between two compounds that react together is denoted by the following equation:

$$\alpha = R_{product}/R_{reactant} \qquad \ldots (1)$$

Where α is the fractionation factor and R the isotopic signature that is the ratio of the heavier isotope to the lighter isotope of the same compound, e.g. ^{18}O\\$^{16}$O. The units are usually expressed in per mils (‰), which are obtained by converting the fractionation factor to an enrichment factor $\varepsilon = 1000(\alpha\text{-}1)$ (Miljevic and Golobocanin, 2007).

Results obtained from the measurement of isotopes are expressed as deviation (δ) of the heavy isotope content of a sample relative to a standard and is given by the following equation (Miljevic and Golobocanin, 2007):

$$\delta = \frac{R_{Sample} - R_{Standard}}{R_{Standard}} . 1000 \qquad \ldots. (2)$$

Where R_{Sample} is the ratio of the heavy to the light isotope content of the sample (e.g. ^{18}O/^{16}O), and $R_{Standard}$ is the given standard relative to the isotope in the study. Sometimes the sample has abundant heavier isotopes than the standard, in this case, R_{Sample} will be greater than $R_{Standard}$ and δ will be positive, the reverse is true if the sample is depleted of heavy isotope than the standard (Miljevic and Golobocanin, 2007). The factor 1000 converts the ratio deviations to per mil/ parts per thousands (‰), thus expressing the results in manageable numbers (Weaver, et al., 2007). Table 1-1 shows the two most commonly used isotopes in water studies, their natural abundance and standards used when calculating their abundance. The following precisions are required: 1 ‰ for δ^2H and 0.05 ‰ to 0.1‰ for δ^{18}O (Miljevic and Golobocanin, 2007).

Table 1-1: Natural abundance of stable isotopes and standards used (Miljevic and Golobocanin, 2007)

Relevant Isotope ratio	Average natural abundance	Standard		Reference
		Name	Absolute value	
^{2}H/^{1}H	1.55×10^{-4}	V-SMOW[1]	0.00015576	(Miljevic and Golobocanin, 2007)
^{18}O/^{16}O	2.04×10^{-3}	V-SMOW	0.0020052	(Miljevic and Golobocanin, 2007)

H and O are among the main elements analysed worldwide. Interpretation of these results depends on the purpose of the study and the number of parameters or variables to be presented. The most common way of presenting data is by using scatter plots (Oulhote, et al., 2011).

Simple methods like the univariate test and bivariate scatter plots (where isotopic ratios are presented by confidence ellipsoids) are used in situations where there is a clear difference in isotopic signatures of various origins. Multivariate statistical methods are applied in situations where there is a small isotopic signature difference across various origins, and then many variables are combined. To determine a source of a certain substance where there is a possibility of multiple sources, for example, a source of contaminant, scatter plots between two isotopic ratios can be used to determine sources. Linear mixing models are also used in determining the pollutant source. The use of simple or more complex interpretation methods largely depends on the overlap between isotopic signatures from different origins (Oulhote, et al., 2011). Results obtained from analysis of oxygen-18 and deuterium are given in units of ‰ (parts per thousands). Samples are then plotted in δ^{2}H-δ^{18}O space; from this, one is able to determine all contributing end members to the source of water under study (Standnyk, et al., 2005). Time series charts can also be plotted for results obtained from long monitoring in an area.

1.2.4 Application of isotopes to environmental studies

Oxygen-18 and deuterium relationship and influencing factors

Craig, (1961) analysed some 400 water samples which were converted to a gas phase on a mass spectrometer. The samples included water from rivers, lakes and precipitation with 40% of the samples collected from North America and the rest from all around the world. The data was plotted on a δ^{18}O against δD scatter plot (Figure 1-7). Most of the precipitation samples are plotted on a fit line called the Global Meteoric Water Line (GMWL) which has a slope of 8 given by the equation:

$$\delta D = 8\delta O^{18} + 10 \qquad \dots (3)$$

Two other sets of samples are observed in Figure 1-7, with the river and lake samples from East Africa plotting on a dashed curved line with a slope of 5 at the high enrichment zone. These waters are exposed to some evaporation. Most waters exposed to free evaporation at room temperature tend to follow this trend. The slope of the two lines (5 and 8) are ratios of vaporization or precipitation under Rayleigh conditions at constant temperature of between -10℃ and +100℃. Craig (1961), therefore concluded that atmospheric precipitation seems to follow the Rayleigh processes at liquid-vapour equilibrium, while free evaporation processes are governed by kinetic factors. Some points on the diagram are influenced by the precipitation temperature.

The other set of data is that obtained from closed basins where the isotopic relationship is governed mostly by evaporation. This data is indicated by an ellipsoid in Figure 1-7 and they plot away from the precipitation fit line.

Figure 1-7 also shows sets of data enriched with oxygen-18 and deuterium and those depleted. Tropical samples show enrichment, while snow and ice from the Arctic and Antarctic are represented by points lighter than -160 and -22 per mil of δD and δO^{18} that show depletions relative to ocean water. The vapour is removed from poleward moving atmospheric air; hence, the observed data from the Arctic and Antarctic ice and snow samples.

Isotope data is therefore, compared to the GMWL, and the data is interpreted relative to this line.

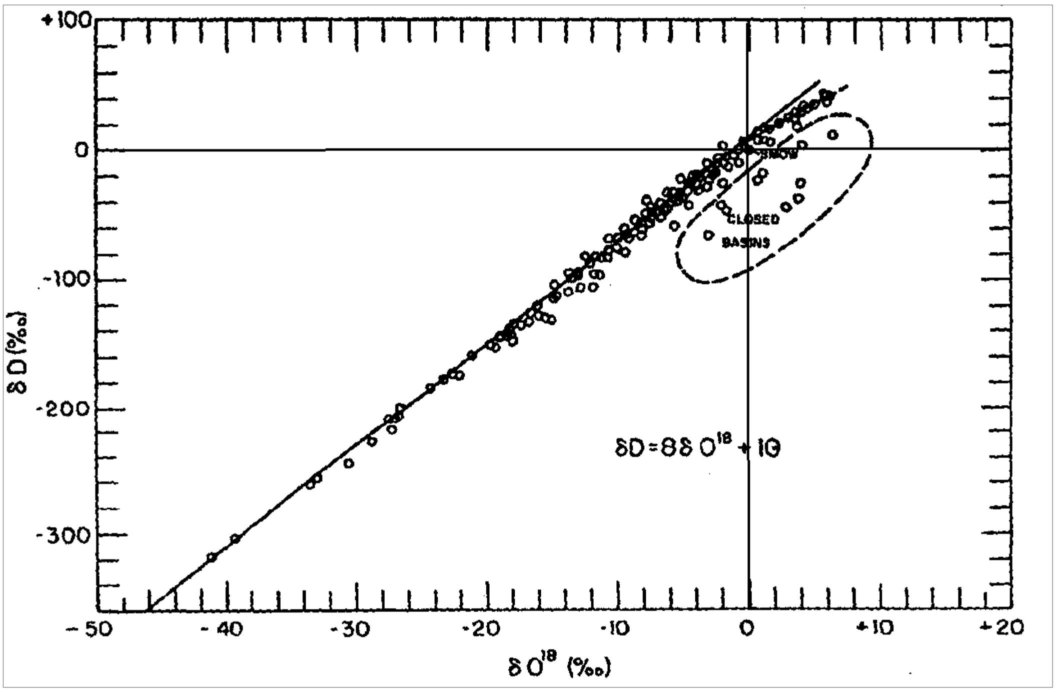

Figure 1-7. A scatter plot of Deuterium and Oxygen-18 variations in rivers, lakes, and precipitation expressed in per mil, (edited from Craig, 1961).

The d-excess value

Recharge and evaporation characteristics in groundwater and surface water can be determined by calculating the d-excess of the particular sample. The d-excess is defined by the formula

$$d = \delta^2 H - 8 \times \delta^{18} O \qquad (4)$$

This value will be less or will decrease due to evaporation of recharging water. Surface water is, thus expected to have low d-excess values than rainwater, which rapidly recharged groundwater. In cases where groundwater is found to have low d-excess values than the corresponding rainwater, this may indicate standing water prior to recharge, exposing it to evaporation. The groundwater d-excess values may thus indicate the effect of evaporation before and during recharge. The d-excess value was used to show different recharge mechanisms for two water bodies in an alluvial aquifer (Choi, et al., 2010).

The d-excess value varies seasonally, where it is usually higher in winter than in summer due to a difference in moisture contribution. Precipitation samples tend to show a good correlation of the d-excess value with changing season when compared to surface water (Figure 1-8). The seasonal variation in both groundwater and surface water is used to study the water residence time. The observed lower variation of the d-excess observed for surface water when compared to rainwater in Figure 1-8 is due to longer residence time of infiltrated water, as well as other inputs like groundwater and snowmelts. Evaporation may also occur during infiltration resulting in depleted d-excess (Katsuyama, et al., 2015).

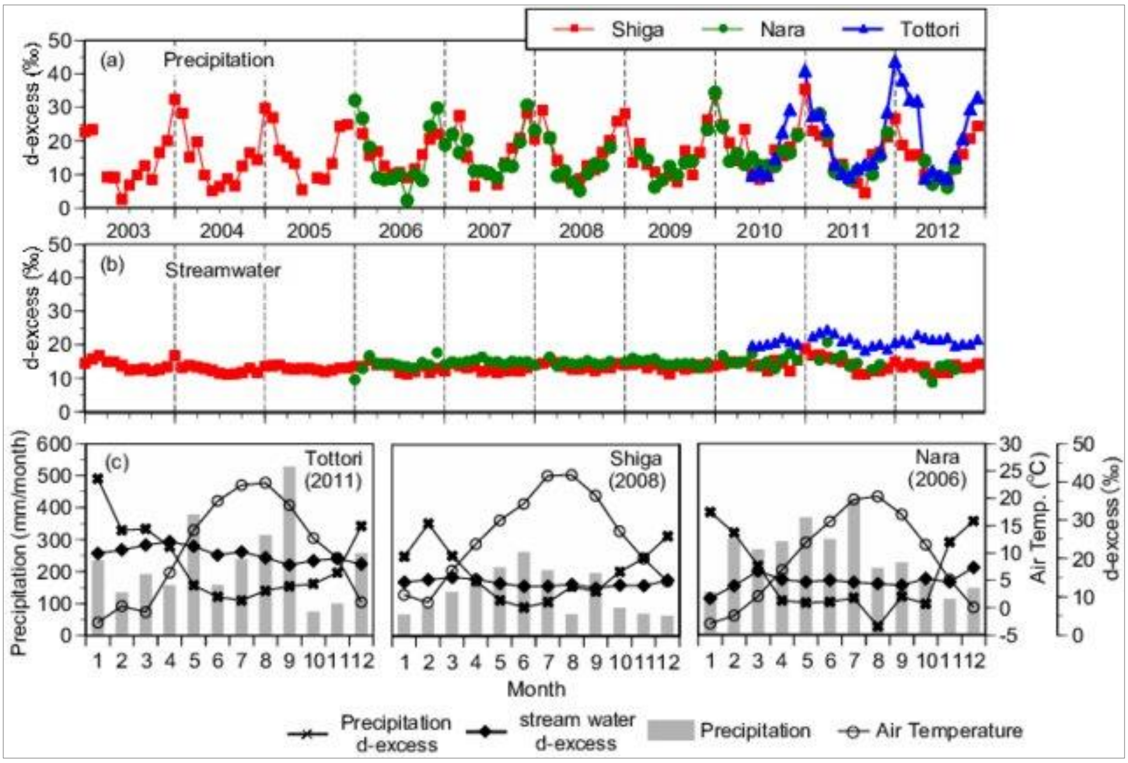

Figure 1-8. Seasonal variation of d-excess values in precipitation and stream water. (a) Long-term variation of monthly d-excess in precipitation. (b) Long-term variation of monthly d-excess in precipitation. (c) Typical examples of monthly d-excess values with monthly precipitation and air temperature (Katsuyama, et al. 2015).

Stable water isotopes in the hydrological cycle

According to Gomez, et al., (2016) the analyses of isotopic compositions of deuterium, oxygen-18 and tritium can be used in different stages of the hydrological cycle to assess groundwater flow patterns, as well as groundwater age, residence times and the evaporation effect on both groundwater and surface water.

Holmes, (2012) indicated the importance of collecting isotope data over a broad spatial scale and longer time series to produce isoscapes. The editors in (Holmes, 2012) defined isoscapes as maps that show stable isotope variation. These maps can be used to determine origins, for example, water sources. This information can further be used to solve other puzzles making isotopes a tool that can be used in broad ranges, including climate models. Among similar studies conducted, include a long-term collection of 435 water samples of precipitation (as rainfall), rivers, springs, seeps, and boreholes. The water samples were collected over a period of two years (2010 to 2012) with the aim of studying the hydrology of Table Mountain Group in South Africa (Diamond, 2014).

Interaction between water resources

Rainfall has a specific isotopic signature, once recharged into the ground, the ^{18}O and ^{2}H isotopes become very conservative underground and can thus be uniquely used as tracers to surface processes that occurred prior to recharge. The sources can be determined by calculating the stable isotope ratios. Old and newly recharged water is usually isotopically different, and will thus, give rise to different isotopic ratios. The isotopic signature of groundwater is usually constant due to minimal processes like evaporations that give rise to fractionation. Thus, any additions as recharge will be quickly picked up when drawing conclusions from the isotopic signature and so is additions to surface water from other water sources (Standnyk, et al., 2005).

Abiye, (2013) indicated how the isotope hydrology study can be used in assessing water resources at local and catchment scale. In his study, he indicated how environmental isotope studies can be used to study the transport and interconnectivity of water resources in the environment through measurement of isotope ratios that make up the water molecule, as well as constituents dissolved in water that could result in change in the hydrogen and oxygen isotopes. During transport, water obtains different isotopic signatures depending on the processes it undergoes, and these can then be traced along its flow path.

Figure 1-9 shows a conceptual model for a study conducted in China. The river hydrological processes and water resource management were studied. Findings from the study indicated similar isotopic values of shallow groundwater and the river. Higher values were observed for these two water resources compared to rainfall, indicating the effect of evaporation from the river and the shallow phreatic zone. Groundwater-surface water exchange was observed more upstream than downstream. The lake isotope values were highest indicating higher evaporation effect and are fed by springs. The deep groundwater is fed by shallow groundwater and river water (Hao, et al., 2019).

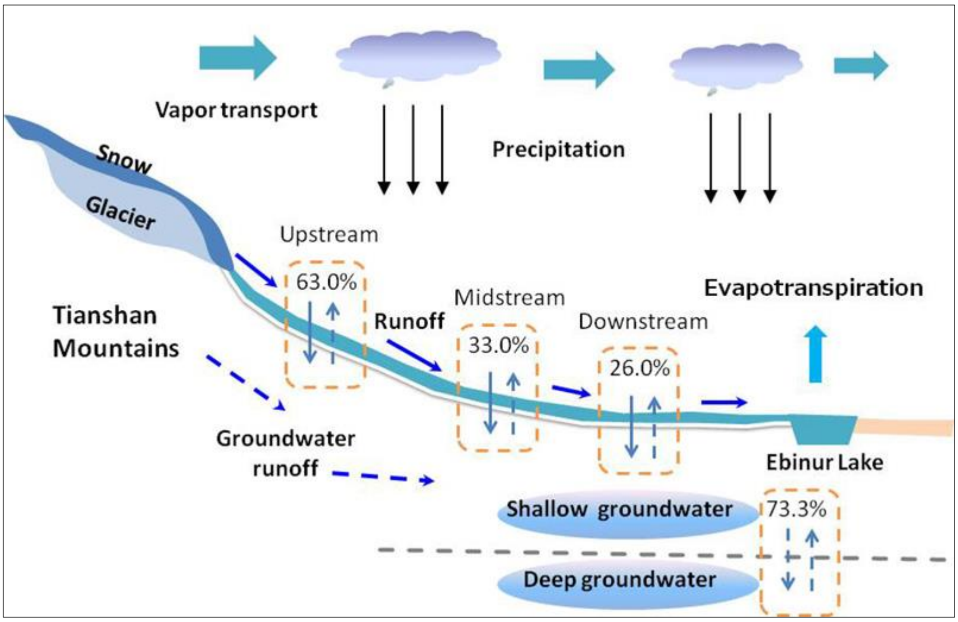

Figure 1-9. Conceptual model of the regional water cycle and the conversion rates in the Ebinur Lake Basin in China (Hao, et al., 2019).

Assumptions that limit the usage of the stable water isotopes in determining the source of water come about when there are other end members with different isotopic signature contributing to a particular water source. It is usually assumed that their contribution is negligible even though they have a different isotopic signature. It is also assumed that each end member has a constant isotopic composition (Standnyk, et al., 2005).

1.2.5 Isotopes as tracers for contaminants

Numerous processes like dissolution, cation exchange, chemical reactions, and mineral depositions may contribute to changes in water types from its source. Since stable water isotopes are conservative, they are used in addition to hydrochemical data in cases like these to determine water sources (Jahanshahi and Mohammad, 2017).

Abiye, (2014) studied the impact of mine water on the groundwater and surface water quality in the south of Johannesburg, South Africa using geochemical data. The findings that mine water leaches into the fractured crystalline, and dolomitic aquifers which further daylights in surface water through baseflow were further substantiated by an isotope study that was conducted in the upper Crocodile River Basin in Johannesburg. The isotope study indicated an existing hydraulic connection between surface water and groundwater, where groundwater was negatively impacted by decanting mine water feeds into surface water, and thus deteriorating the surface water quality. The stream also recharges groundwater through fractures and cavities in the dolomitic aquifers. The findings were indicated by the similar isotopic values of surface water and groundwater (Abiye, et al., 2015).

1.2.6 Tritium isotope as a recharge estimator

Tritium is a radioactive isotope that can be used to study water circulation in the hydrological cycle, as well as the seasonal rainfall pattern. It can occur naturally in Southern African rain in concentrations of 3 tritium units (TU) produced by cosmic ray interaction. In that case, its concentrations can be used to determine rainfall recharge into the aquifer and even surface water. To determine the recharge period of recent rain, the groundwater tritium content in that groundwater area needs to be compared to that of recent rainwater. Tritium contents greater than zero in groundwater will indicate recharge, while zero tritium content in groundwater will indicate slow or no recharge to that particular aquifer (Abiye, 2013).

1.3 The purpose of contaminant transport studies

Life continues, people will also continue dying, and burials will continue to occur. However, measures and awareness need to be put into place to ensure that death and burials do not result in those left behind consuming polluted water due to the decomposition of the dead (Idehen and Ezenwa, 2019).

The current study investigates the impacted of the local water resources whose quality are believed to be impacted by cemetery decomposition products. The study is presented in the form of a contaminant transport study. The information gathered in the study in terms of a literature review and case study will in future assist in choosing burial areas and designing burial methods in such a way that there is less to no negative impact on underlying and nearby water resources’ quality. The results can also be used currently to manage the cemetery under study.

Unlike most studies where water chemistry alone is usually used to study contaminant transport, stable water isotopes were used as indicators to study the interaction of water resources. Isotope results are also used to substantiate geochemical findings among other interpretation methods distinguishing between evaporated and unevaporated water, because unlike most chemical parameters, they are conservative and are not affected by any chemical changes but only physical changes (Standnyk, et al., 2005).

2 Chapter II: Site description - Fontein Street Cemetery, Middelburg, Mpumalanga, South Africa

This section details the work carried out at a cemetery in Middelburg, Mpumalanga, province of South Africa. Monthly surface and groundwater monitoring were carried out and included the collection of water samples from boreholes drilled within the cemetery area, private boreholes that belong to the residents of Middelburg around the study area and from a stream that flows downgradient of the cemetery. Water samples were handed over to Waterlab (Pty) Ltd laboratory (Waterlab), where analyses were carried out for inorganic parameters. The water samples were also analysed for stable water and tritium isotopes. Hydraulic tests were carried out on the boreholes drilled and located within the cemetery, as well as selected surface areas near each of the boreholes in order to characterise the hydraulic characteristics of the unsaturated zone within the study area. Results were presented and interpreted, and conclusions were based on the results obtained and compared to findings from previous studies.

2.1 Locality and land-use

The study area selected includes an approximately 120 years old 15.8 Ha cemetery, which is still in operation (Middelburg Cemetery but termed Fontein Street Cemetery in this study). The cemetery is occupied by, among the new graves, 1 381 graves of women and children who died in the concentration camp which was built in Middelburg during the 2nd Boer War, hence the cemetery is also known as the Mineralia concentration camp cemetery (Wikipedia, 2019; Bergh, 1999).

Fontein Street Cemetery is located in Middelburg, a farming, and industrial town in Mpumalanga province in South Africa (Figure 2-1). The cemetery is situated in a small town named Mineralia that is about 1.5 km north of Middelburg Mall and about 4.5 km north of the N4 highway, at the following coordinate: -25.790884° 29.462134° (cemetery entrance). The area is served and managed by Steve Tshwete Local Municipality, which falls under the Nkangala District Municipality.

Upgradient of the cemetery is a park/soccer field, which was previously a dumping area (indicated by a yellow polygon on Figure 2-1). This could influence the chemical results of the water samples obtained from the study. An upgradient borehole was drilled within the cemetery with the aim of isolating and estimating the effects of upgradient contributors including the dump from the graveyard. The cemetery is surrounded by residential areas, a shopping mall at about 1.5 km upgradient (Middelburg Mall), the main road R35 (Samora Machel St./Fontein Street) runs to the west of the cemetery, and the N4 highway is upgradient of the study area. A stream runs in the north-easterly direction downgradient of the cemetery.

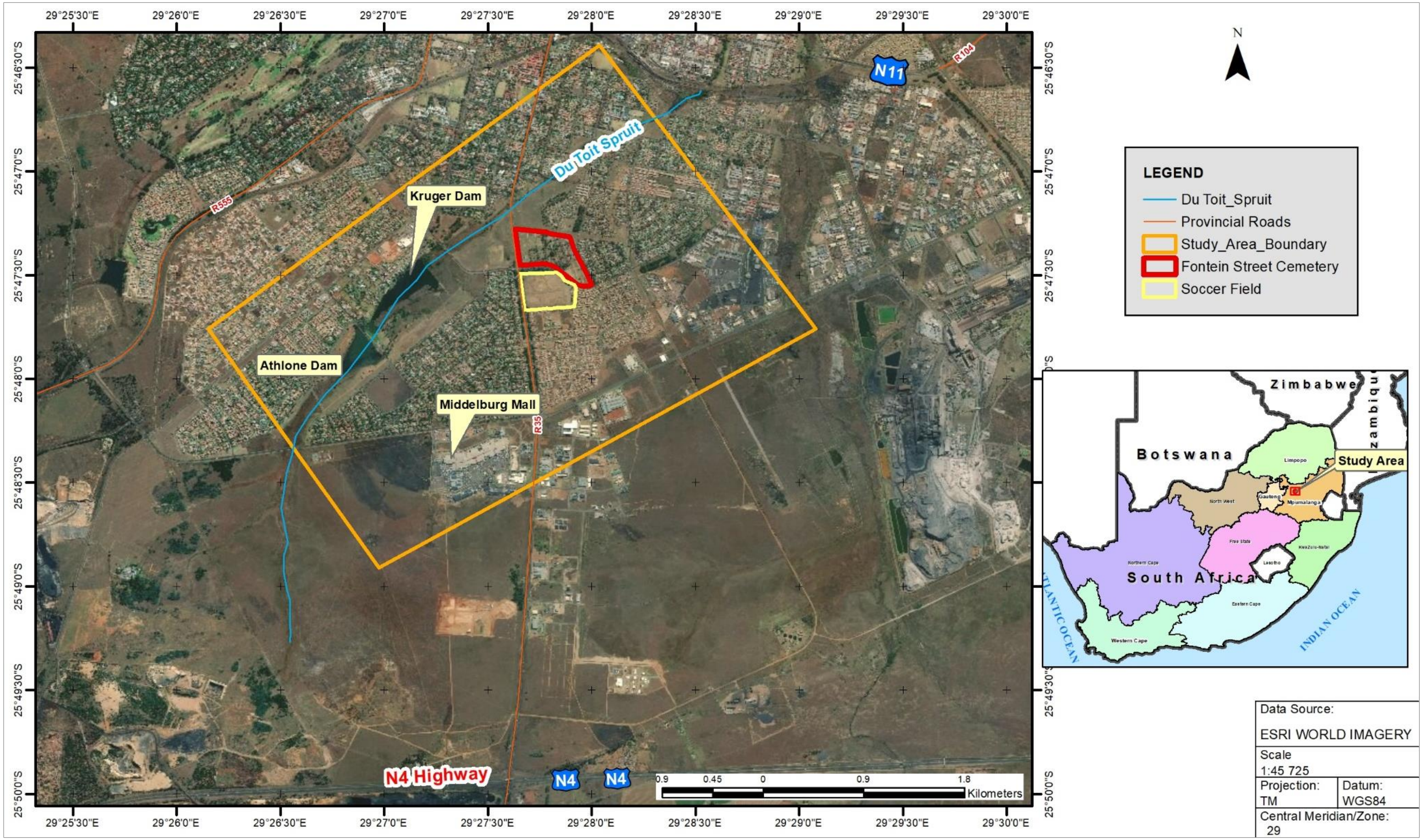

Figure 2-1. Satellite image showing Fontein Street Cemetery (red polygon), the soccer field (Yellow polygon) and other features of the study area.

2.2 Climate

Figure 2-2 shows average monthly temperature and precipitation for Middelburg. Middelburg climate is warm. Temperatures can get as high as 27℃ in December and January, which are the warmest summer months. July and June are the coldest months and temperatures can drop to as low as -1℃. Middelburg experiences summer rainfall with the highest monthly average of 115mm experienced in November. July is the driest month with a rainfall average of 5mm. The area receives an average annual precipitation of 683mm (Climate-Data.org, 2017). The monitoring programme was carried out during the rainy season of the area, between October 2016 and March 2017 with the aim of sampling recently recharged water from the shallow monitoring boreholes. The rainfall data for the entire monitoring period is presented in Figure 2-3. The data was obtained from the South African Weather Services (SAWS) and was recorded from station number 0515826, closest to the site. The results indicate that Middelburg received a mean precipitation of 60mm and a total volume of about 1024.8 mm from the beginning of February 2016 to the end of June 2017. Although Middelburg experienced some rainfall during winter, most of its rainfall occurred during summer from October to April, with the highest volume experienced during March 2016 and November 2016. The lowest rainfall was experienced in August (1.6 mm). This corresponds with the findings by Climate-Data.org, (2017).

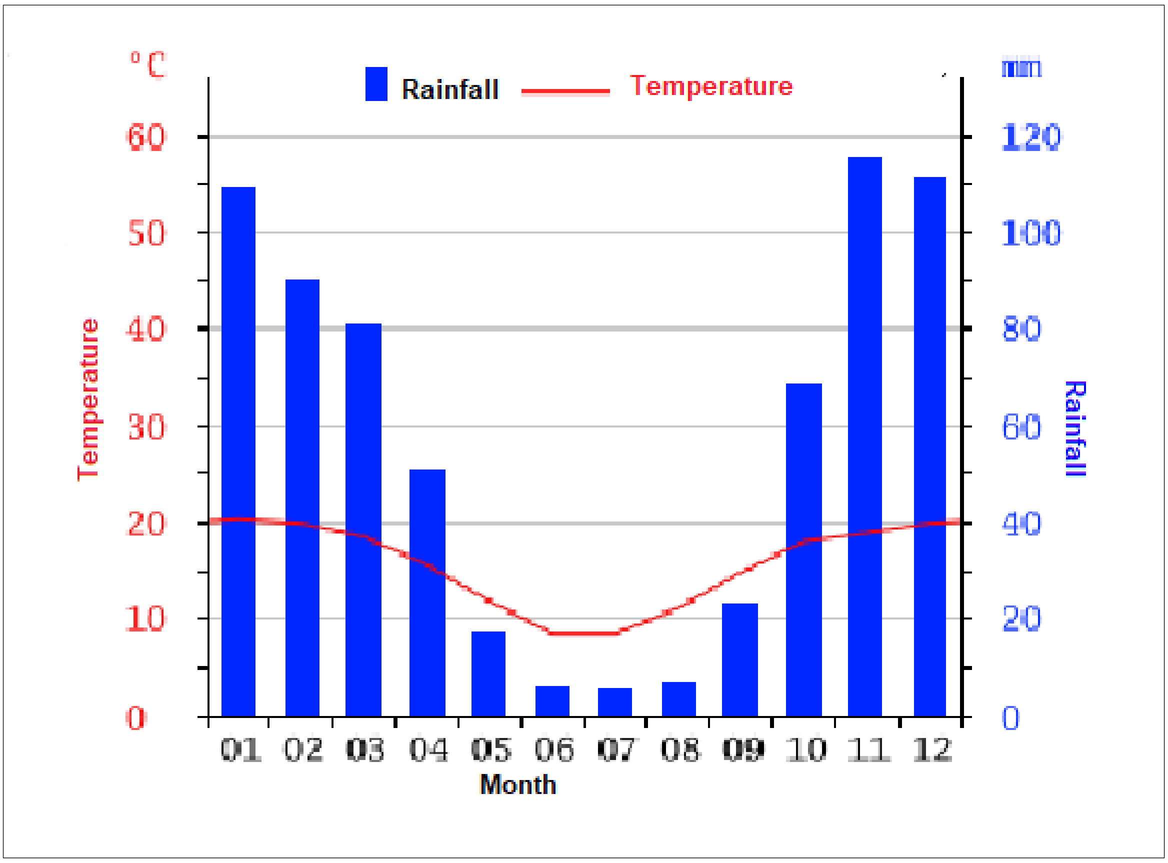

Figure 2-2. Middelburg average monthly rainfall and temperature in 2017 (Climate-Data.org, 2017).

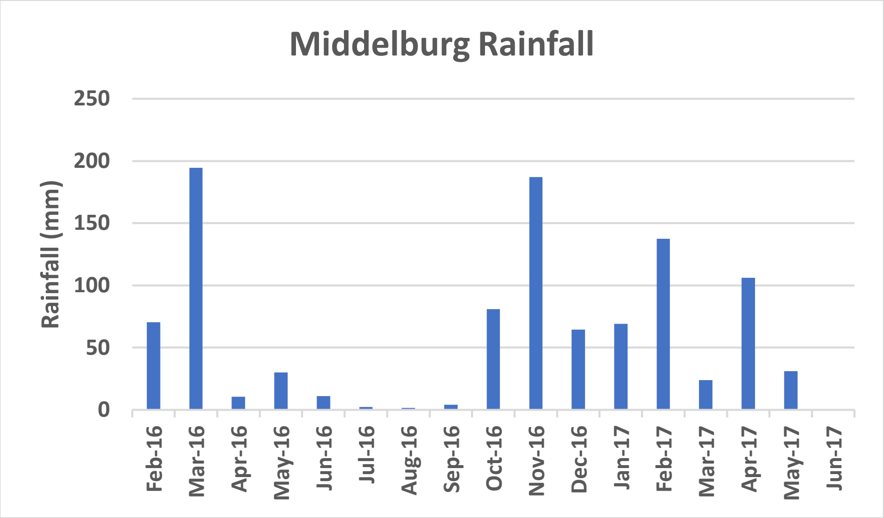

Figure 2-3: Middelburg monthly rainfall at Station 0515826 (data from South African Weather Services (SAWS)).

2.3 Geology

The study area is underlain by the Dwyka Group of the Karoo Supergroup of which its main component is the tillite. Some shale, sandstone and conglomerate are present (Figure 2-4). According to Johnson, et al., (2006), the Karoo Supergroup consists of thick layers of mudrock and sandstone with tillite at the bottom and dolerite intruding the Supergroup.

The area is characterised by Weinert's climate N-value ranging between 2 and 5, weathering is therefore not significant in this area. This is largely dependent on the humidity of the area (the lowest recorded during the study period was in August 2016, 35% and the highest in February 2017, 74% (World Weather Online, 2019). The tillite of the Dwyka Group weathers to clay minerals (illite and kaolinite) (Brink, 1983).

Some of the study's monitoring points, i.e. the two downstream sampling points in the stream and the two boreholes located downgradient of the study area are underlain by shales, sandstone and conglomerates.

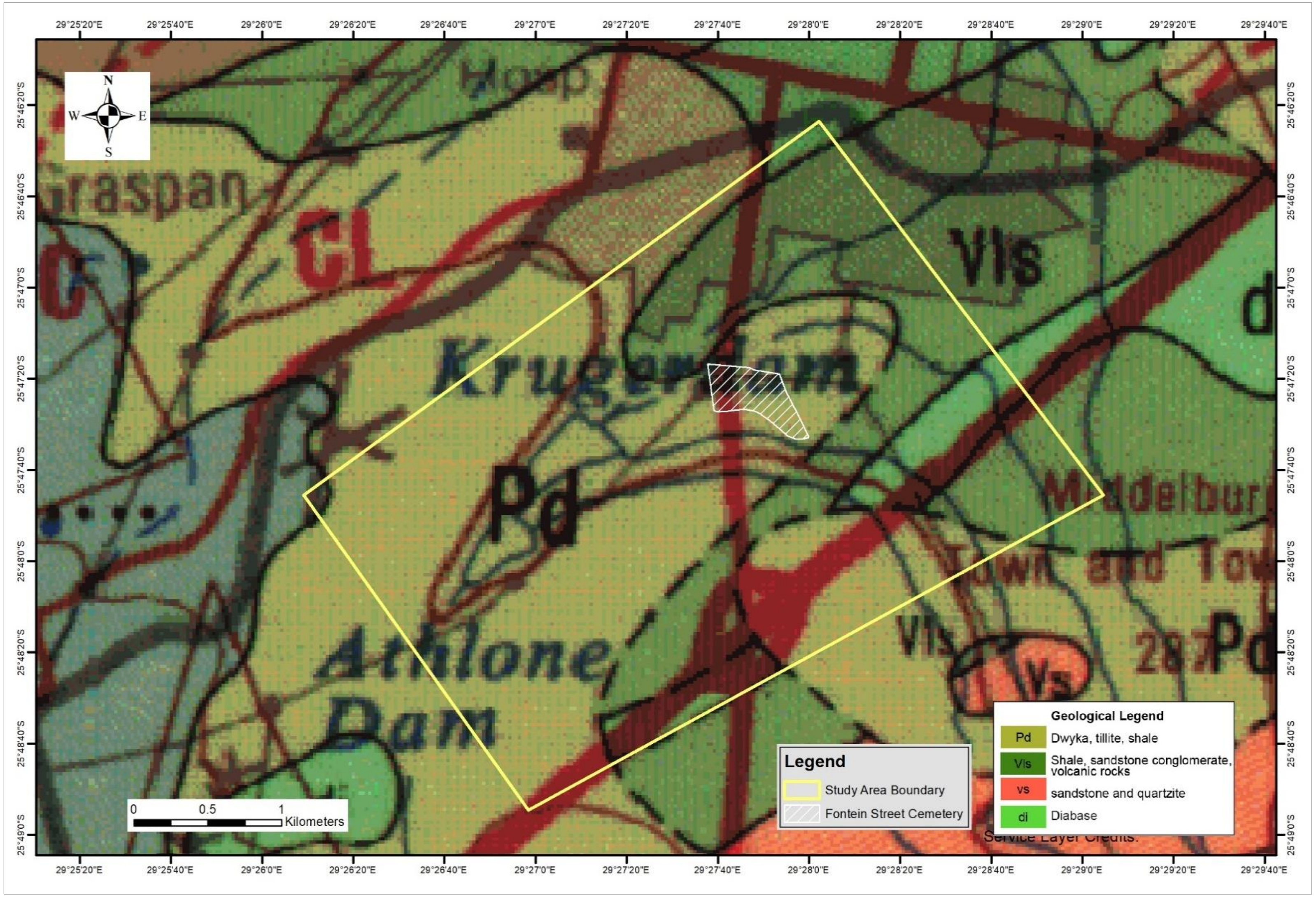

Figure 2-4. Geological Map of the Study Area (Johnson and Wolmarans, 2008).

2.4 Surface drainage

The study area falls under the Olifants River catchment of which the source of the community water supply (Middelburg Dam) is also part. Previous studies conducted on water quality of the community's supplied water indicated elevated sulfate, TDS, ammonia, and nitrate concentrations. Historical data indicates increasing sulfate concentrations since the 1970s, adding to the deterioration of the Middelburg Dam water quality. Possible sources are not only decants and seepages from old mines around the area, but also seepage from waste facilities located next to streams and spills from polluted water management systems and industries (Aurecon, 2011).

A stream which flows to the north-eastern direction is located within a kilometre downgradient from the cemetery. Some wetland areas are also observed in the area indicated by the green (wetland vegetation) and blue fields near the stream area (Figure 2-5). Two Dams, Kruger Dam and Athlone Dam, are situated upstream. The dams provide habitat for some aquatic organisms like fish and other small living organisms. This was evidenced during a hydrocensus where people were observed fishing from these dams.

As part of a desktop study, a 5m contour map of the study area was generated from existing elevation data (Figure 2-5). From the contour map, it was evident that the site has a gentle topography but sloping towards the stream area on both sides of the stream. Other information that can be derived from this map includes the estimated groundwater flow direction, assuming that groundwater flow direction mimics topography. The groundwater and surface water flow directions are indicated by blue arrows on Figure 2-5. It was determined from this map that groundwater flows from the cemetery towards the stream and the same is observed from the northern side of the stream where groundwater flows from the residential area to the stream. The groundwater flow direction is further confirmed from the groundwater levels measured in the drilled boreholes, explained later in the results section.

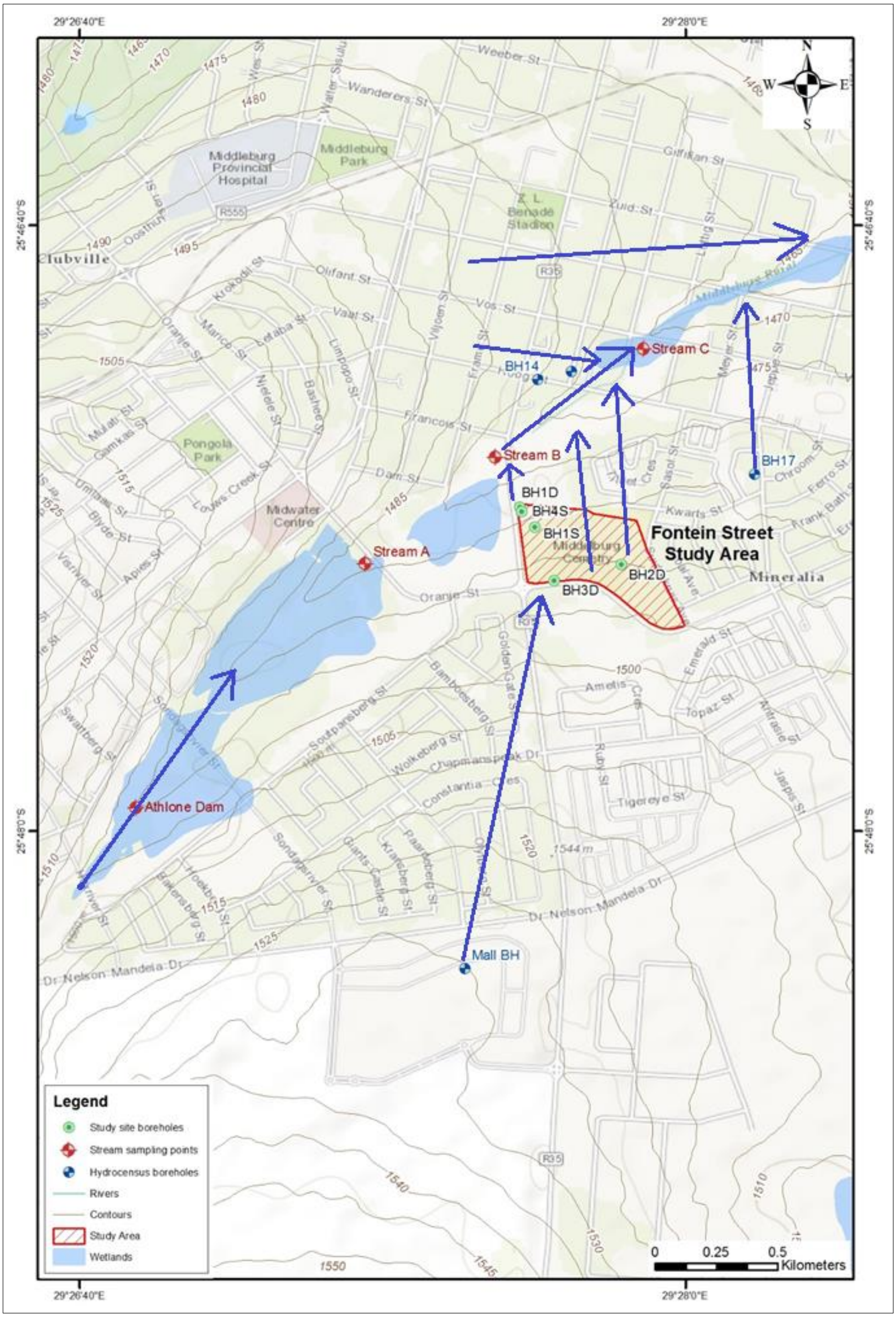

Figure 2-5. Topographical map of Fontein Street Cemetery and surrounding areas showing estimated groundwater and surface water flow direction (blue arrows) (Department of Rural Development and Land Reform, 2006).

2.5 Aquifer classification

According to The Department of Water and Forestry (DWAF) (2008), the area is classified under one of the six Vegter hydrogeological regions (the Middelburg Basin hydrogeological region). According to the Department of Water and Sanitation (DWS) (2012), the aquifer underlying the area is classified as a minor aquifer. This type of aquifer does not have high primary permeability and has a moderately yielding system of variable water quality (DWAF, 2008). Boreholes in this region are moderately yielding with a median yield range of 0.1-0.5 l/s for intergranular and fractured type of aquifer (Figure 2-6) (Barnard, 1999).

The area is underlain by fractured aquifers of low development potential. Such aquifer systems are known to possess a low risk to pollution. The shales in the area are characterised by low permeability. Permeability is higher at contacts between shale and sandstone rocks and possibly at contacts between the country rock and where a dolerite dyke has intruded. Seepage of water through these rocks takes place mainly through the joints (Brink, 1983).

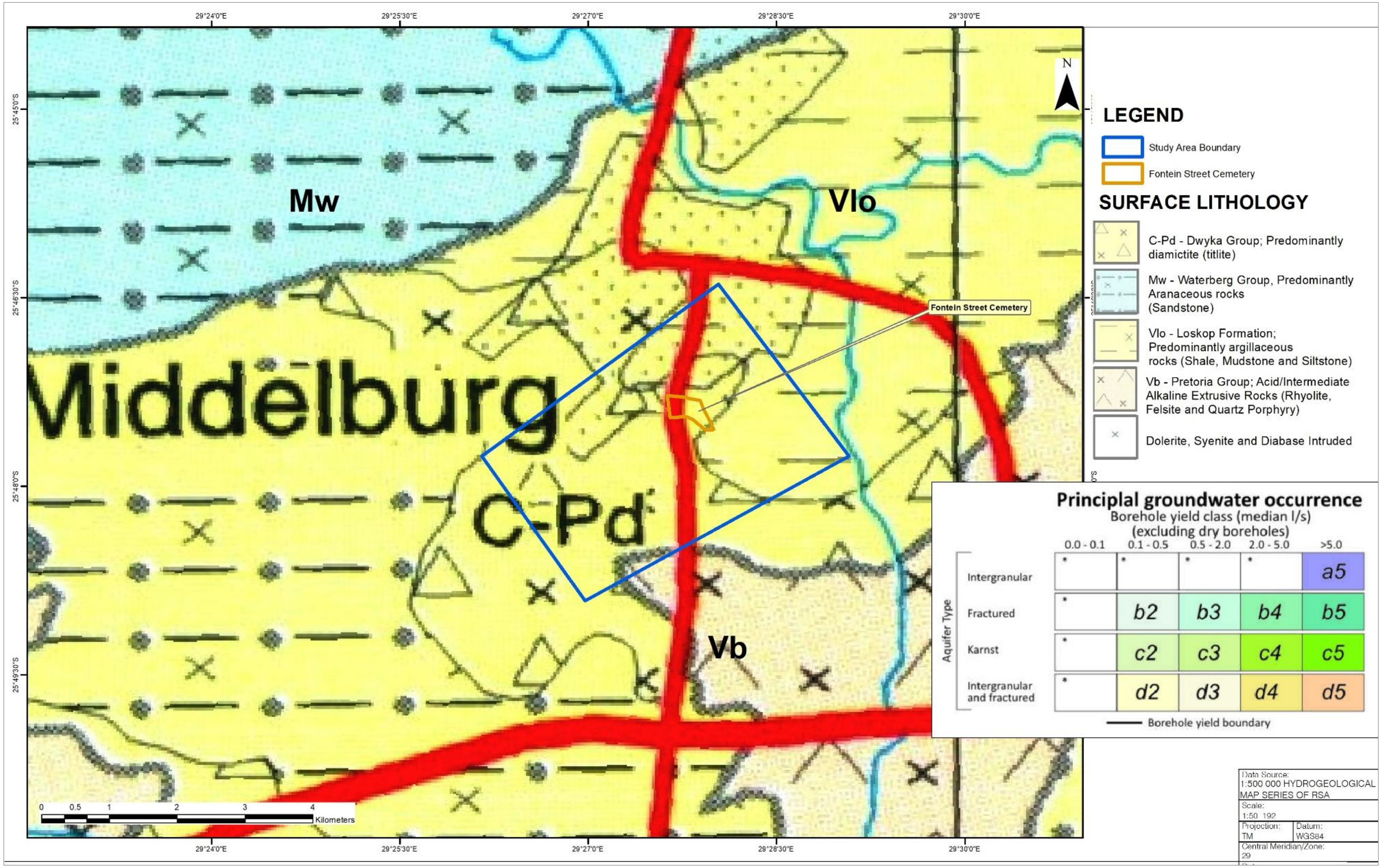

Figure 2-6. Hydrogeological map (Barnard, 1999).

3 Chapter III: Methodology and Approaches

This section describes activities carried out during the investigation to obtain all the required data for the study. Sampling locations were selected based on the aim of the study. They were located within the cemetery, upgradient, and downgradient of the cemetery. The drilling procedure, sampling protocol, analytical procedure, and a brief statistical analysis are described.

3.1 Desktop study

The desktop study involved all work done prior to starting the actual fieldwork and comprised mainly the experimental design.

Work carried out during the desktop study included the following:

3.1.1 Site selection

Selection of the study site was based on the following:

- agreement with involved parties i.e. the University (lecturers and students), the municipality, the project sponsors; Water Research Commission (WRC) and thus the funding;
- age of cemetery;
- accessibility for conducting scientific research;
- geology;
- hydrology and hydrogeology; and
- additional information regarding the study area and its relation to nearby water sources obtained during the desktop study.

Fontein Street Cemetery was thus chosen as the study area for the case study.

3.1.2 Review of available documents

A review of available information about the selected study area was carried out, and that included: a review of available maps (geological, hydrological, hydrogeological, topographical, etc.), a review of similar or other studies carried out in the same area or near the study area, and a review of other useful information published about the site available from published documentation, such as climate, hydrology, hydrogeology, land-use, etc.

The information obtained from the review was used to plan for the fieldwork, select study location and design a monitoring plan. The decision on materials to be used and methods to be applied to carry out the investigation were selected and based on similar work previously carried out.

3.1.3 Planning for fieldwork

A meeting was held among the project team, including students, WRC, Steve Tshwete Local Municipality (STLM) and supervisors from the University of Pretoria (UP) and the University of KwaZulu Natal (UKZN). During the meeting, the work to be carried out on the study area was discussed and that included, planning an initial site visit to familiarise the researcher with the site, planning for a hydrocensus, selection of positions where boreholes are to be drilled, and planning a monitoring programme and sampling protocol.

3.2 Hydrocensus

A hydrocensus was conducted around the study area, with the aim of identifying water sources in the area, their uses, as well as potential receptors to possible contamination and sources thereof. It was tried by all means to limit the hydrocensus to within 1 km radius of the cemetery and to accessible water sources and groundwater users. The process included a desktop study, which involved searching for boreholes located within the study area on the National Groundwater Archives (NGA) website, by using four sets of coordinates from the polygon delineating a 1 km radius from the study area. Unfortunately, there were no boreholes found to be registered on the NGA website. A tour around the study area was conducted on the 8th of November 2016. The residents within the Mineralia town assisted in identifying households that had boreholes. The easiest way to find household boreholes was to find signs with the word "Boorgat", an Afrikaans word that translates to "borehole" in English, which were placed at the outside wall or gate of a household that had a borehole installed. The hydrocensus also included identifying surface water bodies and details about their surrounding areas (Figure 3-1**Error! Reference source not found.**).

During conduction of the hydrocensus, details of the identified boreholes were recorded. The descriptions included GPS coordinates, description of their location relative to the cemetery and potential sources of contamination, owner's details, and their drilling information (drilling dates, depths, etc.). Short interviews were conducted with the borehole owners about the use of groundwater in the area. Water samples were collected from their taps that lead from the borehole pumps or the tanks where the pumped water is stored. In case of surface water, water samples were collected directly from the stream. Field parameters were measured, and lastly, photographs were taken where possible.

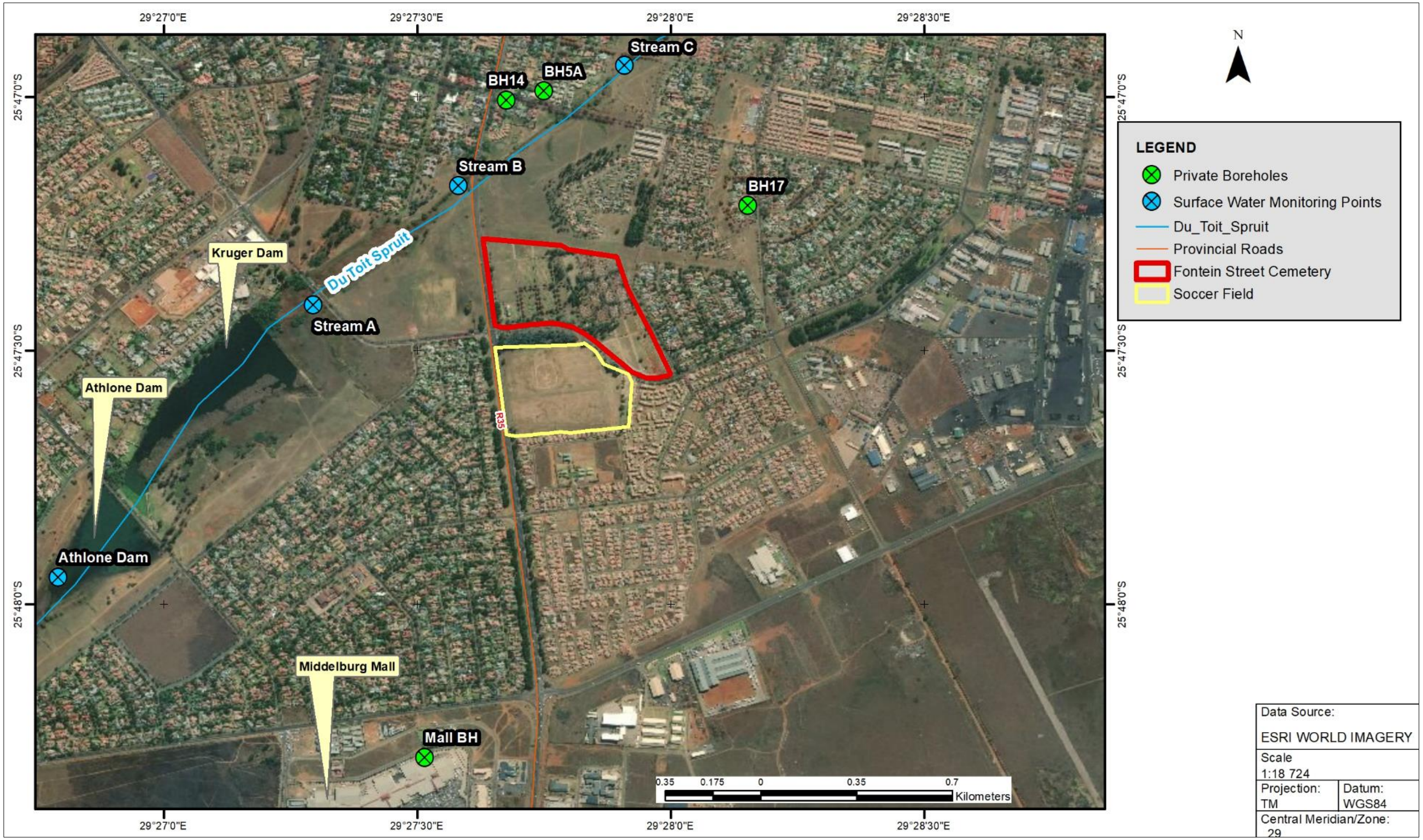

Figure 3-1. Hydrocensus monitoring points locations.

3.3 Monitoring boreholes installation

Monitoring wells were drilled within the cemetery with the aim of using them as groundwater monitoring points, as well as to perform field permeability tests on them, to estimate hydraulic characteristics of the unsaturated and saturated zones of the underlying area. A total of four monitoring holes were drilled using a drilling rig, and one hole was excavated by hand using pick and shovel.

3.3.1 Selection of monitoring borehole positions

Positions for drilling and excavating monitoring points for groundwater were selected based on the purpose of the study. The boreholes were meant to monitor and compare local groundwater physical, chemical, and isotopic properties from upgradient to downgradient of the cemetery, assuming groundwater flow direction mimics topography. Four drilling locations were proposed. The locations were labelled BH (Borehole) with the next letter indicating the depth of the borehole in relation to the shallowest and a numerical number based on the drilling sequence, e.g. BH1D is deeper than BH1S and was drilled first.

3.3.2 Drilling

The boreholes located within the cemetery were drilled by 121 Drilling using air percussion drilling method on the 10th February 2016 (Figure 3-2). Four boreholes were drilled to shallow depths (BH1D, BH1S, BH2D, BH3D) with the deepest borehole being 17 meters below ground level (mbgl) (BH1D). Their positions are shown in Figure 3-3.

During drilling, drill samples were collected at every meter and laid out on the ground in the order of increasing depth as indicated by Figure 3-4

Geological logging was carried out according to the standards outlined in the guidelines for soil and logging in South Africa (Brink and Bruin, 1990). The final logs were plotted using the Log plot software and are presented in Appendix A. Photos of the drill samples were taken and presented in Figure 3-4. The figures are labelled with arrows showing drilling progress from surface and text indicating water or seepage strikes.

Some challenges were experienced during drilling of the boreholes upgradient and to the west within the graveyard (BH2D and BH3D) where collapsing at depth below the water table occurred due to the highly weathered formations intercepted. The drill rods and bit were withdrawn as a result, and 3m long, 6.5inch diameter plain steel casings were installed at the surface. These boreholes were later (from April 2016 and the latest installation being in February 2017) equipped with 53mm diameter slotted un-plasticised Polyvinyl Chloride pipe (uPVC) casings with caps at both ends, and gravel pack was added outside the PVC casings. The aim of adding the gravel was to enhance the efficiency of the borehole during pumping and filter the water inside the boreholes of aquifer fines, to ensure water with less turbidity water was sampled.

Figure 3-2. Drilling of monitoring boreholes at Fontein Street Cemetery.

Figure 3-3. Cemetery borehole positions.

Figure 3-4. Photos showing drill samples laid on the ground. Red arrow shows the direction of increasing depth.

3.3.3 Excavation

The 5th groundwater monitoring point (test pit BH4S) was excavated by hand as it was later realised that there was a need to have an additional shallow monitoring point at the centre of the cemetery area between the upgradient borehole (BH3D) and the downgradient boreholes (BH1D and BH1S). The work was carried out in June 2016 by Prof. Simon Lorentz with assistance from casual labourers from eMalahleni (Figure 3-5). The pit was dug to a final depth of 1.60 mbgl and equipped to depth with a slotted 53 mm diameter uPVC casing capped at both ends. The decision on the final depth of the pit was determined by the ability to excavate further, as hard rock was intercepted at the final depth.

Table 3-1 gives details on boreholes installed within the cemetery that were used as part of the groundwater level and quality monitoring. The water levels presented in Table 3-1 are those measured in October 2016, eight months after drilling. During this period most of the boreholes onsite were dry with groundwater detected in only one of the deepest boreholes, drilled to a depth of about four metres below the water table and about 8 mbgl (BH2D).

Figure 3-5. Excavation of the 5th groundwater monitoring point.

Table 3-1: Cemetery borehole details.

Borehole ID	**Depth (mbgl)**	**Static Water level (mbgl)**	**Location (Lat, Long, Elevation (mamsl))**	**Construction details**	**Location onsite**
BH1S	1.56	Dry	25°35’57.6” S 28°27’04.8” E 1388	Equipped with 53mm uPVC plastic casing to depth, capped at both ends	Downgradient of cemetery.
BH1D	3.74	Dry	25°47’17.0” S 29°27’38.1” E 1488	Equipped with outer 6m long, 6.5” diameter plain steel surface casing and 53mm uPVC plastic casing to depth, capped at both ends inside the steel casing	Downgradient of cemetery. Close to and downgradient but deeper than BH1S.
BH2D	8.10	5.13	25°47’24.75” S 29°27’51.7” E 1500		Centre and upgradient of Cemetery, Deepest borehole onsite
BH3D	5.42	Dry	25°47’26.6” S 29°27’42.8” E 1499		Upgradient of cemetery and downgradient of soccer field
BH4S	1.60	Dry	25°47’19.4” S 29°27’40.5” E	Equipped with 53mm uPVC plastic casing to depth, capped at both ends	Centre of cemetery, downgradient of BH3D

3.4 Determining hydraulic parameters

Two types of hydraulic tests were carried out at the cemetery. One was conducted on the surface, and one was conducted underground inside the boreholes. The selection of the tests to be carried out was dependent on information to be gathered, available labour and equipment, as well as the need for more quantitative data for the different phases in the hydrological cycle. The tests carried out were; the double ring surface infiltration test and the falling head or slug test. The infiltration test was carried out as outlined in the South African National Standard No. 10252-2 (SANS, 1993) (Part 2: Drainage installations for buildings).

3.4.1 The double ring surface infiltration test

The aim of conducting the DRI tests was to determine the downward entry rate of water directly from the soil and infiltrating into the soil during a rainy event situation, where the soil becomes saturated, and movement of water is downward. The tests were carried out in June 2017 together with the falling head tests. It was ideal to carry out the tests during the dry season when there is low or no recharge when the groundwater level is at its natural lowest state. This increased the confidence in our results as there were no other water sources during testing (Misstear, et al., 2017).

The DRI test was carried out using two rings, the large outer and the small inner rings of different diameters, in such a way that the one fits inside the other.

The following equipment was used (Figure 3-6):

- 30cm diameter and 20cm deep outer steel ring;
- 15cm diameter and 50cm deep inner acrylic glass ring;
- driving tool – a mallet was used specifically to avoid breaking the acrylic glass inner ring;
- spirit level, to ensure the rings are levelled properly;
- water supply was from a tank loaded on a bakkie; water was drawn from the tank using a garden hose;
- stopwatch – used cellphone built-in stopwatch;
- depth gauge, ruler;
- notebook for recording.

The surface DRI test (Falling head test) was carried out as per the South African National Standard (SANS, 1993) as follows:

- both rings were driven 5cm into the ground using a mallet;
- a ruler was affixed to the outside of the inner ring to monitor the water level inside the inner ring;
- water was added first into the outer ring. The water level in this ring was kept constant throughout the test;
- the inner ring was then filled with water. The time it took for the water in the inner ring to drop each centimetre was recorded;
- the tests were repeated where possible;

- note that the test was carried out at the same time as the borehole falling head test. The test was conducted downgradient of the borehole being tested so as not to interfere with the falling head test being carried out on that particular borehole.

Figure 3-6. Double ring infiltration test setup showing constant head kept in outer ring and observed falling head in inner ring.

3.4.2 Falling head tests inside boreholes

The falling head tests were conducted with the aim of characterising the hydraulic properties of the vadose zone and aquifer system, the near borehole-wall aquifer underlying the site. Falling head tests were conducted on the drilled holes and entailed displacement of the water level already in the hole, i.e. increasing the volume by simply adding more water into the hole. The rate at which the water level returned to its undisturbed state (the rate at which the aquifer was recharged) was recorded. The information obtained from the test was then used to estimate the aquifer's hydraulic conductivity. The AquiferTest software was used to interpret the results and calculate the estimated hydraulic conductivities (K) for each test. The Bouwer and Rice method was selected to perform the analysis (Bouwer, 1989). The results from the programme are presented in Appendix B.

The following equipment was used to carry out the falling head tests (Figure 3-7):

- water supply – through a garden hose from a tank loaded on a bakkie;
- an electronic water level metre to measure the hole depth and for water level measurements;
- a levelogger - measured the pressure from the water column above it, which was converted to the water level. The levelogger was placed at the bottom of the borehole;
- a stopwatch to record the time; and
- a water bucket to measure the flow through the hose used to add water into the borehole, this was necessary to calculate the volume of water added.

Figure 3-7. Measuring water level in BH3D during a falling head test.

The falling head test was carried out as follows:

- the static water level and borehole depth were measured and recorded;
- the levelogger was started, using the Solinst Levelogger computer software. The time on the levelogger was synced to that on the computer used to setup the levelogger. The levelogger attached to a secure cable was then placed at the bottom of the borehole. The cable was tied onto a fixed object on the surface, so the levelogger was retrievable;
- the holes were filled with water. The time filling started and stopped were noted and recorded. Depending on the permeability of the soil, some holes filled quickly and were filled to the top (BH1S BH1D and BH4S with shallow water tables and possibly low permeability) but some did not fill quickly (BH2D, BH3D those with a deep-water table situated upgradient in the cemetery);
- the initial depth to water was measured manually using the electronic water level metre and recorded. This was to ensure the accuracy of the data collected using the levelogger;
- the water level in the borehole started dropping, and the test was run for a maximum of 2 and half hours (for a less permeable site, BH3D); and
- the logger was then removed at the end of the test, and the data was downloaded using the computer’s levelogger software.

3.5 Sampling

Sampling procedures for groundwater and surface water were done according to the appropriate standards (Weaver, et al., 2007). The sampling procedures followed onsite, specifically for this study, are described in the section below. A monthly monitoring programme was planned, and the sampling was carried out each month, particularly on any day during the first two weeks of each month for consistency purpose. The programme was started in October 2016 through to June 2017. The last samples were collected in June 2017, when the hydraulic tests were conducted. Borehole conditions and the surrounding environment were also inspected during this time. That included measuring groundwater levels, stream water levels and other stream dimensions such as depth and stream width; photos were also taken where necessary.

3.5.1 Groundwater sampling

Groundwater was collected whenever possible. Most of the boreholes could only be sampled after a significant rainfall event, since they were shallower than the natural water table during the dry season. The sampling was carried out on the boreholes within the cemetery, and some of the boreholes identified during hydrocensus.

The following equipment was used to carry out groundwater sampling:

- a low flow pump that needed to be connected to a vehicle 12V battery to operate, was used to pump water from the borehole. The pump was equipped with a long plastic pipe that acted as a suction main during pumping;
- a 20L bucket was used to collect water during purging;
- sampling bottles for collecting water samples. 1L or 1.5L for collecting water to be analysed for inorganic chemistry parameters and metals, another 1L or 1.5L for tritium analysis and 15ml bottles for stable water isotope (Oxygen-18 and deuterium) analysis;
- a calculator for calculating volume to be purged where necessary;
- an electronic water level metre;
- pH, electrical conductivity (EC), dissolved Oxygen (DO), etc. probes for measuring field parameters during purging and sampling;
- plastic cups;
- notebook for recording results; and
- a bailor and pump for sampling. Either of the two was used to sample. A bailor was used where water columns were quite short, e.g. in BH3D and a pump was mostly used in BH2D with a 4m water column.

Groundwater sampling was carried out as follows (Figure 3-8):

- Firstly, the environmental conditions were observed, included the climate, most importantly, a record of any rainfall during or prior to sampling;
- the water level and depth of the borehole were measured; the volume of water to be purged was calculated. Purging was carried out to remove the stagnant water from the borehole; a fresh-water sample that was representative of the aquifer water quality conditions was required. The fresh-water sample comprises water that just percolated into the borehole and contains the actual chemistry of the aquifer. According to Weaver, et al., (2007), about three times the volume of the water in the borehole is the amount of water to be removed during purging;
- the pump was installed at a depth of just about half a metre from the bottom so as not to pump silt that had accumulated at the bottom;

- the borehole was purged, and the pumped water was collected in a 20L bucket, used to measure the volume of water removed. pH, EC and temperature were monitored during purging, and at least three consecutive similar readings of the field parameters were similar, purging was stopped with care not to pump the borehole dry. Alternatively, purging was stopped when three times the volume of borehole water was removed;
- after purging, three samples were collected from each borehole for laboratory analysis. The sampling bottles were labelled on the outside (Site name, borehole ID, Date and time of sampling) with a permanent marker. The sampling bottle caps were also labelled with borehole ID and date.
    - the sampling bottles for isotopes were filled to the top, ensuring that there were no air bubbles in the bottles. This was done by slightly squeezing the bottle when replacing the caps;
- a sample was collected at the end of the purging process in an open cup to measure and record the field parameters (pH, EC, DO) using the appropriate probes. These parameters were later compared to the laboratory analyses results for quality control purpose, and
- the hydrocensus boreholes were already equipped with pumps, and therefore, samples were collected from the taps by the owners of the boreholes. Some residents had water stored in tanks, and some samples were collected from pipes coming directly from the boreholes (BH17). Some information like the borehole depth and water level was unknown for these boreholes.

Figure 3-8. Collecting a water sample from BH2D.

3.5.2 Surface water sampling

Surface water was collected from a stream downgradient of the study area. Sampling points were selected based on accessibility, considering safety issues and location with reference to the cemetery. The 1st point was selected at a dam located upgradient of the study area (Athlone Dam, Figure 3-1**Error! Reference source not found.**), the 2nd was a point downgradient of the dam's discharge point (Stream A), the 3rd was located adjacent to the cemetery (Stream B) and the last was located further downstream of all the points and the study area (Stream C).

The following equipment was used for sampling:

- sampling bottles similar to those used for groundwater sampling;
- tape measure for measuring the stream dimensions; and
- probes and a plastic cup for measuring field parameters.

Stream water sampling was carried out as follows (Figure 3-9):

- water samples were collected by immersing the sampling bottle in water. In situations where it was needed for the sampler to stand in water, the sample was taken facing upstream and standing downstream of the sampling point to avoid contamination of the sample collected. To avoid air bubbles in the isotope samples, the cap was replaced with the filled sampling bottle underwater;
- the sampling bottles were wiped dry and labelled with a permanent marker;
- field parameters (pH, EC, etc.) were measured; and
- a tape measure and stick were used to measure the stream dimensions including the stream depth to the top of the water level.

Figure 3-9. Surface water sampling from a stream passing downgradient of the cemetery.

3.6 Laboratory analysis

All samples collected were preserved in a cooler box and kept in a refrigerator before analysis.

3.6.1 Chemical analysis

Water samples collected in 1L or 1.5L plastic bottles were delivered to the laboratory (Waterlab (Pty) Ltd (Waterlab) situated in Pretoria) for chemical analysis at the earliest convenient time. The samples were accompanied by a chain of custody, a written list of sample descriptions, as well as instructions for the laboratory indicating which parameters to analyse for.

A standard chemical analysis was conducted by Waterlab on samples collected, the analyses included, among others, physical and inorganic parameters.

3.6.2 Stable isotope analysis

Hydrogen-18 and Deuterium sample preparation

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 and at the UP's Stable Isotope Laboratory for the University's Mammal Research Institute. The sample preparation and analysis are explained, and the results obtained are presented in the next section (Lorentz, 2016).

Samples were shaken to equilibrate, and 1.5ml of each sample was pipetted into marked autosampler vials with a fresh pipette tip. The samples were then capped with septa and stacked into an autosampler tray. A set of three standards was placed in the autosampler tray before every five samples to be analysed, as well as after the last 5-sample set. All 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: Los Gatos Research (LGR)2 (δ2H -117.00, δ18O -15.55), VSMOW2 (International Atomic Energy Agency (IAEA)) (δ2H 0.0, δ18O 0.0) and IA-RO53 (IAD) (δ2H -61.97, δ18O -10.18). The accuracy of the standards calibration for analyses of the first batch of samples is presented in Table 3-2 and Figure 3-10 and is within acceptable limits for all three standards. Therefore, this accuracy is acceptable. The standard deviations are also acceptably low (<2) (Tanweer, et al., 2009).

Table 3-2: LGR DT - 100 Standard checks.

SBEEH STANDARD	Calibrated δ^{2}H (‰)	Current run δ^{2}H (‰)	Std Dev Current run δ2H (‰)	Calibrated ^{18}O (‰)	Current run δ^{18}O (‰)	Std Dev Current run δ^{18}O (‰)
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

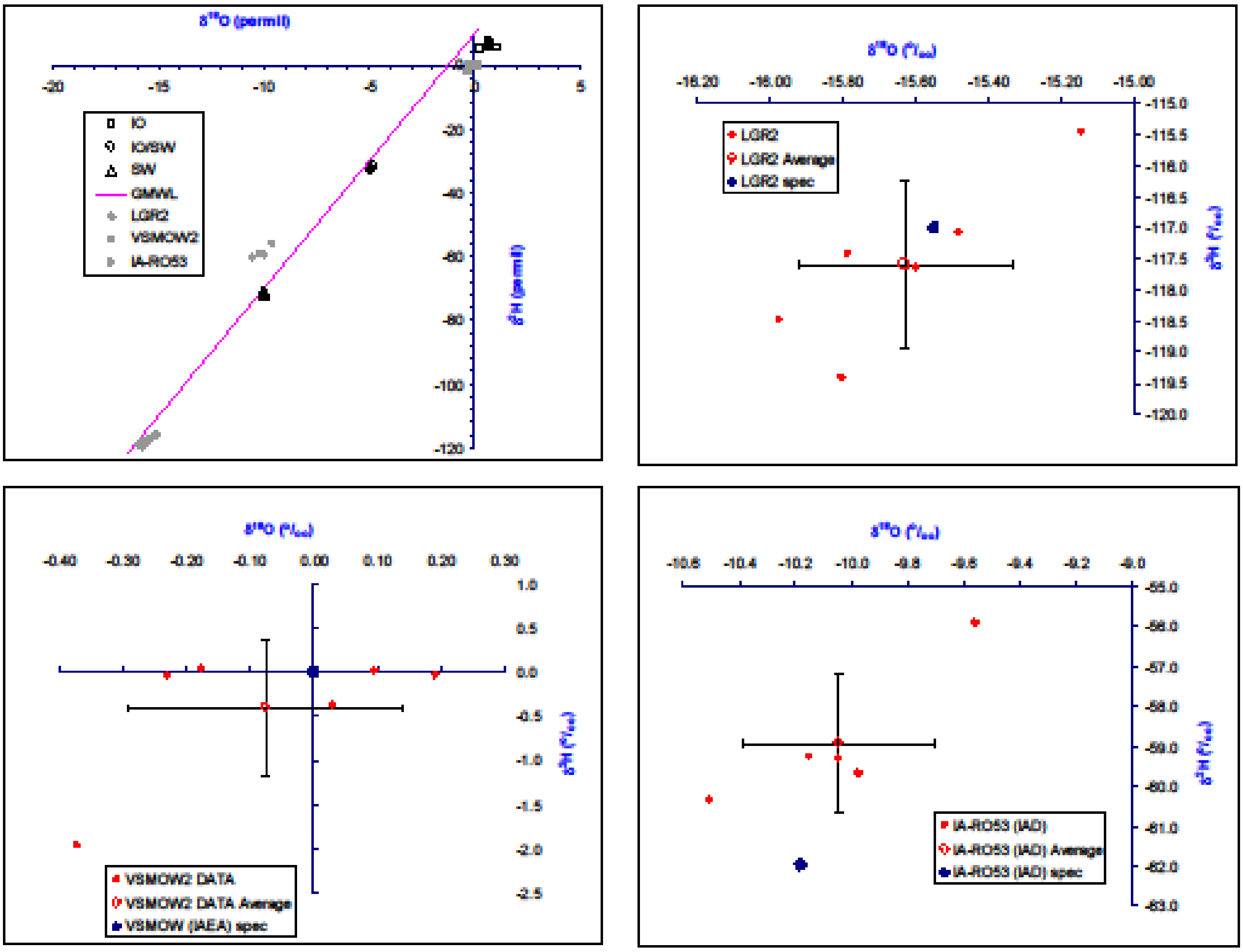

Figure 3-10. LGR-100 Accuracy of preparation standards.

Sample measurements

The spectrum of the analyser was verified and the sub-sampling of the autosampler programmed. Each sample and standard were sub-sampled and analysed six 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 $^{2}H/H$ and $^{18}O/^{16}O$ 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, 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 the standard deviation for each measurement less than 0.004°C);
- sub-sample density (the density was between 2 to 4x1016 molecules/cm^{3} and the standard deviation between measurements less than 1000 times smaller than the injected density); and
- deviation of the $^{2}H/H$ and $^{18}O/^{16}O$ ratios (Standard deviation of $^{2}H/H$ ratio was less than 1000x smaller than measured ratio; $^{18}O/^{16}O$ 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 six sub-sample determinations. The standard deviation of the ^{2}H results was less than 1 (‰) and for the ^{18}O samples, less than 0.25 (‰).

3.6.3 Tritium analysis

Twenty-two samples were delivered on 12 June 2017 to the iThemba Isotope Laboratory, for analysis of tritium. The samples were contained in labelled plastic bottles.

The analysis of the samples was carried out in the following manner (Butler, et al., 2018):

The samples were distilled and subsequently enriched by electrolysis. The electrolysis cells consist of two concentric metal tubes, which are insulated from each other. The outer anode, which is also the container, is made of stainless steel. The inner cathode is made of mild steel with a special surface coating. 500 ml of the water sample, having first been distilled and containing sodium hydroxide, was introduced into the cell. A direct current of 10–20 ampere was then passed through the cell, which was cooled because of the heat generation. After several days, the electrolyte volume was reduced to 20 ml. The volume reduction of 25 times produced a corresponding tritium enrichment factor of about 20. Samples of standard known tritium concentration (spikes) were run in one cell of each batch to check on the enrichment attained.

For liquid scintillation counting, samples were prepared by directly distilling the enriched water sample from the now highly concentrated electrolyte. 10 ml of the distilled water sample was mixed with 11 ml Ultima Gold and placed in a vial in the analyser and counted two to three cycles of four hours. Detection limits were 0.2 TU for enriched samples.

4 Chapter IV - Data

The raw data collected for this study is presented below. The data is interpreted and discussed in section 6.

4.1 Hydrocensus findings

During the hydrocensus, it was identified that a stream (Du Toit Spruit) is located at about 0.2Km downgradient of the study area, and in between the stream and study area is a wetland. Two dams (Athlone and Kruger Dams) are located upstream before the study area.

Three boreholes are located downgradient of the cemetery (BH5A, BH14 and BH17), in residential households, and only one was located at about 1.5Km upgradient of the cemetery at Middelburg Mall (Mall BH). The water abstracted from the boreholes in the residential area was being used for irrigation, and the two households (owning BH5A and BH14) also use it for human consumption. One of the owners (BH5A) mentioned that they filter their water before consumption. Middelburg Mall has two boreholes drilled within their property. Only one of these boreholes is equipped with a pump, and the water abstracted is stored in a tank and used for irrigation. BH17 owner is the only one that does not store their water in a tank and pumps directly to their irrigation system.

Table 4-1 presents a summary of the findings from the hydrocensus. This is also indicated in Figure 3-1. The elevations presented were obtained using a handheld GPS. The hydrocensus boreholes and stream sampling positions were included in the monitoring programme. The hydrocensus boreholes were important in that water samples from these boreholes were considered as coming from deep aquifers as compared to that from the cemetery boreholes and also upgradient and downgradient of the cemetery. Laboratory analyses results for water samples collected from these boreholes were thus compared to those from the cemetery boreholes from which water is considered as coming from shallow aquifers and where possible sources of contamination were located. The hydrocensus boreholes were also used a as backup for the monitoring, sampling of boreholes upgradient and downgradient of the study area, when most of the boreholes within the cemetery were dry. However, samples were only collected whenever it was possible, with permission from the borehole owners. Municipal water was also added to the sampling programme. Where water was collected from a water supply tap that is located within the cemetery area.

Table 4-1: Hydrocensus Monitoring points.

Monitoring position	Location (Lat, Long, Elevation (mamsl))	Location	Owner and address	Date drilled	Borehole depth	Water uses
BH5A	-25.783151° 29.462501° 1479.91	About 1Km downgradient of cemetery to the south of Du Toit Spruit	5 Morkel Street Middelburg	2014	42	Tank storage. Used for Irrigation and drinking - filtered
BH14	-25.783451° 29.461277° 1482.17	About 1Km downgradient of the cemetery and north of Du Toit Spruit	Ms Harnse, 14 Hoog Street Middelburg	More than 20 years old	Unknown	Tank storage. Irrigation and drinking
BH17	-25.786920° 29.469209° 1482.08	About 1Km downgradient of the cemetery and north of Du Toit Spruit	Mr and Ms Fourie, 17 Jeppe Street Middelburg	October 2016	30	Irrigation only. Water pumped directly to irrigation system
Mall BH	-25.805042° 29.458587° 1528.02	About 1.5Km upgradient of the cemetery	Middelburg Mall Mpumalanga	2014	unknown	Tank storage. Irrigation only
Athlone Dam	-25.799125° 29.446539° 1506.16	Athlone dam and upgradient of Kruger dam, upstream of all stream sampling points	-	-	-	-
Stream A	-25.790186° 29.454928° 1492.88	Upstream before the cemetery and just after the dams. Located near, culvert for road crossing, shopping centre upgradient, Dam upstream of this point. Visible pollution by human, short grass and reeds cover the area of the stream	. -	-	-	-
Stream B	-25.786270° 29.459702° 1485.45	Adjacent to the cemetery. Residential area points just before Samora Machel busy road, visible sewer line manholes about 2m from stream. Tall trees and short grass at area	. -	-	-	-
Stream C	-25.782308° 29.465152° 1476.01	Downstream after the cemetery, located at park area and near residential area. Tall reeds and short grass, tall few trees	. -	-	-	-
Mun1		Municipal water supply tap in the graveyard				

4.2 Water levels

Water level data are presented in Table 4-2. During the monitoring period, some of the boreholes were dry as indicated in the table. N/A indicates periods where no measurements were made. No water level measurements were conducted at the private boreholes during the hydrocensus and during the monitoring period as these boreholes are already equipped with pumps and some of the water is used for domestic purpose.

Table 4-2: Water table levels during the monitoring period.

Monitoring Dates	Water Levels (mbgl)					Average Stream Depth (m)		
	BH1S	**BH1D**	**BH2D**	**BH3D**	**BH4S**	**Stream A**	**Stream B**	**Stream C**
14/04/2016	Dry	1.46	4.22	Dry	Dry	N/A	N/A	N/A
20/10/2016	Dry	Dry	5.13	Dry	Dry	0.13	0.50	0.50
08/11/2016	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
08/12/2016	1.02	0.65	4.02	Dry	0.93	0.37	0.42	0.81
15/01/2017	Dry	1.57	3.93	Dry	Dry	0.25	0.57	0.72
12/02/2017	Dry	2.14	4.09	Dry	Dry	0.245	0.31	0.48
16/03/2017	1.19	2.11	3.44	5.26	0.92	0.32	0.67	0.69
03/06/2017	0.86	1.37	3.74	4.99	1.07	N/A	N/A	N/A

4.2.1 Depth to groundwater

Figure 4-1 indicates the groundwater level changes throughout the monitoring programme compared to daily rainfall. Most of the boreholes were dry as they were very shallow and drilled to a depth above the water table. In November 2016, a significant amount of rain was experienced in the area as indicated by the rainfall peaks. This resulted in recharge to groundwater and streams and thus a rise in the water table. More rainfall peaks are observed in late February to early March, early April, as well as mid-May 2017.

Note that BH2D (which was the deepest borehole onsite) shows a clear pattern of changing water level with changing seasons, and recharge from precipitation as it never went dry and was drilled well below the water table (its final depth was about 4m below the water table). BH2D shows an increasing water table depth following the dry season. It is not known if the increase happened immediately after the reduced rainfall, as there was a gap of no monitoring between April and October 2016. The graph is seen to decline gradually as soon as the rainy season started in October 2016, where recharge was evident. The graph continued to decline with a slight increase starting in June 2017 when it stopped raining.

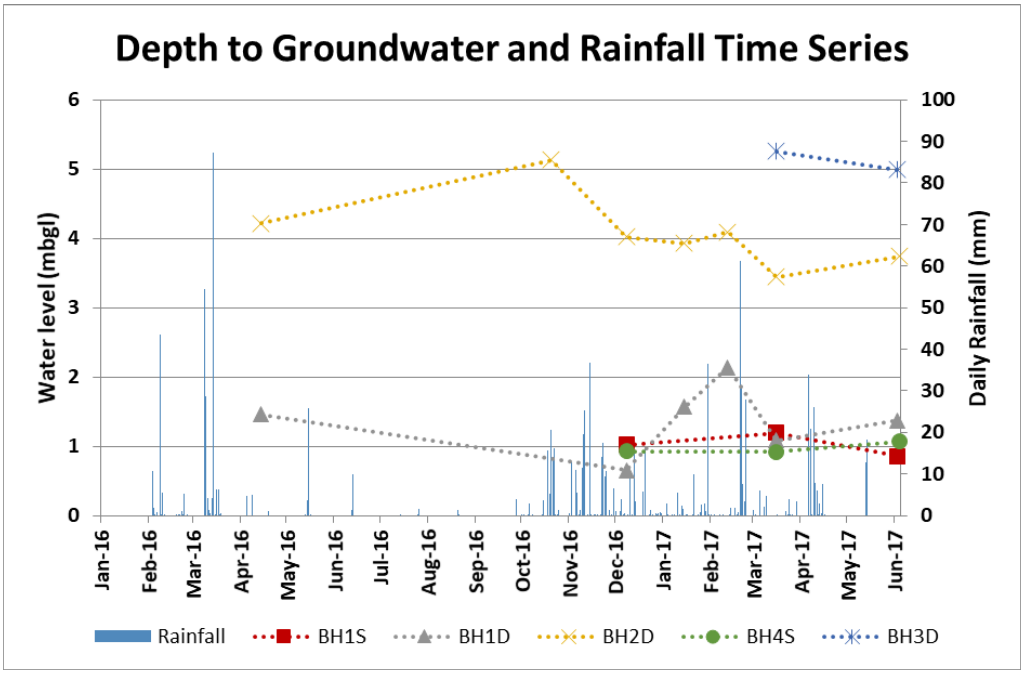

Figure 4-1. Borehole water levels during the monitoring period.

4.2.2 Surface water levels

Figure 4-2 indicates the stream water depths measured for the three stream sampling positions. This is compared to the daily rainfall data for Middelburg. Note that the monitoring programme for the stream was only started during the rainy season in November 2016. An increase in stream depth is observed to be proportional to rainfall records between October and December 2016. A drop from December 2016 to February 2017 is observed. This is believed to be due to evaporation as the temperatures were higher during this period. An increase in stream depth is observed again following a spike 61.2mm rainfall on 20 February 2017.

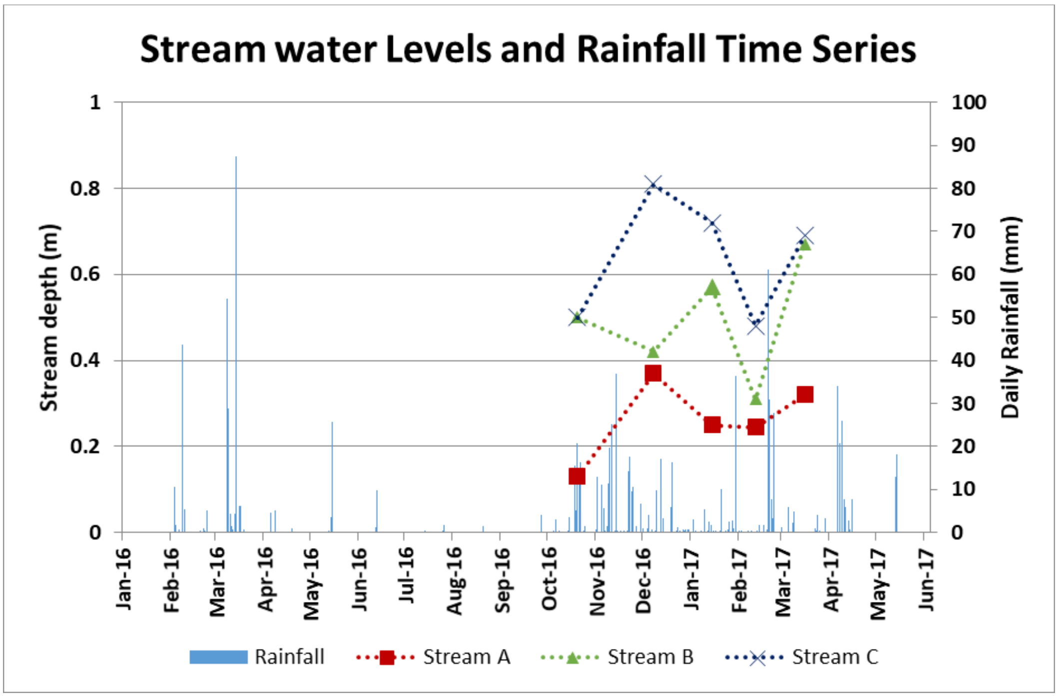

Figure 4-2. Stream water depths.

4.3 Hydraulic Test results

4.3.1 Falling head tests

The results from the AquiferTest programme used for the analysis of the falling head test data are presented in Appendix B1.

The added water took longer to recharge into the aquifer and for the water level to get back to its initial undisturbed state. The time taken was longer for boreholes on the eastern and upgradient part of the cemetery (BH2D, BH3D and BH4S), as compared to those downgradient (BH1S and BH1D). Their positions are shown in Figure 3-3. Low to intermediate hydraulic conductivity ranging between 0.05 and 0.18m/d was calculated for the shale and sandstone aquifers underlying the cemetery (Table 4-3 and Figure 4-3). The hydraulic conductivity values are compared to literature values and presented in Figure 4-4.

Table 4-3. Falling head test results.

Borehole ID	Initial SWL[1]	Initial WL[2] at start of test	Final WL at end of test	Drawdown	Duration of test	Geology	Hydraulic conductivity (m/day)
BH1S	0.86	0	-	-	0h56	Sandstone	1.35×10^{-1}
BH1D	1.37	0	-	-	1h09	Sandstone	1.81×10^{-1}
BH2D	3.47	2.42	3.36	0.94	1h19	Shale	9.93×10^{-2}
BH3D	5.42	0.97	2.41	1.44	2h25	Shale	1.47×10^{-1}
BH4S	1.07	0	0.82	0.82	1h15	Shale	4.96×10^{-2}

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[1] SWL – Surface Water Level

[2] WL – Water Level

Figure 4-3. Distribution of hydraulic conductivity values across the site.

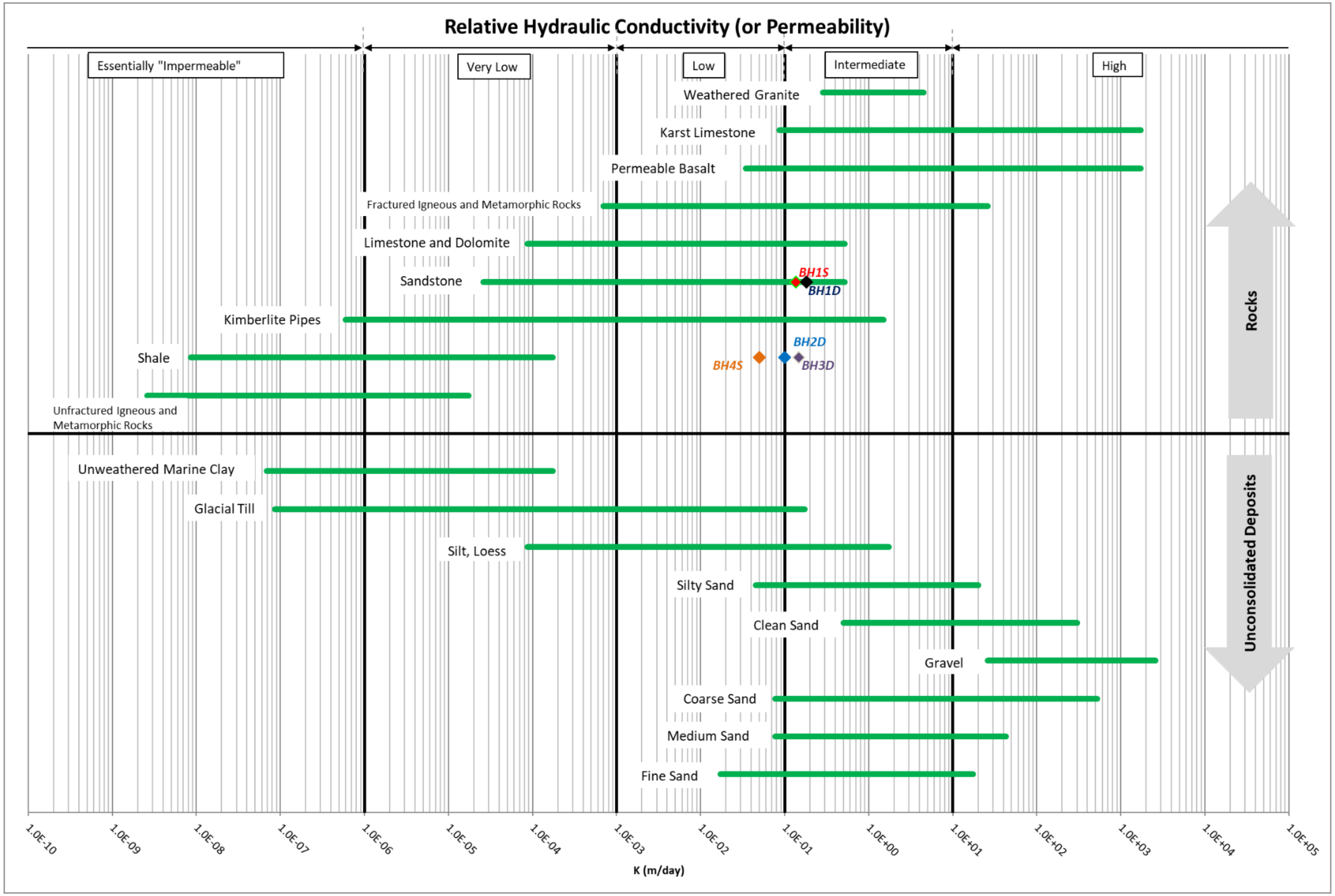

Figure 4-4. Relative hydraulic conductivity for boreholes at Fontein Street Cemetery.

4.3.2 Double Ring Infiltration (DRI) tests results

Results from the DRI tests are presented in Appendix B2. The average infiltration rates are calculated and summarised in Table 4-4.

The infiltration rates are lower on the eastern side of the cemetery, a similar behaviour observed from the falling head data. The soil in this area is quite clayey and compacted. In that case, any rainfall or irrigation water will take longer to infiltrate the eastern side of the cemetery than the western side. The highest infiltration rate is observed near BH3D, which is upgradient of the cemetery, under trees where not much activity happens.

Table 4-4: Average infiltration rates from DRI tests.

Nearest borehole where test was conducted	Average infiltration rate (m/d)
BH1D	2.55×10^{-5}
BH2D	4.08×10^{-6}
BH3D	1.88×10^{-4}
BH4S	1.73×10^{-5}

4.4 Laboratory results

4.4.1 Chemical analysis

Laboratory results for the water chemistry analyses from Waterlab are presented in Appendix C1.

Accuracy and Precision of the chemical analysis results

The precision of the water quality results was measured through calculation of the RPD of two data sets generated from a similar source (New Jersey Department of Environmental Protection, 2014). The RPD method applies to duplicate samples, however, in this case, it is applied to laboratory results compared to field results (pH and EC). It is given by the formula:

$$RPD = \frac{|A-B|}{(A+B)/2} \times 100 \qquad \ldots(5)$$

Where:

- A = analytical results from first measurement (e.g. Field pH) and
- B = analytical results from the second measurement (e.g. Lab pH)

The results are presented in Appendix C2.

Field parameters measured in-situ include pH, EC, DO and temperature. The results are presented in Appendix C2 and are compared to laboratory results with calculated RPD values. The EC values obtained from the lab are much more similar to those obtained in the field. Most of the lab pH values are lower than those measured in the field. For an acceptable analysis, the value of RPD should be ≤30% to represent a high degree of precision in the analytical method. Most of the samples' RPD values are less than 30%, with only three sample values exceeding 30%. These are values calculated when comparing field EC and laboratory measured EC for samples collected in December 2016 and analysed in January 2017. The lab measured EC was lower when compared to the field EC. The values are further compared to values measured during other months, and it was concluded that the lab measurements could be a mistake or changes in EC could be due to reactions that might have taken place during transportation of samples to the laboratory or during storage where cross contamination might have occurred. The samples were stored for over a month before analysis. These laboratory measurements were considered as outliers and excluded from further analyses.

Data presentation

The water quality results were compared across the site and over the entire monitoring period to identify any observable water quality impact due to the cemetery. Attention was paid to the health risk parameters, such as nitrates and total coliforms that were possibly derived from decaying burial material. Other water quality parameters interpreted include pH, total dissolved solids, chlorides, copper, iron, manganese, and sulfate, as they may indicate water pollution (Üçisik and Rushbrook, 1998).

The results are presented as time series charts in Appendix C3. The blank data gaps indicate periods where no sample was collected from that particular monitoring point due to no access in the case of private boreholes, or dry borehole in the case of cemetery boreholes. Zero values show that the laboratory analysis results for that sample were below the laboratory's detection limit (details in Appendix C1 laboratory certificates).

High sulfate concentration was measured in surface water (Stream A, Stream B, Stream C and Mun1 water samples) when compared to groundwater sulfate concentration. The sulfate concentration in surface water ranges between 74 and 368 mg/l. The source of elevated sulfate concentration, especially in municipal water, is believed to be mining related (Aurecon, 2011). Other possible sources of elevated sulfate concentrations in the stream include sewer overflows or leaking sewer lines as sewer manholes were spotted near Stream A sampling point. Various activities by the community, which include littering and washing of clothes in the stream, were also observed near Stream B sampling point that is located in a park, and that could contribute to the elevated sulfate and other related parameter measurements.

The lowest measured sulfate concentration in groundwater is less than the laboratory's detection limit of 2 mg/l at BH2D where it remained constant throughout the monitoring period 9mg/l measured in October 2016, before it started raining. The highest sulfate concentration measured was 129mg/l at BH4S in December 2016. However, a sample collected from the same borehole in March 2017 indicated a lower sulfate concentration, which was lower than the laboratory's detection limit. A decrease in sulfate concentration in March 2017 is observed for all samples except BH1D, which measured 26 mg/l in March 2017 compared to the last measurement of 15 mg/l measured in January 2017.

No sample was collected for chemical analysis from BH3D as the water table was deeper and below the bottom of the borehole. The only time that a sample could be taken from BH4S was in December 2016 and March 2017 sampling periods. Note that this is one of the shallow boreholes of which any samples collected were assumed to be recently recharged rainwater as the borehole was excavated to a final depth above the natural water table. Laboratory results show elevated sulfate concentration during this period (December 2016), with a value of 219 mg/l reported, with quite a high difference as compared to <2 mg/l reported in March 2017.

Total organic carbon highest and lowest values were measured in groundwater, with the highest values (22 mg/l) measured in cemetery boreholes (BH2D) and lowest values (less than the laboratory's detection limit) measured in private boreholes in December 2016. The high value of Total Organic Carbon at BH2D follows significant recharge and a rise in the water table and is an indicator of organic contamination. The carbon is more likely to be related to cemetery leachate.

The private boreholes have lower concentrations of total coliform bacteria when compared to samples from other monitoring points. The highest measured total coliform bacteria count is greater than

100 000 /100ml, which is believed to be associated with littering by the community. The highest measured total coliform bacteria at the cemetery borehole was 65 000 /100ml, measured at BH1D which is downgradient of the cemetery site. Possible contributors may be the cemetery leachate and leachate from what used to be the dumping site where the soccer field is. The private boreholes and municipal water have better quality in terms of biological contaminants.

BH4S and BH2D show chloride concentrations higher than those of other monitoring points throughout the monitoring programme when samples were collected. The chloride concentrations remained constant in the stream.

The pH values for groundwater and surface water are mostly in the same range of 6.1 and 8.5.

EC is elevated in water samples with elevated sulfate and chloride salts, i.e. in municipal and stream water samples when compared to that measured in groundwater. BH4S and BH2D also show significant EC values with an increase in March 2017. The relationship is similar to TDS.

Concentrations for three selected metals are shown as time series charts. Most of the samples have copper concentrations below the laboratory’s detection limit. However, those with detected copper (BH5A and BH14A) also show low concentrations with the highest being 0.117 mg/l at BH5A. The sources are not believed to be derived from the cemetery. BH2D shows distinct (higher) iron and manganese concentrations when compared to other samples. Looking at the position of BH2D relative to other sampling points, one can relate these chemistries to that of cemetery leachate. Manganese concentration is seen to increase with increasing recharge.

4.4.2 Stable water isotope results

The stable water isotope results are presented as scatter plots relative to the GMWL in Figure 4-5. The results are also presented in a table in Appendix D.

The rainfall analysis results become increasingly enriched with the lighter isotope (^1H) between December 2016 and February 2017, correlating with the increasing rainfall frequency and volumes and possibly less evaporation. The January and February samples plot close to and above the GMWL, while the December rainfall signal plots below the GMWL.

Evaporated surface water is expected to plot in the light isotope depleted region and to the right-hand side of the GMWL (Craig, 1961). The November isotope results from surface water analyses plotted in the region of depleted lighter isotopes, indicating exposure to evaporation. In December 2016, shortly after a significant rainfall event after the rainy season started, surface water analysis results plotted close to and above both the GMWL, as well as the groundwater. Both surface water and shallow groundwater show enrichment in lighter isotopes in response to the November 2016 rainfall input. The January and February 2017 surface water samples plots above the GMWL and thus still show influence of the January and a little of the February rainfall. In March 2017, the surface water signal moves towards the lighter isotope depleted region due to evaporation and slow-moving water with most of it from the dams. With no rain in June and surface water points plotting in the lighter isotope enriched region, it can be concluded that the effect was due to groundwater input.

The Athlone Dam water show a slight enrichment in the lighter isotopes. The dam water may be highly influenced by input from catchments upstream, which are composed of rainfall that may have different signals to the rainfall sampled in this study.

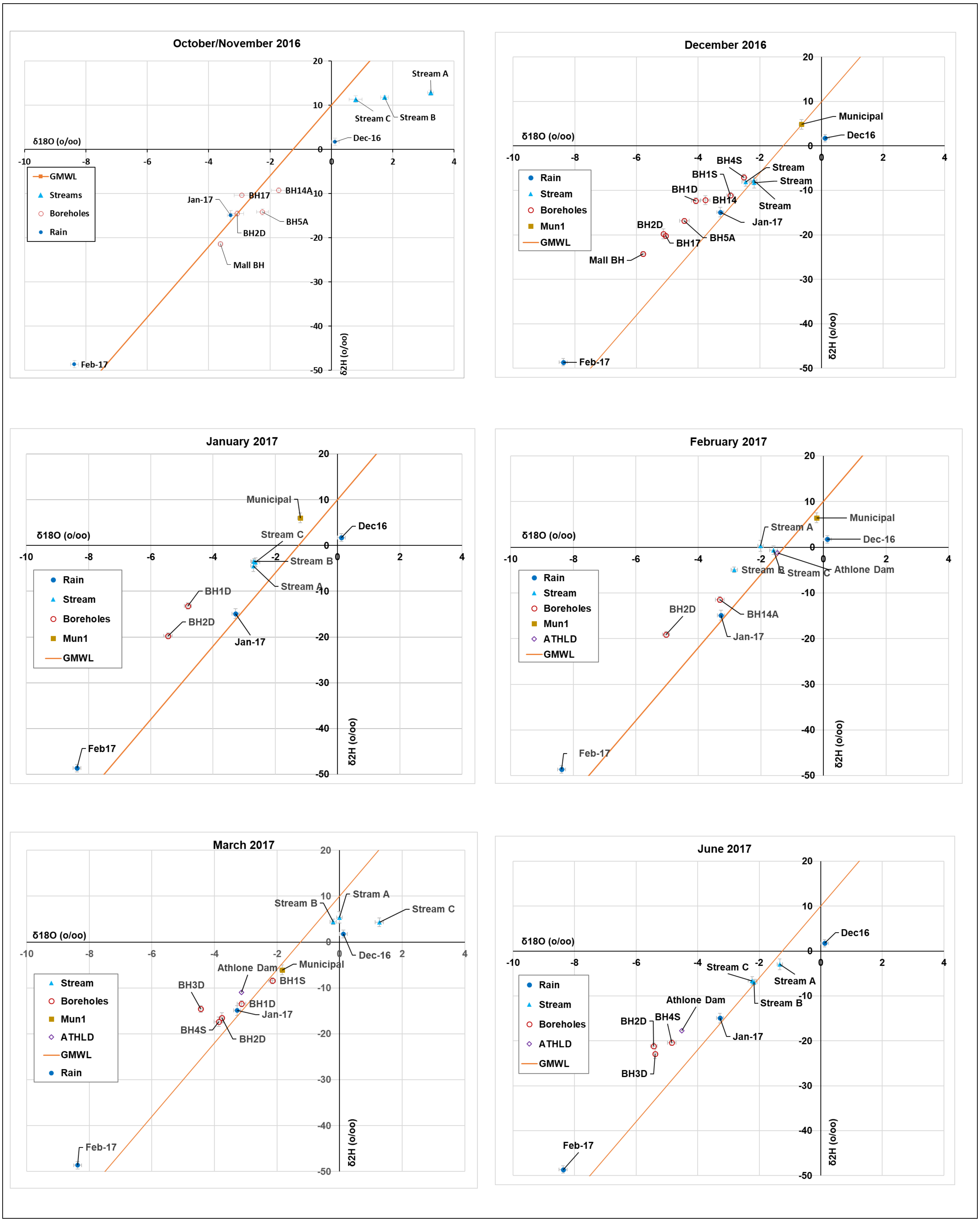

Figure 4-5. Monthly plots of δD vs δ18O.

Groundwater plots in the lighter isotope enrichment region throughout the monitoring programme. Just as it happened with surface water samples, the effect of rainfall recharge starts showing in December where all samples plot above the GMWL. Samples from the shallow boreholes (BH4S and BH1S) show a slight depletion in lighter isotope as they plotted further up, due to the evaporation of shallow groundwater.

Tritium analysis results

Results from tritium analyses of some of the groundwater, surface water, and February rain samples are also presented in Appendix D. The tritium results are presented in TU. The analytical precision, which is presented with the results, is well below ± 1.0 TU. The results are also presented in Figure 4-6, where they are plotted with Middelburg rainfall to show the effect of rainfall on the tritium content in the site's rain, ground, and surface water.

Low tritium content was measured for the private boreholes (Mall BH, BH14A, and BH17), compared to other monitoring points, with values ranging from as low as 0 (BH5A) to 1.0 TU (BH17). Since tritium naturally occurs with rain (Abiye, 2013), shallow groundwater and surface water are, therefore expected to show tritium content equivalent to that of rain as was observed with the tritium content of stream samples and cemetery borehole samples. Municipal and stream tritium contents were seen to decrease in June 2017, with a decrease in rainfall, and thus recharge.

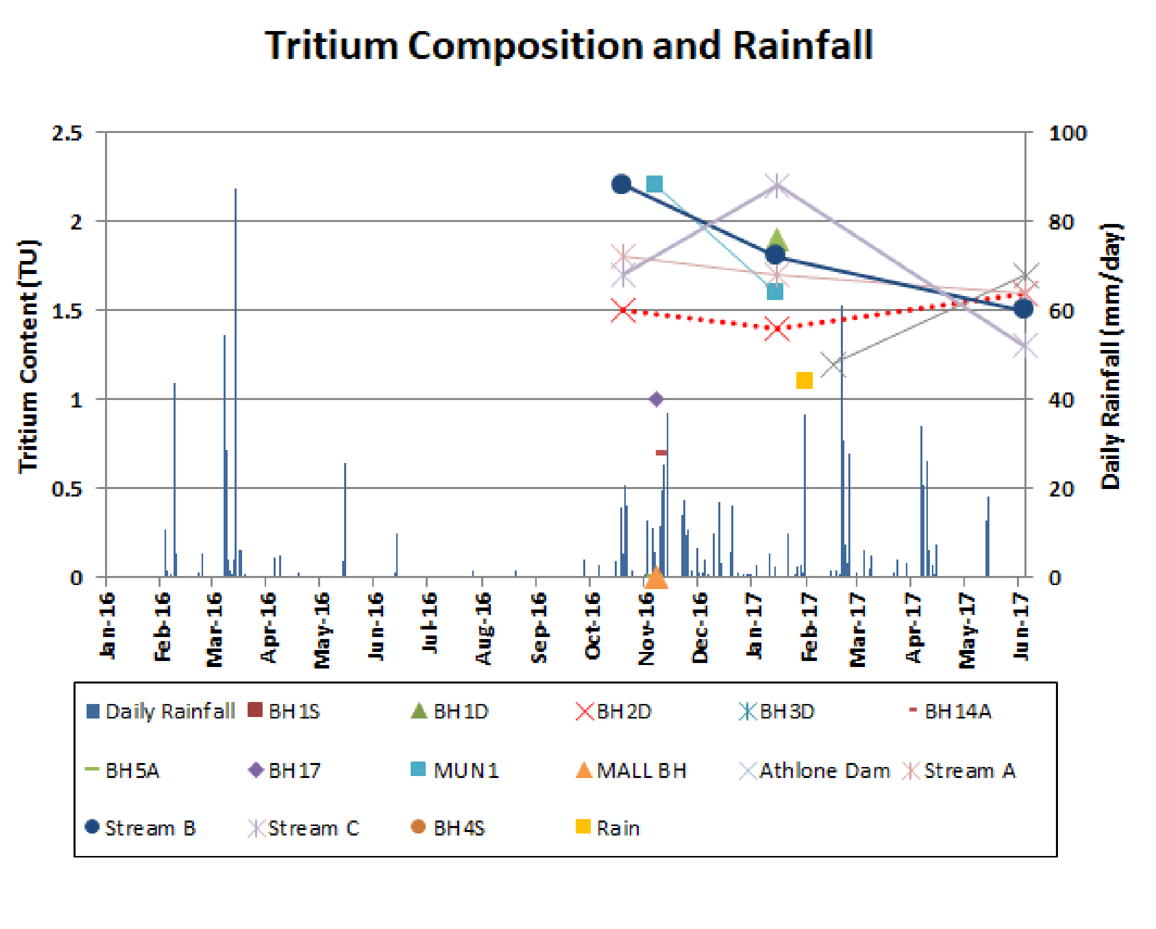

Figure 4-6. Tritium composition in groundwater, surface water and rainwater samples and rainfall in Middleburg.

5 Chapter V: Discussion

5.1 Groundwater quality in the area – implications to Middelburg's residential groundwater quality

In general, groundwater is used to a very limited extent by the surrounding communities for localised irrigation of gardens. Some residents use it for domestic purposes, including drinking. Most Middelburg residents make use of the municipal supplied water from their taps.

groundwater quality from the residential boreholes shows acceptable quality when compared to that below the cemetery. It is assumed that pumping is from the deeper aquifer (in relation to the cemetery shallow boreholes) where dilution occurs should there be any connection between the shallow near-surface water with the deeper groundwater.

Parameters used as cemetery-derived pollutant indicators (Fe, Mn, total coliforms, sulfate salts, chlorides, and total organic carbon) seem to be concentrated in the middle of the cemetery at BH2D and BH4S. Only a few parameters, such as Mn, chloride and total organic carbon, have elevated (but at lower concentrations than at BH2D) downgradient of the cemetery, at the stream and at downgradient boreholes (BH5A and BH14A) which are closer to the stream.

Of the private boreholes, BH14A which is located close to the stream seems to have been impacted negatively; showing deteriorated water quality compared to the other private boreholes. There may be a possibility that BH14A which is closest to the stream and downgradient of the cemetery to have been impacted by contamination from the cemetery and from the stream. This is based on the observed higher concentrations of parameters like chloride, nitrate, sulfate and copper in samples from this borehole when compared to water quality at other private boreholes. No any other water samples indicated detectable copper. According to Sponger and Becks (2000), copper is one of the indicator metals to cemetery contamination. There was, however, no fishy odour (associated with cemetery leachate) from BH14A samples, which may indicate that the stream could be the main impact on this borehole's water quality. There is a possibility of stream water and groundwater mixing, whereby the stream might be bringing in different water quality, especially in terms of sulfate concentration, of which the source is not cemetery-derived, but from possible leaking sewerage lines or other anthropogenic activities, such as mining.

The elevated Fe and Mn at BH2D indicate the presence of microbes that result in reduced conditions (Thomas et al., 2016). Further downslope, at BH1D, Fe and Mn concretions were found during drilling, which indicates oxidising conditions in the vadose zone. The Fe and Mn concentrations were also lower in this area (BH1D), compared to BH2D. Other parameters were also lower in this region. This may indicate the role played, particularly by Fe, as an absorbent to decomposition products and some organic substance fragments, and thereby limiting their influx into or removing them from groundwater, and thus limiting their transport to the next water source (Zychowski, 2011).

In general, the water believed to be impacted by cemeteries appears to be diluted by the time it gets to the stream. Other contributing factors to improved quality include the low to intermediate hydraulic conductivity of the fractured aquifer. The slow-moving water allows for various natural attenuation processes to take place before the water gets to the stream. The presence of a wetland between the cemetery and stream also plays a role in purifying water by slowing it down, especially surface runoff, and thereby filtering and adsorbing some contaminants (Macfarlane, et al., 2016).

5.2 Water movement – impacts on contaminant transport

Results from the hydraulic tests indicated slight variation in hydraulic conductivity across the site. The infiltration rate being lower near boreholes BH2D and BH4S compared to other sites. A similar behaviour was observed for hydraulic conductivity calculated from the falling head test data where hydraulic conductivity is lower at BH2D and BH4S and intermediate at other boreholes (Figure 4-4). Figure 5-1 shows the correlation between the subsurface infiltration rate to the hydraulic conductivity. An R^2 of 0.2 is shown that indicates poor correlation between the two. In general, the surface infiltration rate is quite lower when compared to the subsurface conductivity for reasons, which includes the following:

- The subsurface vadose zone and aquifer may be fractured.
- The surface especially at BH2D and BH4S get compacted during burial and cemetery maintenance activities, which involve mobile machinery used for excavation and maintaining the cemetery. The subsurface is less compacted and more porous.
- BH3D is located in an area where not much activity, including burial occurs. The area is dominated by organic matter of decaying leaves and appears to be spongy and thus allows faster infiltration, hence the highest infiltration rate at this site when compared to all other sites.

Compacted areas of the cemetery will result in less rain infiltrating and thus more runoff. The water will also take longer to infiltrate into the ground and will therefore, evaporate more quickly before it recharges the underlying aquifer. The variation in infiltration rates and hydraulic conductivity across the site is also due to the observed variation in the geology of the site. The eastern side (BH2D area) and near BH4S have more clayey soils (low infiltration and recharge), while the north-western side (BH1D and BH1S) have a silty textured soil, and thus exhibit larger pores (higher hydraulic conductivity).

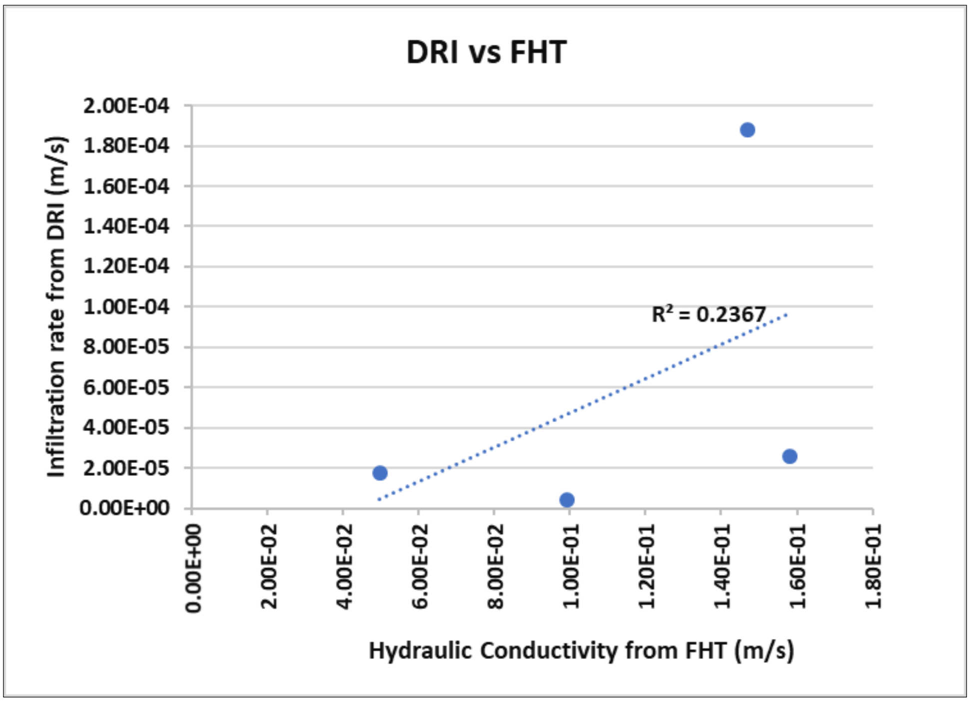

Figure 5-1. Subsurface hydraulic conductivity vs surface infiltration rate.

The water table below BH2D is, therefore, expected to respond quite slower following a rainfall event when compared to the water table at BH1D. Other reasons are that the water table at BH2D is deeper (3.74 mbgl) when compared to that at BH1D (1.37 mbgl). The near-surface water at BH1D will be more exposed to evaporation when compared to that at BH2D, as the water table is closer to the surface (Figure 4-1). Any contamination derived from the cemetery will, therefore, enter the groundwater quickly on the north-western side of the cemetery compared to the eastern side. Due to the thick vadose zone and slow infiltration rate on the south-eastern side, there is also time available for natural attenuation where some redox processes in reduced conditions will occur in the vadose zone. Some of these processes will limit the influx of the decomposition products into the groundwater, as discussed in section 7-1.

5.3 Isotopic changes in the water cycle

When rain hits the ground, its travel time to reach groundwater may have an impact on the changes in isotopic composition, which are a result of processes like evapotranspiration. Shallow water tables will more likely result in isotopic composition similar to that of rain but may also be exposed to evaporation. However, mixing with old water of a certain isotopic composition also occurs when rainwater recharges the groundwater. The amount of rain recharging will determine if the rainwater will have a significant change in the groundwater’s isotopic composition.

Figure 5-2 presents a conceptual model of the study area showing possible interconnections in the hydrological cycle. Processes that brought about possible changes in the isotopic signature are indicated in Figure 5-2 and Figure 5-3, and include rainfall recharge into groundwater and surface water, evaporation of shallow groundwater and surface water, and mixing of groundwater and surface water.

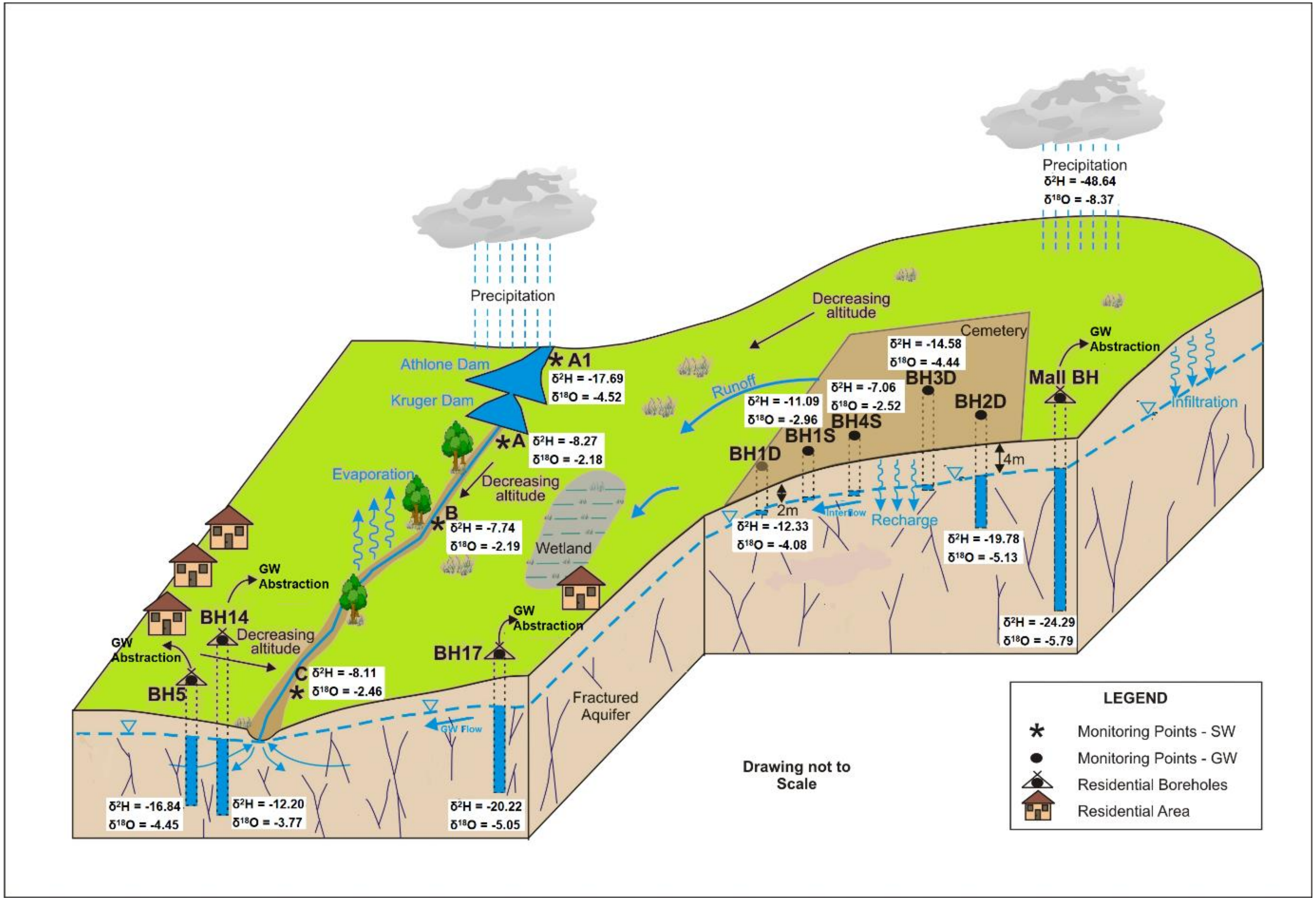

Figure 5-2. Conceptual model of the study area.

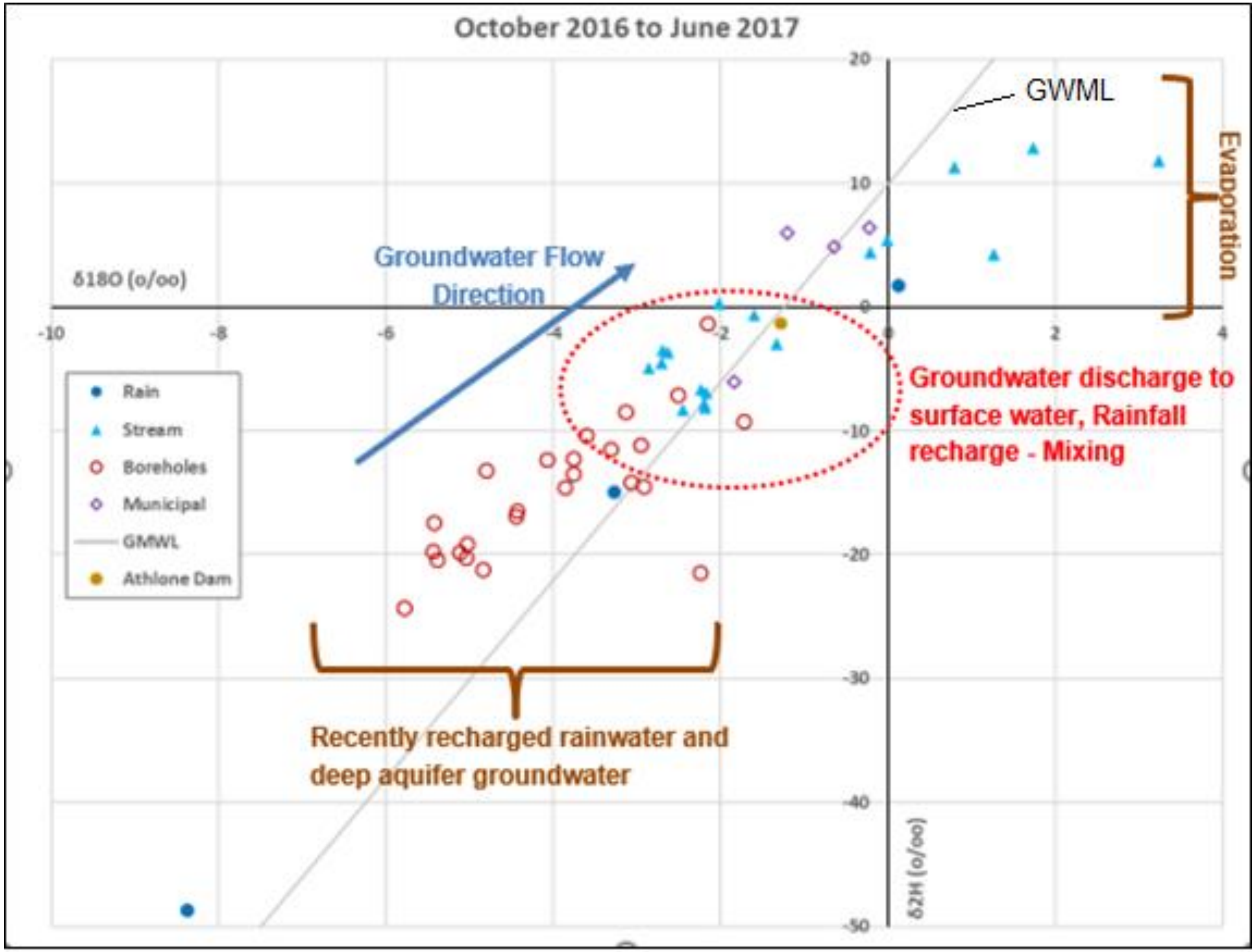

Figure 5-3. Sample values and the groundwater meteoric water line (GMWL).

The tritium results from the shallow cemetery boreholes show that recharge to the shallow groundwater mainly occurs through direct infiltration. The fact that there was detectable tritium in the surface water shows the effect of shallow interflow and runoff recharging the stream. However, tritium was also detected in surface water samples during the dry months. This may be due to baseflow input into the stream generated from near-surface interflow, which comprises the main contributing water source to the stream in this reach, during winter.

Rainfall can be viewed as the limiting factor in this study as observations on the resulting changes in surface water isotopic compositions were unclear. The rainfall caused a change in isotopic signatures in both the surface water and groundwater. The d-excess values, (a measure of the variation from equilibrium fractionation or GMWL), for surface water and groundwater were plotted with rainfall to show this effect (Figure 5-4). The d-excess in surface water has a higher variation to that in groundwater, suggesting that water that has experienced significant fractionation contribute to the stream flow. This is particularly true for the sample location at Stream C, the most downstream site, whose reach includes contributions from the cemetery catena. In addition, the d-excess variation was greater in the shallow groundwater (cemetery boreholes) than in the deep groundwater (private boreholes), further supporting the contributions of near-surface lateral flows, which are subject to evaporation in the soil profile. The surface water and groundwater were affected by progressive rainfall between October 2016 and January 2017 with rising d-excess values. These d-excess drops significantly in March 2017 after low rainfall in February, due to contributions to streamflow and groundwater being supplied predominantly from the evaporated soil water. Thereafter, with the continued lack of rain, the June 2017 d-excess values reflect those of the groundwater, suggesting this to be the main source of water and pathway for winter stream flows.

The variation of the d-excess is lower in the groundwater samples than that in the surface water samples. Nevertheless, these also increase with accumulating rainfall and drop off after a dry spell (February 2017), only to increase to the regional groundwater d-excess values in the middle of the dry season (June 2017). Again, this suggests rainfall contributions between November 2016 and February 2017, and then contributions from evaporated soil water in March, with stable groundwater d-excess values by mid-winter.

The fact that over 50% of surface water samples plot in the groundwater region in Figure 5-3, shows the interaction of groundwater and surface water where the two mix, as groundwater discharges into the stream. Water levels within the cemetery area are also quite close to the surface as one moves downgradient from upgradient within the study area with a wetland where the groundwater daylights. Du Toit Spruit, is thus a gaining stream.

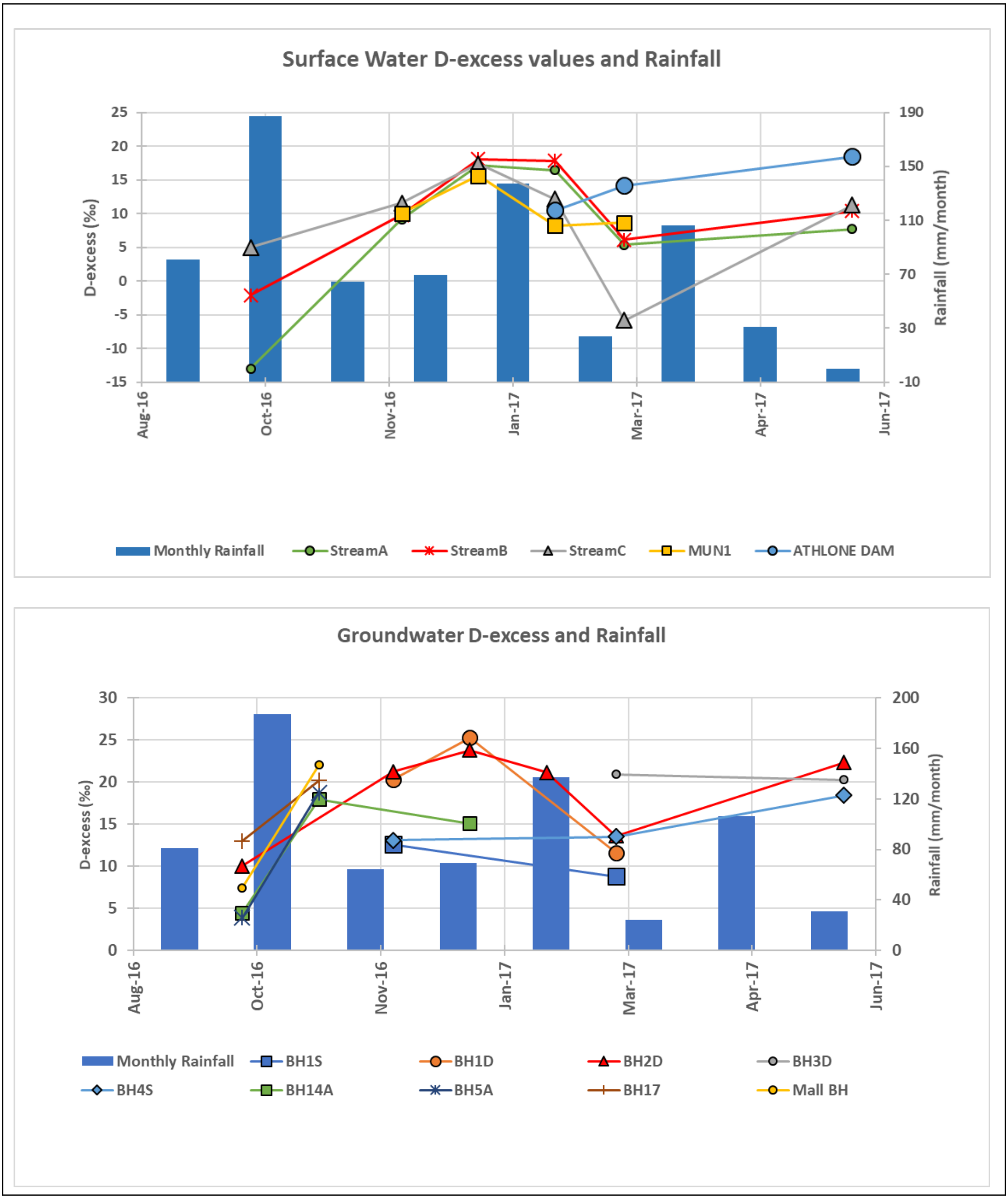

Figure 5-4. Variation of d-excess values in surface water and groundwater.

6 Chapter VI: Conclusion and Recommendations

6.1 Limitations and assumptions

Restriction were raised on the use of stable and tritium isotopes as tracers to contaminant transport where there was additional water input into the system of study, which in this case was rainfall. Not enough rainfall samples were collected, and this reduces the confidence of the findings in this study. More focus should, therefore, be paid to all contributing water and contamination sources in the future.

The data collected is insufficient for a high level of confidence that would be required for water resources and cemetery management. Nevertheless, there is clear evidence of the switching of sources to the stream varying between rainfall event water, near-surface, lateral flow contributions, well into the dry months, as well as deep groundwater contributions in the mid dry season.

The method used for collecting water levels which involved lack of continuous measurement resulted in limited data to indicate the effect of rainfall on the groundwater level fluctuation. This is because the water levels were taken only on spots. In addition, the upgradient borehole was most of the time dry throughout the monitoring period. This borehole was meant to give an idea of upgradient contaminant source contributors like the old soccer dump. In that case, the old dump was not isolated from the cemetery contribution.

The insufficiency of data collected is also highlighted by unclear conclusion of the possible source of some parameters detected in samples collected from borehole BH14A located downgradient of the cemetery and close to the stream. The source can either be from the stream or from the cemetery but cannot be clearly explained due to lack of continuous data and more data collected on this side of the stream and cemetery.

6.2 Main findings

The literature review has enabled familiarisation with similar studies that have been conducted around the subject. Reliable methodologies have therefore been adopted from the published literature and applied on the current research.

The borehole logs and results from the hydraulic conductivity tests indicated that the material underlying the cemetery site is that of low hydraulic conductivity. As a result, slower groundwater movement is expected and thus improved natural attenuation.

The results from tritium analyses indicate direct rainfall recharge into the surface water and groundwater. The presence of tritium in surface water during the dry months is concluded to be largely input from near-surface water and groundwater. This is further supported by the stable water isotope results for surface water receiving contributions from near-surface water sources during dry spells in the rainy season and from groundwater sources by the middle of the dry season. The depth to groundwater also decreases as one moves closer to the stream, indicating that the stream is a gaining stream. The presence of the seasonal wetland can also be interpreted as lateral flow sources and possibly groundwater daylighting on surface or stream flows during the rainy season.

Therefore, there is an existing hydraulic connection between the surface water and local soil water and groundwater, where groundwater provides baseflow to the stream when the stream’s water level recedes. With that said, near-surface flows and deep groundwater are capable of impacting the surface water quality.

Based on the water quality results, the water quality at the stream shows better quality in terms of the cemetery contamination indicator parameters, compared to groundwater sampled at the stream. This is due to various factors that can be defined as natural attenuation of cemetery pollution from the vadose zone and groundwater. These factors include thick vadose zones with low hydraulic conductivity, at least on the south-eastern side of the cemetery, allowing enough time for natural attenuation to take place before the cemetery-derived pollution plume reached the receptors, which are the groundwater users in the vicinity of the cemetery and the stream and its users. The wetland also plays an important role in filtering the pollutants. Finally, redox processes that take place in the vadose zone appear to remove some of the decomposition products from subsurface flows.

The stream's water quality is, nevertheless, deteriorated in terms of microbiological quality due to other inputs near the stream.

6.3 Way forward

Results from this study provide the first step in designing water resource management from the hydrological processes. The knowledge of the hydrological processes can be improved by conducting long-term continuous monitoring of the water quality, isotopic data, and water levels at the selected monitoring points. A long-term water quality, water level, and isotopic database should be created. Since rainfall became the limiting factor in determining groundwater-surface water interaction, the long-term data should be used to estimate recharge, and sources of baseflow. Continuous measurements of water levels are also recommended to ensure a clear observation of the impact that rainfall has on the fluctuating groundwater levels. This can be done by either taking daily measurements or installing data loggers set up to take water level measurements ore pressures at selected intervals. These data can be used to improve confidence in water resource management and contribute to cemetery guidelines.

With the shallow water table intercepted on the north-western side of the cemetery, it is advised that no burial should take place in this area for the protection of groundwater and surface water, which is the stream.

Since isotope data indicated to be a useful tool in studying water resource interactions, the methodology should form part of site investigations for cemetery development or on existing cemeteries to study the current impact and/or predict future impacts that the cemetery may have on the water resources. The methodology best applies in areas with multiple water resources, where there may be an interconnection between them. The isotope studies can also be used to estimate recharge and thus contaminant transport rate of the cemetery leachate.

7 Chapter VII: References

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Appendices

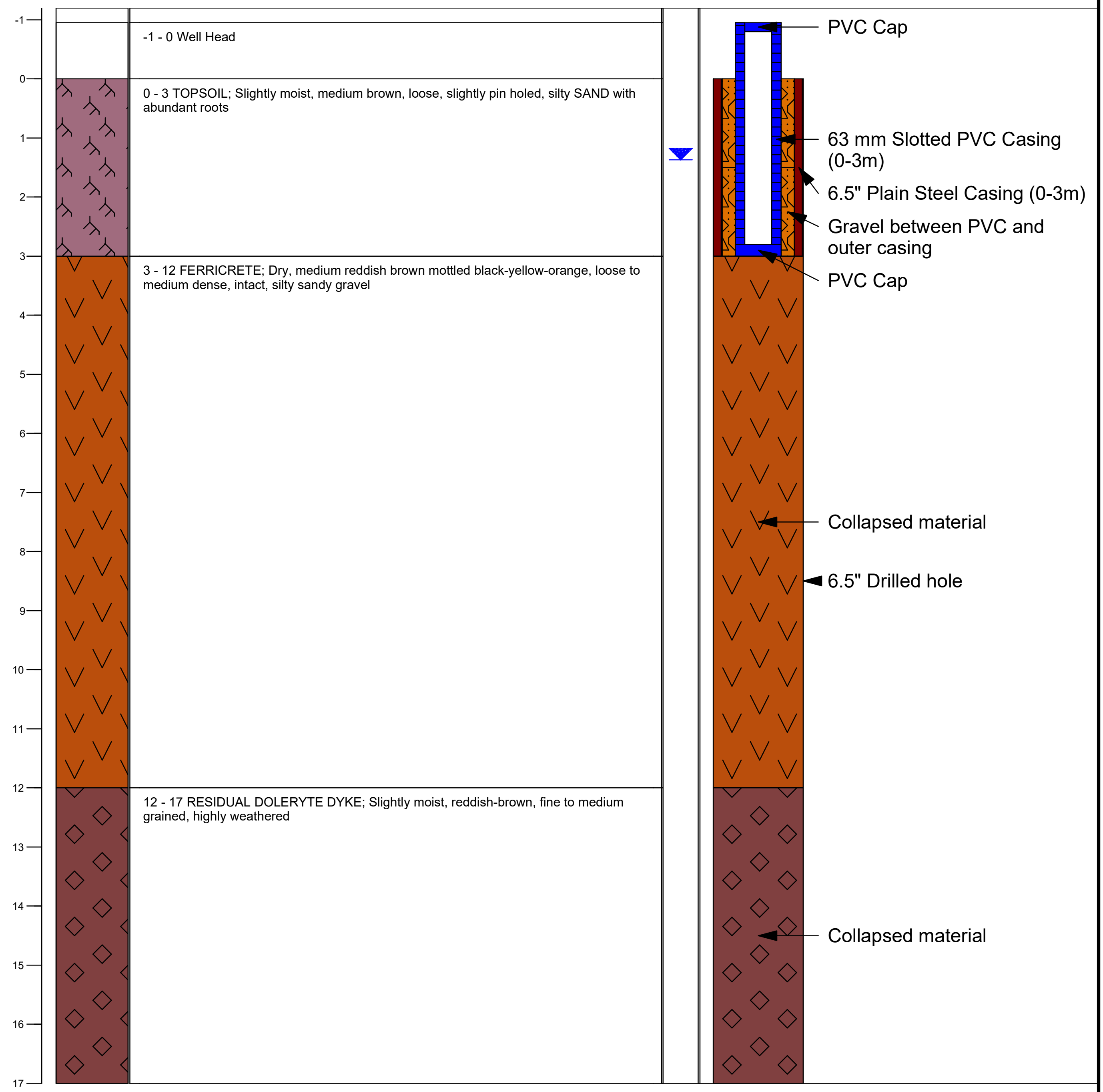
Appendix A: Lithological Logs

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

BH1D

PROJECT NAME:	FONTEIN STREET CEMETERY	COORD. SYST. :		BOREHOLE ELEVATION:	1485.4 masl
PROJECT NO:		EASTING	-25.788122	COLLAR HEIGHT:	0.95 magl
CLIENT NAME:	UNIVERSITY OF PRETORIA	NORTHING	29.460608	METHOD OF DRILLING:	Air percussion
BOREHOLE ID:	BH1D	DIP:	Vertical	DATE DRILLED:	10/02/2016
SITE LOCATION:	MIDDELBURG, MP	AZIMUT:	0	DATE COMPILED:	22/12/2017
PURPOSE:	MONOTORING BOREHOLE	TOTAL DEPTH:	17 m	LOGGED BY:	SARAH MAHLANGU

DEPTH (mbgl)	LITHOLOGY	STATIC WL (mbgl)	BOREHOLE CONSTRUCTION



-1 - 0 Well Head

0 - 3 TOPSOIL; Slightly moist, medium brown, loose, slightly pin holed, silty SAND with abundant roots

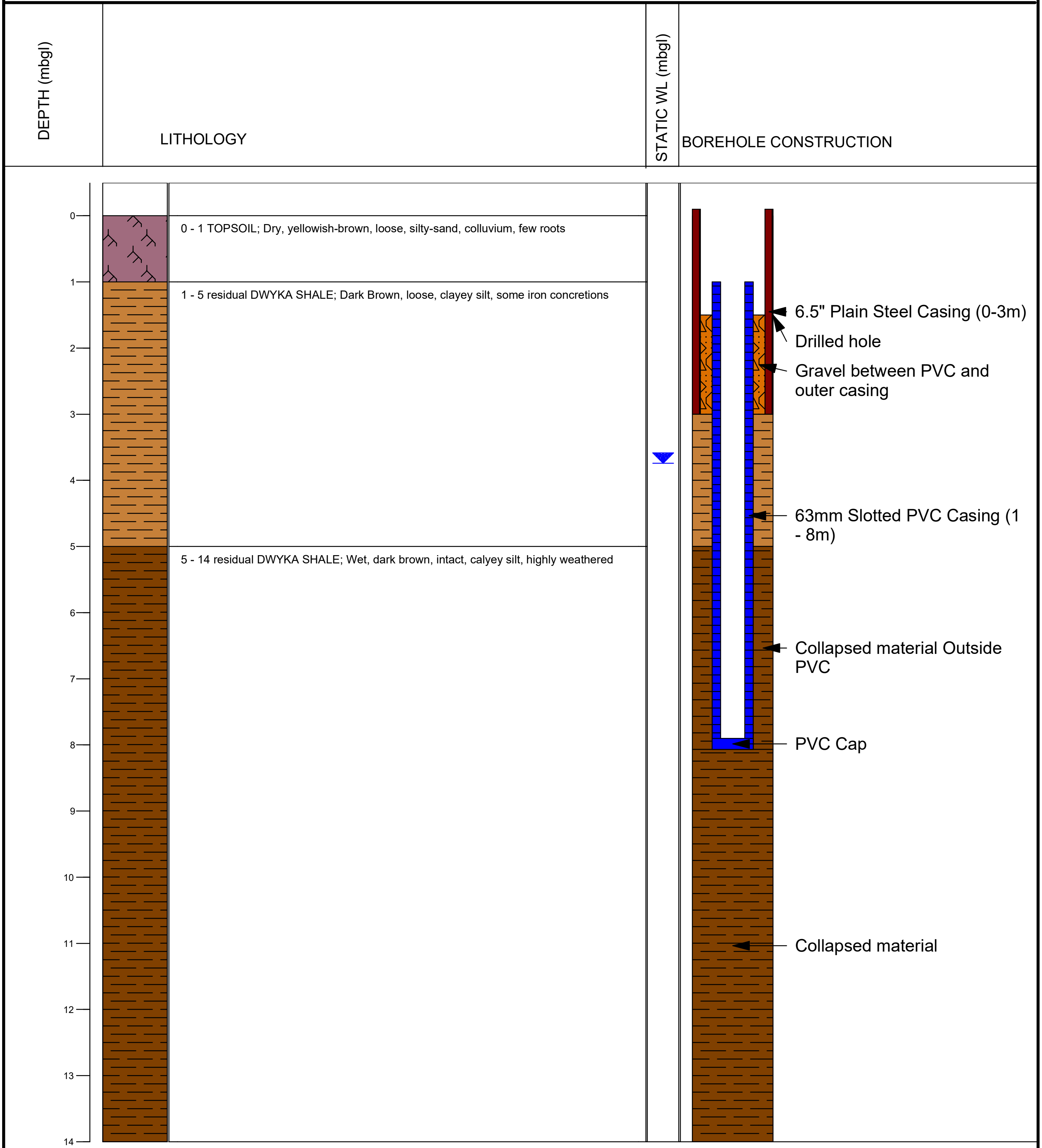
3 - 12 FERRICRETE; Dry, medium reddish brown mottled black-yellow-orange, loose to medium dense, intact, silty sandy gravel

12 - 17 RESIDUAL DOLERYTE DYKE; Slightly moist, reddish-brown, fine to medium grained, highly weathered

Soil samples collecetd at every meter. Slight moisture intercepted at 12m. Borehole collapsed at 3m

BH2D

PROJECT NAME:	FONTEIN STREET CEMETERY	COORD. SYST. :		BOREHOLE ELEVATION:	1489.11 masl
PROJECT NO:		EASTING	-25.790227	COLLAR HEIGHT:	0.1 magl
CLIENT NAME:	UNIVERSITY OF PRETORIA	NORTHING	29.464333	METHOD OF DRILLING:	Air percussion
BOREHOLE ID:	BH2D	DIP:	Vertical	DATE DRILLED:	10/02/2016
SITE LOCATION:	MIDDELBURG, MP	AZIMUT:	0	DATE COMPILED:	22/12/2017
PURPOSE:	MONOTORING BOREHOLE	TOTAL DEPTH:	14 m	LOGGED BY:	SARAH MAHLANGU



0 - 1 TOPSOIL; Dry, yellowish-brown, loose, silty-sand, colluvium, few roots

1 - 5 residual DWYKA SHALE; Dark Brown, loose, clayey silt, some iron concretions

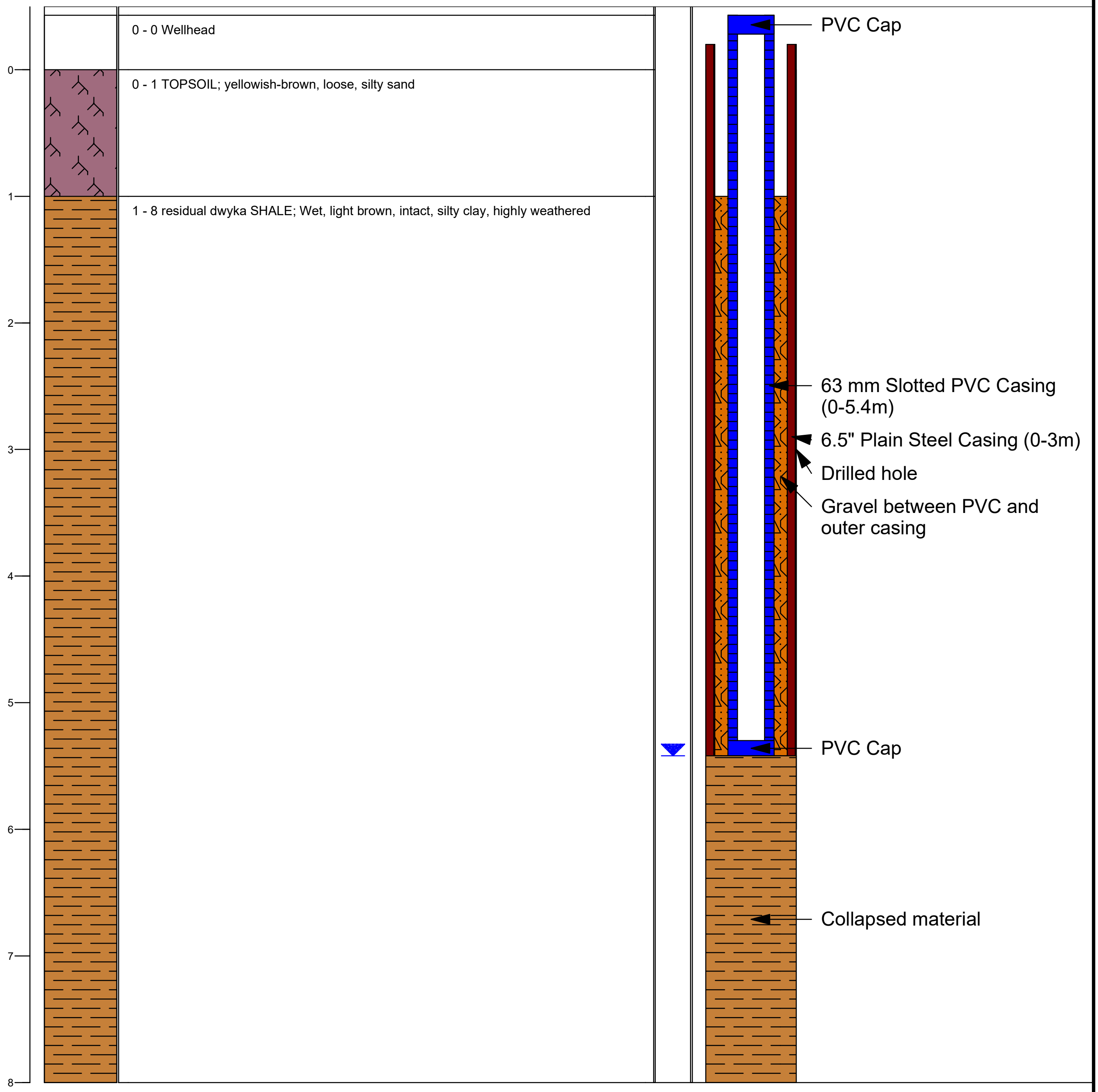
5 - 14 residual DWYKA SHALE; Wet, dark brown, intact, calyey silt, highly weathered

Water strike at about 5mbgl. Collapsed at about 3m, PVC sinked into collapsed material

BH3D

PROJECT NAME:	FONTEIN STREET CEMETERY	COORD. SYST. :		BOREHOLE ELEVATION:	1490.33 masl
PROJECT NO:		EASTING	-25.790819	COLLAR HEIGHT:	0.43 m
CLIENT NAME:	UNIVERSITY OF PRETORIA	NORTHING	29.461859	METHOD OF DRILLING:	Air percussion
BOREHOLE ID:	BH3D	DIP:	Vertical	DATE DRILLED:	10/02/2016
SITE LOCATION:	MIDDELBURG, MP	AZIMUT:	0	DATE COMPILED:	22/12/2017
PURPOSE:	MONOTORING BOREHOLE	TOTAL DEPTH:	8 m	LOGGED BY:	SARAH MAHLANGU

DEPTH (mbgl) | LITHOLOGY | STATIC WL (mbgl) | BOREHOLE CONSTRUCTION



0 - 0 Wellhead

0 - 1 TOPSOIL; yellowish-brown, loose, silty sand

1 - 8 residual dwyka SHALE; Wet, light brown, intact, silty clay, highly weathered

Water strike at 7m

Appendix B: Hydraulic Test Results

Appendix B1: Falling Head Test Results

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Slug Test - Water Level Data Page 1 of 2

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg	Slug Test: BH1D	Test Well: BH1D
Test Conducted by: Sarah Mahlangu	Test Date: 03/06/2017	
Water level at t=0 [m]: 0.00	Static Water Level [m]: 3.17	Water level change at t=0 [m]: -3.17

	Time [s]	Water Level [m]	WL Change [m]
1	60	0.2537	-2.9173
2	120	0.5288	-2.6422
3	180	0.7345	-2.4365
4	240	0.8948	-2.2762
5	300	1.0061	-2.1649
6	360	1.0779	-2.0931
7	420	1.127	-2.044
8	480	1.1658	-2.0052
9	540	1.1981	-1.9729
10	600	1.224	-1.947
11	660	1.2455	-1.9255
12	720	1.2655	-1.9055
13	780	1.2825	-1.8885
14	840	1.2972	-1.8738
15	900	1.3122	-1.8588
16	960	1.3235	-1.8475
17	1020	1.3118	-1.8592
18	1080	1.323	-1.848
19	1140	1.333	-1.838
20	1200	1.3414	-1.8296
21	1260	1.3497	-1.8213
22	1320	1.3566	-1.8144
23	1380	1.3637	-1.8073
24	1440	1.3696	-1.8014
25	1500	1.3761	-1.7949
26	1560	1.3817	-1.7893
27	1620	1.3872	-1.7838
28	1680	1.3938	-1.7772
29	1740	1.3991	-1.7719
30	1800	1.4029	-1.7681
31	1860	1.407	-1.764
32	1920	1.4088	-1.7622
33	1980	1.414	-1.757
34	2040	1.4171	-1.7539
35	2100	1.4217	-1.7493
36	2160	1.4249	-1.7461
37	2220	1.4286	-1.7424
38	2280	1.4296	-1.7414
39	2340	1.4334	-1.7376
40	2400	1.436	-1.735
41	2460	1.4385	-1.7325
42	2520	1.4414	-1.7296
43	2580	1.4426	-1.7284
44	2640	1.4454	-1.7256
45	2700	1.448	-1.723
46	2760	1.4497	-1.7213
47	2820	1.4524	-1.7186
48	2880	1.4543	-1.7167
49	2940	1.4554	-1.7156
50	3000	1.4573	-1.7137
51	3060	1.4598	-1.7112
52	3120	1.461	-1.71

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Slug Test - Water Level Data Page 2 of 2

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

	Time [s]	Water Level [m]	WL Change [m]
53	3180	1.4632	-1.7078
54	3240	1.4648	-1.7062
55	3300	1.4662	-1.7048
56	3360	1.4678	-1.7032
57	3420	1.4706	-1.7004
58	3480	1.471	-1.70
59	3540	1.4728	-1.6982
60	3600	1.4752	-1.6958
61	3660	1.4761	-1.6949
62	3720	1.4776	-1.6934
63	3780	1.4787	-1.6923
64	3840	1.4796	-1.6914
65	3900	1.4786	-1.6924
66	3960	1.4796	-1.6914
67	4020	1.4823	-1.6887
68	4080	1.4836	-1.6874
69	4140	1.4859	-1.6851

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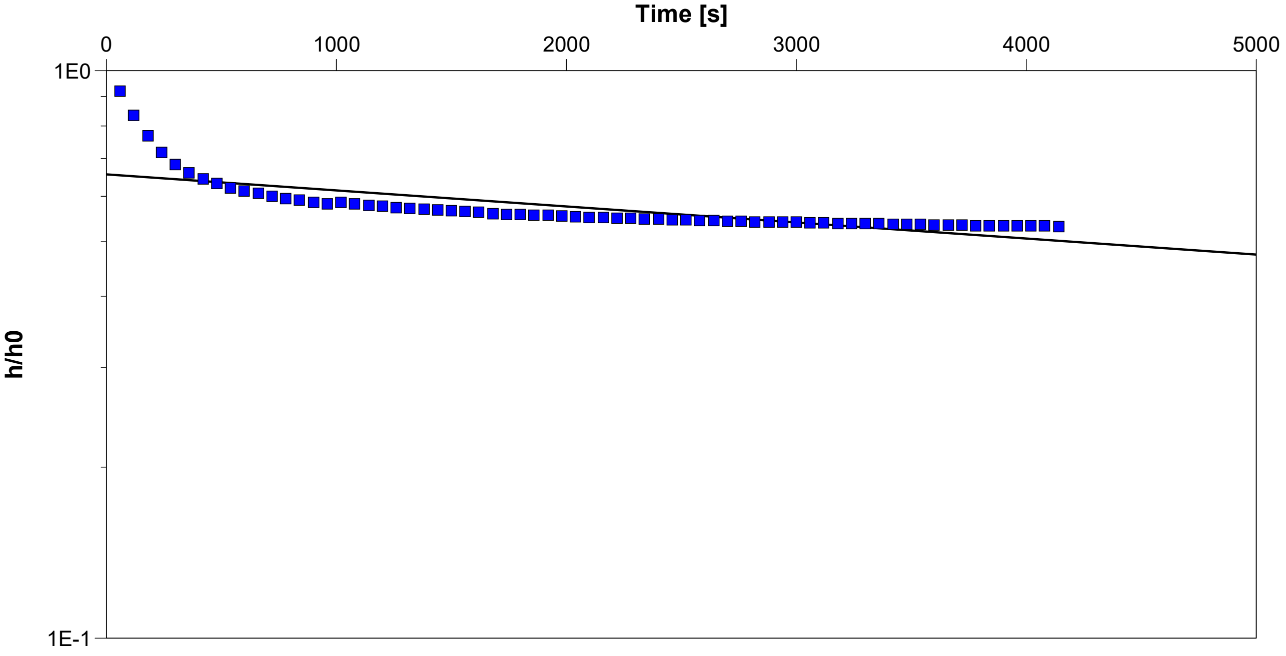
Slug Test Analysis Report
Project: Fontein Street Cemetery
Number:
Client: University of Pretoria

Location: Middelburg	Slug Test: BH1D	Test Well: BH1D
Test Conducted by: Sarah Mahlangu		Test Date: 03/06/2017
Analysis Performed by: Sarah Mahlangu	Bouwer & Rice	Analysis Date: 18/12/2017
Aquifer Thickness: 0.81 m		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]	
BH1D	1.81×10^{-1}	

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Slug Test - Analyses Report

Project: Fontein Street Cemetery
Number:
Client: University of Pretoria

Location: Middelburg	Slug Test: BH1D	Test Well: BH1D
Test Conducted by: Sarah Mahlangu		Test Date: 03/06/2017
Aquifer Thickness: 0.81 m		

	Analysis Name	Analysis Performed	Analysis Date	Method name	Well	T [m²/d]	K [m/d]	S
1	Bouwer & Rice	Sarah Mahlangu	18/12/2017	Bouwer & Rice	BH1D		1.81×10^{-1}	

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Slug Test - Water Level Data

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg

Slug Test: BH1S Slug Test

Test Well: BH1S

Test Conducted by: Sarah Mahlangu

Test Date: 03/06/2017

Water level at t=0 [m]: 0.00

Static Water Level [m]: 1.15

Water level change at t=0 [m]: -1.15

	Time [s]	Water Level [m]	WL Change [m]
1	0	0.00	-1.15
2	60	0.275	-0.875
3	120	0.3946	-0.7554
4	180	0.4573	-0.6927
5	240	0.5241	-0.6259
6	300	0.5505	-0.5995
7	360	0.5647	-0.5853
8	420	0.5774	-0.5726
9	480	0.5884	-0.5616
10	540	0.597	-0.553
11	600	0.6047	-0.5453
12	660	0.6128	-0.5372
13	720	0.6204	-0.5296
14	780	0.627	-0.523
15	840	0.6341	-0.5159
16	900	0.6415	-0.5085
17	960	0.6487	-0.5013
18	1020	0.6564	-0.4936
19	1080	0.6634	-0.4866
20	1140	0.67	-0.48
21	1200	0.678	-0.472
22	1260	0.6843	-0.4657
23	1320	0.6911	-0.4589
24	1380	0.6976	-0.4524
25	1440	0.7057	-0.4443
26	1500	0.7117	-0.4383
27	1560	0.7188	-0.4312
28	1620	0.7239	-0.4261
29	1680	0.7319	-0.4181
30	1740	0.7363	-0.4137
31	1800	0.7427	-0.4073
32	1860	0.7475	-0.4025
33	1920	0.7523	-0.3977
34	1980	0.7586	-0.3914
35	2040	0.7634	-0.3866
36	2100	0.7674	-0.3826
37	2160	0.7723	-0.3777
38	2220	0.7758	-0.3742
39	2280	0.7799	-0.3701
40	2340	0.7844	-0.3656
41	2400	0.788	-0.362
42	2460	0.7909	-0.3591
43	2520	0.7944	-0.3556
44	2580	0.7986	-0.3514
45	2640	0.8015	-0.3485
46	2700	0.8052	-0.3448
47	2760	0.808	-0.342
48	2820	0.8107	-0.3393
49	2880	0.8136	-0.3364
50	2940	0.8177	-0.3323
51	3000	0.8199	-0.3301
52	3060	0.8222	-0.3278

Slug Test - Water Level Data

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

	Time [s]	Water Level [m]	WL Change [m]
53	3120	0.8248	-0.3252
54	3180	0.828	-0.322
55	3240	0.8291	-0.3209

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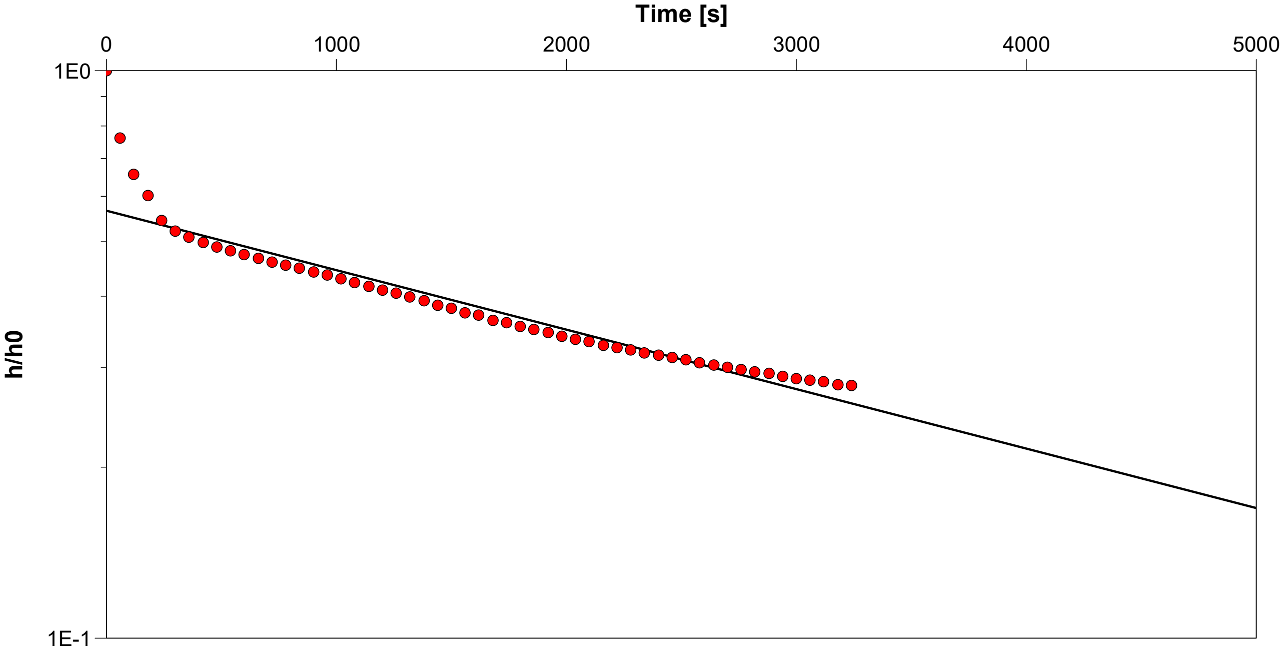
Slug Test Analysis Report	
Project:	Fontein Street Cemetery
Number:	
Client:	University of Pretoria

Location: Middelburg	Slug Test: BH1S Slug Test	Test Well: BH1S
Test Conducted by: Sarah Mahlangu		Test Date: 03/06/2017
Analysis Performed by: Sarah Mahlangu	Bouwer & Rice	Analysis Date: 19/12/2017
Aquifer Thickness: 0.42 m		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]	
BH1S	1.35×10^{-1}	

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Slug Test - Analyses Report

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg

Slug Test: BH1S Slug Test

Test Well: BH1S

Test Conducted by: Sarah Mahlangu

Test Date: 03/06/2017

Aquifer Thickness: 0.42 m

	Analysis Name	Analysis Performed	Analysis Date	Method name	Well	T [m²/d]	K [m/d]	S
1	Bouwer & Rice	Sarah Mahlangu	19/12/2017	Bouwer & Rice	BH1S		1.35×10^{-1}	

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Slug Test - Water Level Data Page 1 of 2

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg	Slug Test: BH2D Slug Test	Test Well: BH2D
Test Conducted by: Sarah Mahlangu	Test Date: 04/06/2017	
Water level at t=0 [m]: 2.42	Static Water Level [m]: 3.74	Water level change at t=0 [m]: -1.32

	Time [s]	Water Level [m]	WL Change [m]
1	0	2.42	-1.32
2	60	2.535	-1.205
3	120	2.6297	-1.1103
4	180	2.7046	-1.0354
5	240	2.7713	-0.9687
6	300	2.8265	-0.9135
7	360	2.8738	-0.8662
8	420	2.9139	-0.8261
9	480	2.9476	-0.7924
10	540	2.9817	-0.7583
11	600	3.011	-0.729
12	660	3.0373	-0.7027
13	720	3.0612	-0.6788
14	780	3.0821	-0.6579
15	840	3.1026	-0.6374
16	900	3.1228	-0.6172
17	960	3.1376	-0.6024
18	1020	3.1545	-0.5855
19	1080	3.1682	-0.5718
20	1140	3.1807	-0.5593
21	1200	3.1929	-0.5471
22	1260	3.2025	-0.5375
23	1320	3.2122	-0.5278
24	1380	3.2181	-0.5219
25	1440	3.2245	-0.5155
26	1500	3.2328	-0.5072
27	1560	3.239	-0.501
28	1620	3.2453	-0.4947
29	1680	3.2518	-0.4882
30	1740	3.2572	-0.4828
31	1800	3.2612	-0.4788
32	1860	3.2672	-0.4728
33	1920	3.271	-0.469
34	1980	3.2709	-0.4691
35	2040	3.2755	-0.4645
36	2100	3.2786	-0.4614
37	2160	3.2778	-0.4622
38	2220	3.2791	-0.4609
39	2280	3.2822	-0.4578
40	2340	3.2862	-0.4538
41	2400	3.1993	-0.5407
42	2460	3.2034	-0.5366
43	2520	3.2065	-0.5335
44	2580	3.2069	-0.5331
45	2640	3.2121	-0.5279
46	2700	3.2121	-0.5279
47	2760	3.2154	-0.5246
48	2820	3.2178	-0.5222
49	2880	3.2202	-0.5198
50	2940	3.2213	-0.5187
51	3000	3.2243	-0.5157
52	3060	3.2252	-0.5148

Slug Test - Water Level Data

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

	Time [s]	Water Level [m]	WL Change [m]
53	3120	3.2262	-0.5138
54	3180	3.227	-0.513
55	3240	3.2302	-0.5098
56	3300	3.2327	-0.5073
57	3360	3.2331	-0.5069
58	3420	3.2345	-0.5055
59	3480	3.2364	-0.5036
60	3540	3.2382	-0.5018
61	3600	3.2388	-0.5012
62	3660	3.2407	-0.4993
63	3720	3.2425	-0.4975
64	3780	3.2426	-0.4974
65	3840	3.2433	-0.4967
66	3900	3.245	-0.495
67	3960	3.2459	-0.4941
68	4020	3.2468	-0.4932
69	4080	3.2481	-0.4919
70	4140	3.2494	-0.4906
71	4200	3.2495	-0.4905
72	4260	3.2509	-0.4891
73	4320	3.2521	-0.4879
74	4380	3.2523	-0.4877
75	4440	3.2526	-0.4874
76	4500	3.2541	-0.4859
77	4560	3.256	-0.484
78	4620	3.2574	-0.4826
79	4680	3.2574	-0.4826

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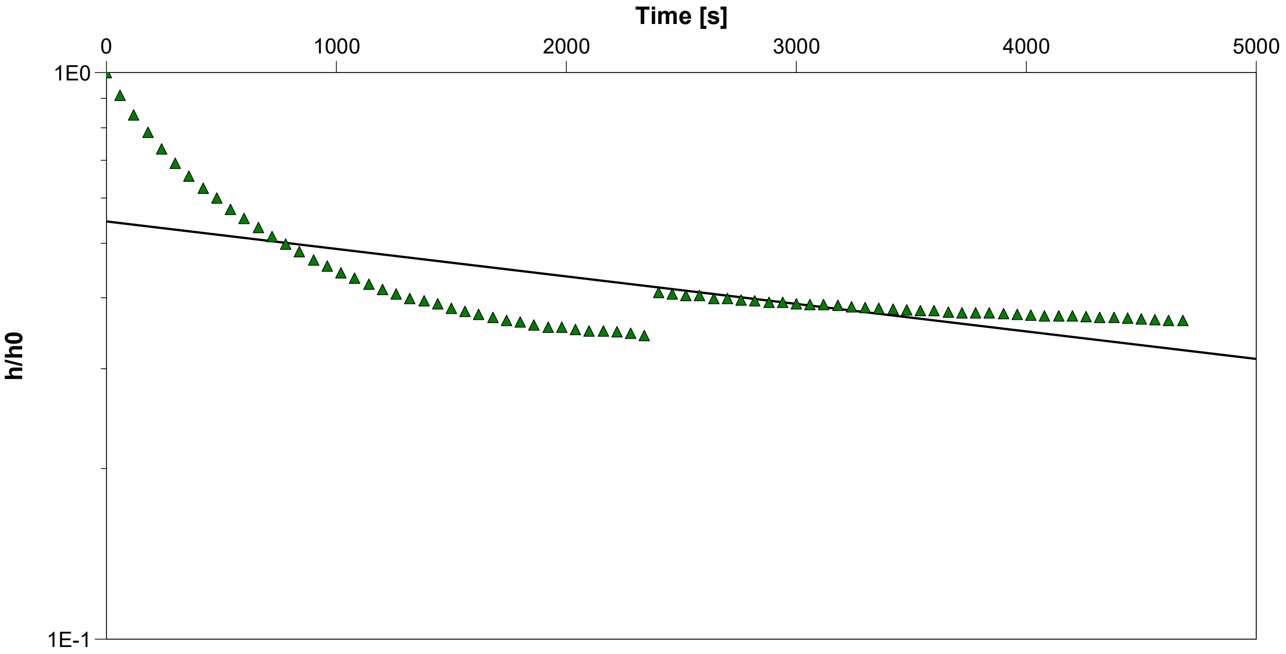
Slug Test Analysis Report

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg	Slug Test: BH2D Slug Test	Test Well: BH2D
Test Conducted by: Sarah Mahlangu		Test Date: 04/06/2017
Analysis Performed by: Sarah Mahlangu	Bouwer & Rice	Analysis Date: 19/12/2017
Aquifer Thickness: 4.33 m		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]	
BH2D	9.93×10^{-2}	

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Slug Test - Analyses Report

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg	Slug Test: BH2D Slug Test	Test Well: BH2D
Test Conducted by: Sarah Mahlangu		Test Date: 04/06/2017
Aquifer Thickness: 4.33 m		

	Analysis Name	Analysis Performed	Analysis Date	Method name	Well	T [m²/d]	K [m/d]	S
1	Bouwer & Rice	Sarah Mahlangu	19/12/2017	Bouwer & Rice	BH2D		9.93×10^{-2}	

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Slug Test - Water Level Data

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg	Slug Test: BH3D Slug Test	Test Well: BH3D
Test Conducted by: Sarah Mahlangu	Test Date: 03/06/2017	
Water level at t=0 [m]: 1.40	Static Water Level [m]: 4.99	Water level change at t=0 [m]: -3.59

	Time [s]	Water Level [m]	WL Change [m]
1	0	1.40	-3.59
2	60	1.4441	-3.5459
3	120	1.4789	-3.5111
4	180	1.5085	-3.4815
5	240	1.5293	-3.4607
6	300	1.5459	-3.4441
7	360	1.5608	-3.4292
8	420	1.5765	-3.4135
9	480	1.5943	-3.3957
10	540	1.6089	-3.3811
11	600	1.6225	-3.3675
12	660	1.6362	-3.3538
13	720	1.6517	-3.3383
14	780	1.6644	-3.3256
15	840	1.6756	-3.3144
16	900	1.6884	-3.3016
17	960	1.699	-3.291
18	1020	1.7098	-3.2802
19	1080	1.7212	-3.2688
20	1140	1.7304	-3.2596
21	1200	1.7399	-3.2501
22	1260	1.7492	-3.2408
23	1320	1.758	-3.232
24	1380	1.7668	-3.2232
25	1440	1.7751	-3.2149
26	1500	1.7846	-3.2054
27	1560	1.793	-3.197
28	1620	1.8076	-3.1824
29	1680	1.8174	-3.1726
30	1740	1.8267	-3.1633
31	1800	1.8364	-3.1536
32	1860	1.8448	-3.1452
33	1920	1.8531	-3.1369
34	1980	1.8624	-3.1276
35	2040	1.8707	-3.1193
36	2100	1.8805	-3.1095
37	2160	1.8873	-3.1027
38	2220	1.8976	-3.0924
39	2280	1.9068	-3.0832
40	2340	1.9155	-3.0745
41	2400	1.9231	-3.0669
42	2460	1.9288	-3.0612
43	2520	1.9361	-3.0539
44	2580	1.9426	-3.0474
45	2640	1.949	-3.041
46	2700	1.9576	-3.0324
47	2760	1.9666	-3.0234
48	2820	1.9767	-3.0133
49	2880	1.9847	-3.0053
50	2940	1.9937	-2.9963
51	3000	2.0019	-2.9881
52	3060	2.0094	-2.9806

Slug Test - Water Level Data

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

	Time [s]	Water Level [m]	WL Change [m]
53	3120	2.0231	-2.9669
54	3180	2.0311	-2.9589
55	3240	2.0394	-2.9506
56	3300	2.0465	-2.9435
57	3360	2.055	-2.935
58	3420	2.0622	-2.9278
59	3480	2.0694	-2.9206
60	3540	2.0774	-2.9126
61	3600	2.0897	-2.9003
62	3660	2.0989	-2.8911
63	3720	2.1085	-2.8815
64	3780	2.1161	-2.8739
65	3840	2.1262	-2.8638
66	3900	2.133	-2.857
67	3960	2.142	-2.848
68	4020	2.151	-2.839
69	4080	2.1565	-2.8335
70	4140	2.162	-2.828
71	4200	2.1674	-2.8226
72	4260	2.174	-2.816
73	4320	2.1812	-2.8088
74	4380	2.1876	-2.8024
75	4440	2.1941	-2.7959
76	4500	2.2003	-2.7897
77	4560	2.2084	-2.7816
78	4620	2.2152	-2.7748
79	4680	2.2213	-2.7687
80	4740	2.2359	-2.7541
81	4800	2.2446	-2.7454
82	4860	2.2512	-2.7388
83	4920	2.259	-2.731
84	4980	2.2664	-2.7236
85	5040	2.2736	-2.7164
86	5100	2.2806	-2.7094
87	5160	2.2875	-2.7025
88	5220	2.2954	-2.6946
89	5280	2.2992	-2.6908
90	5340	2.3048	-2.6852
91	5400	2.3088	-2.6812
92	5460	2.315	-2.675
93	5520	2.319	-2.671
94	5580	2.3248	-2.6652
95	5640	2.33	-2.66
96	5700	2.3355	-2.6545
97	5760	2.3411	-2.6489
98	5820	2.348	-2.642
99	5880	2.3524	-2.6376
100	5940	2.3583	-2.6317
101	6000	2.3644	-2.6256
102	6060	2.3691	-2.6209
103	6120	2.3753	-2.6147
104	6180	2.3807	-2.6093
105	6240	2.386	-2.604
106	6300	2.3906	-2.5994
107	6360	2.4033	-2.5867
108	6420	2.4091	-2.5809
109	6480	2.4143	-2.5757

	Time [s]	Water Level [m]	WL Change [m]
110	6540	2.4215	-2.5685
111	6600	2.4267	-2.5633
112	6660	2.4336	-2.5564
113	6720	2.4387	-2.5513
114	6780	2.4442	-2.5458
115	6840	2.4499	-2.5401
116	6900	2.4543	-2.5357
117	6960	2.4582	-2.5318
118	7020	2.4621	-2.5279
119	7080	2.4658	-2.5242
120	7140	2.4698	-2.5202
121	7200	2.4728	-2.5172
122	7260	2.478	-2.512
123	7320	2.482	-2.508
124	7380	2.4862	-2.5038
125	7440	2.4898	-2.5002
126	7500	2.4947	-2.4953
127	7560	2.50	-2.49
128	7620	2.5042	-2.4858
129	7680	2.5074	-2.4826
130	7740	2.5116	-2.4784
131	7800	2.5165	-2.4735
132	7860	2.5211	-2.4689
133	7920	2.5256	-2.4644
134	7980	2.5294	-2.4606
135	8040	2.5348	-2.4552
136	8100	2.5378	-2.4522
137	8160	2.5429	-2.4471
138	8220	2.5466	-2.4434
139	8280	2.5516	-2.4384
140	8340	2.5553	-2.4347
141	8400	2.5605	-2.4295
142	8460	2.5738	-2.4162
143	8520	2.578	-2.412
144	8580	2.5833	-2.4067
145	8640	2.5885	-2.4015
146	8700	2.5922	-2.3978
147	8760	2.597	-2.393
148	8820	2.6019	-2.3881
149	8880	2.6064	-2.3836
150	8940	2.6103	-2.3797
151	9000	2.6148	-2.3752
152	9060	2.6196	-2.3704
153	9120	2.6248	-2.3652
154	9180	2.6286	-2.3614
155	9240	2.6331	-2.3569
156	9300	2.6373	-2.3527
157	9360	2.6425	-2.3475
158	9420	2.6459	-2.3441
159	9480	2.651	-2.339
160	9540	2.6551	-2.3349
161	9600	2.6603	-2.3297
162	9660	2.6677	-2.3223
163	9720	2.6783	-2.3117
164	9780	2.6938	-2.2962
165	9840	2.7033	-2.2867
166	9900	2.7125	-2.2775

	Time [s]	Water Level [m]	WL Change [m]
167	9960	2.7244	-2.2656
168	10020	2.7346	-2.2554
169	10080	2.746	-2.244
170	10140	2.7581	-2.2319
171	10200	2.7705	-2.2195
172	10260	2.7885	-2.2015
173	10320	2.8038	-2.1862

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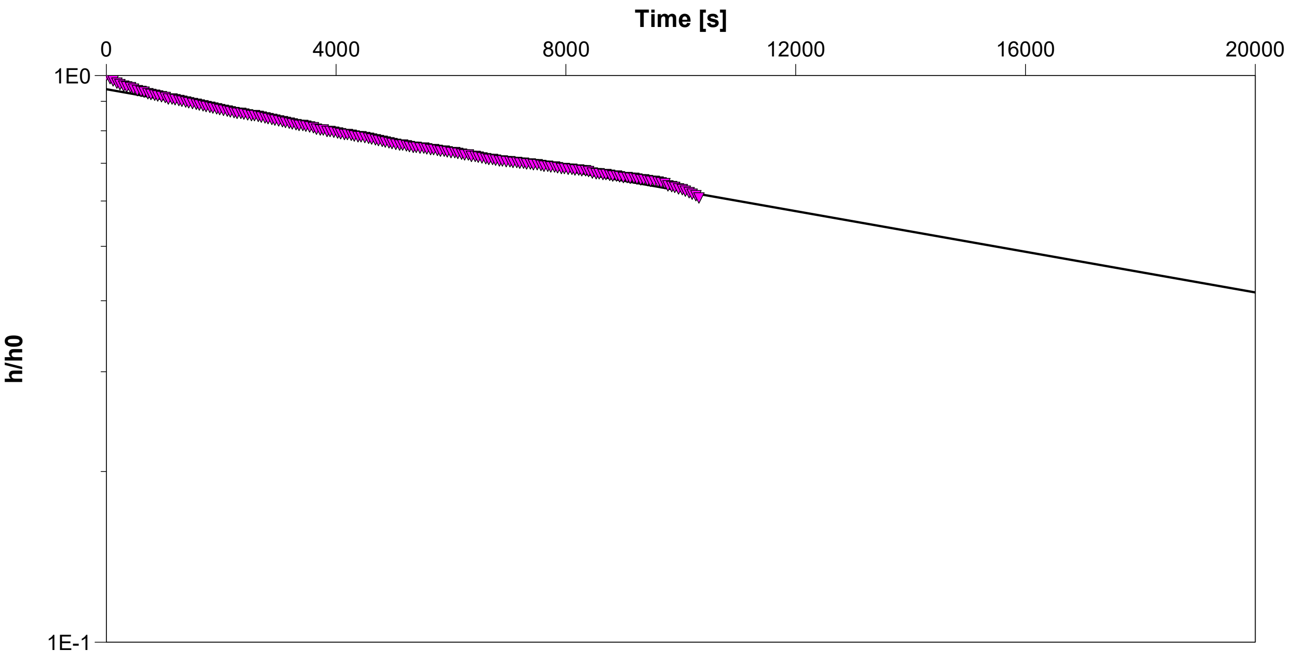
YUNIBESITHI YA PRETORIA

Slug Test Analysis Report

Project:	Fontein Street Cemetery
Number:	
Client:	University of Pretoria

Location: Middelburg	Slug Test: BH3D Slug Test	Test Well: BH3D
Test Conducted by: Sarah Mahlangu		Test Date: 03/06/2017
Analysis Performed by: Sarah Mahlangu	Bouwer & Rice	Analysis Date: 20/12/2017
Aquifer Thickness: 0.50 m		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]	
BH3D	1.47×10^{-1}	

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Slug Test - Analyses Report

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg	Slug Test: BH3D Slug Test	Test Well: BH3D
Test Conducted by: Sarah Mahlangu		Test Date: 03/06/2017
Aquifer Thickness: 0.50 m		

	Analysis Name	Analysis Performed	Analysis Date	Method name	Well	T [m²/d]	K [m/d]	S
1	Bouwer & Rice	Sarah Mahlangu	20/12/2017	Bouwer & Rice	BH3D		1.47×10^{-1}	

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Slug Test - Water Level Data Page 1 of 2

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg	Slug Test: BH4S Slug Test	Test Well: BH4S
Test Conducted by: Sarah Mahlangu	Test Date: 03/06/2017	
Water level at t=0 [m]: 0.00	Static Water Level [m]: 1.07	Water level change at t=0 [m]: -1.07

	Time [s]	Water Level [m]	WL Change [m]
1	0	0.00	-1.07
2	60	0.4322	-0.6378
3	120	0.4693	-0.6007
4	180	0.4775	-0.5925
5	240	0.4861	-0.5839
6	300	0.4945	-0.5755
7	360	0.5011	-0.5689
8	420	0.5075	-0.5625
9	480	0.5124	-0.5576
10	540	0.5176	-0.5524
11	600	0.5214	-0.5486
12	660	0.5258	-0.5442
13	720	0.5302	-0.5398
14	780	0.5333	-0.5367
15	840	0.5364	-0.5336
16	900	0.5408	-0.5292
17	960	0.5442	-0.5258
18	1020	0.5484	-0.5216
19	1080	0.5517	-0.5183
20	1140	0.5549	-0.5151
21	1200	0.5572	-0.5128
22	1260	0.5599	-0.5101
23	1320	0.5635	-0.5065
24	1380	0.5658	-0.5042
25	1440	0.5684	-0.5016
26	1500	0.5714	-0.4986
27	1560	0.5744	-0.4956
28	1620	0.5768	-0.4932
29	1680	0.5798	-0.4902
30	1740	0.5827	-0.4873
31	1800	0.5845	-0.4855
32	1860	0.588	-0.482
33	1920	0.5891	-0.4809
34	1980	0.5912	-0.4788
35	2040	0.5939	-0.4761
36	2100	0.5965	-0.4735
37	2160	0.599	-0.471
38	2220	0.6004	-0.4696
39	2280	0.6029	-0.4671
40	2340	0.6058	-0.4642
41	2400	0.6072	-0.4628
42	2460	0.6082	-0.4618
43	2520	0.6104	-0.4596
44	2580	0.6123	-0.4577
45	2640	0.6145	-0.4555
46	2700	0.6162	-0.4538
47	2760	0.6172	-0.4528
48	2820	0.6196	-0.4504
49	2880	0.6216	-0.4484
50	2940	0.6233	-0.4467
51	3000	0.623	-0.447
52	3060	0.6243	-0.4457

Slug Test - Water Level Data

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

	Time [s]	Water Level [m]	WL Change [m]
53	3120	0.6274	-0.4426
54	3180	0.6273	-0.4427
55	3240	0.6286	-0.4414
56	3300	0.6296	-0.4404
57	3360	0.6313	-0.4387
58	3420	0.6315	-0.4385
59	3480	0.6322	-0.4378
60	3540	0.6342	-0.4358
61	3600	0.6359	-0.4341
62	3660	0.6365	-0.4335
63	3720	0.6386	-0.4314
64	3780	0.6382	-0.4318
65	3840	0.6398	-0.4302
66	3900	0.6402	-0.4298
67	3960	0.6408	-0.4292
68	4020	0.642	-0.428
69	4080	0.6429	-0.4271
70	4140	0.6451	-0.4249
71	4200	0.6459	-0.4241
72	4260	0.647	-0.423
73	4320	0.6477	-0.4223
74	4380	0.6534	-0.4166
75	4440	0.6524	-0.4176
76	4500	0.6529	-0.4171

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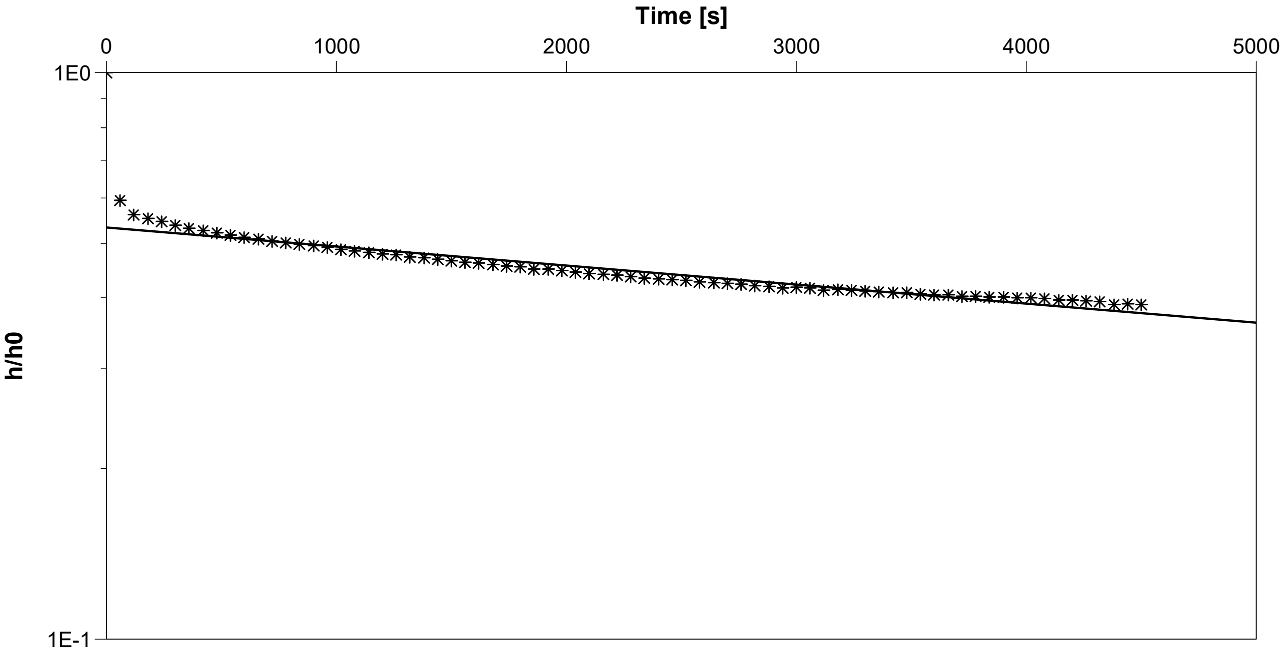
Slug Test Analysis Report

Project: Fontein Street Cemetery	
Number:	
Client: University of Pretoria	

Location: Middelburg	Slug Test: BH4S Slug Test	Test Well: BH4S
Test Conducted by: Sarah Mahlangu		Test Date: 03/06/2017
Analysis Performed by: Sarah Mahlangu	Bouwer & Rice	Analysis Date: 20/12/2017
Aquifer Thickness: 0.11 m		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/d]	
BH4S	4.96×10^{-2}	

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Slug Test - Analyses Report

Project: Fontein Street Cemetery

Number:

Client: University of Pretoria

Location: Middelburg	Slug Test: BH4S Slug Test	Test Well: BH4S
Test Conducted by: Sarah Mahlangu		Test Date: 03/06/2017

Aquifer Thickness: 0.11 m

	Analysis Name	Analysis Performed	Analysis Date	Method name	Well	T [m²/d]	K [m/d]	S
1	Bouwer & Rice	Sarah Mahlangu	20/12/2017	Bouwer & Rice	BH4S		4.96×10^{-2}	

Appendix B2: Double Ring Infiltration Test Results

BH2D - 04 June 2017								
Water Depth Interval (cm)		Water Depth (m)	Cumulative Depth	Time		Total Time (s)	Cumulative Time	Infiltration Rate(m/s)
From	To			minutes	Seconds			
0	0.5	0.005	0.005	25	24	1524	1524	3.28E-06
0.5	1	0.005	0.01	24	29	1469	2993	3.40E-06
1	1.5	0.005	0.015	15	40	940	3933	5.32E-06
1.5	2	0.005	0.02	19	20	1160	5093	4.31E-06
Average Infiltration Rate (m/s)								4.08E-06

BH4S - 04 June 2017								
Water Depth Interval (cm)		Water Depth (m)	Cumulative Depth	Time		Total Time (s)	Cumulative Time	Infiltration Rate(m/s)
From	To			minutes	Seconds			
0	1	0.01	0.01	7	3	423	423	2.36E-05
1	2	0.01	0.02	8	39	519	942	1.93E-05
2	3	0.01	0.03	9	0	540	1482	1.85E-05
3	4	0.01	0.04	9	3	543	2025	1.84E-05
4	5	0.01	0.05	11	5	665	2690	1.50E-05
5	6	0.01	0.06	10	24	624	3314	1.60E-05
6	7	0.01	0.07	12	36	756	4070	1.32E-05
7	8	0.01	0.08	11	35	695	4765	1.44E-05
Average Infiltration Rate (m/s)								1.73E-05

BH1D - 03 June 2017						
Water Depth Interval (cm)		**Water Depth (m)**	**Time**		**Total Time (s)**	**Infiltration Rate(m/s)**
From	**To**		**minutes**	**Seconds**		
0	3	0.03	18	4	1084	2.77E-05
3	4	0.01	5	34	334	2.99E-05
4	5	0.01	5	10	310	3.23E-05
5	6	0.01	7	24	444	2.25E-05
6	7	0.01	7	14	434	2.30E-05
0	1	0.01	6	10	370	2.70E-05
1	2	0.01	7	14	434	2.30E-05
2	3	0.01	7	14	434	2.30E-05
3	4	0.01	6	30	390	2.56E-05
4	5	0.01	7	15	435	2.30E-05
5	6	0.01	6	30	390	2.56E-05
6	7	0.01	7	15	435	2.30E-05
Average Infiltration Rate (m/s)						2.55E-05

BH3D - 03 June 2017						
Water Depth Interval (cm)		**Water Depth (m)**	**Time**		**Time (s)**	**Infiltration Rate(m/s)**
From	**To**		**minutes**	**Seconds**		
0	15	0.15	10	24.98	624.98	2.40E-04
0	15	0.15	11	18.77	678.77	2.21E-04
15	30	0.15	23	30.32	731.55	2.05E-04
0	15	0.15	14	34.14	874.14	1.72E-04
15	30	0.15	30	2	927.86	1.62E-04
0	15	0.15	15	13	913	1.64E-04
15	30	0.15	31	28	975	1.54E-04
Average Infiltration Rate (m/s)						1.88E-04

Appendix C: Chemical Analysis Results

Appendix C1: Laboratory Certificates

WATERLAB

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sanas Testing Laboratory
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CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2017 - 01 - 19
Date completed: 2017 - 02 – 10
Project number: 215
Report number: 64529
Order number: 0000481196

Client name: University of Pretoria
Contact person: Mr. M. Dippenaar
Address: Private Bag X20, Geology Department, Hatfield, 0028
e-mail: matthysd@icloud.com
Telephone: 082 826 5468
Facsimile: -
Mobile: 082 826 5468

Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification**				
		BH2D 20/10/2016	**Stream A 20/10/2016**	**Stream B 20/10/2016**	**Stream C 20/10/2016**	**Hydro-census BH14A 08/11/2016**
Sample Number		26382	26383	26384	26385	26386
pH – Value at 25°C *	WLAB065	6.2	6.3	7.0	6.5	7.0
Electrical Conductivity in mS/m at 25°C	WLAB002	31.4	82.7	69.0	63.6	56.8
Total Dissolved Solids at 180°C *	WLAB003	250	660	556	454	398
Colour in PtCo Units *	WLAB006	61	18	25	39	11
Odour in T.O.N *	WLAB038	<5	<5	<5	<5	<5
Turbidity in N.T.U	WLAB005	1 752	4.0	1.0	4.1	0.4
Chloride as Cl	WLAB046	63	20	17	17	49
Sulphate as SO_4	WLAB046	9	276	243	217	68
Fluoride as F	WLAB014	<0.2	0.3	0.3	0.4	<0.2
Nitrate as N	WLAB046	1.1	0.2	0.3	0.1	9.0
Nitrite as N	WLAB046	<0.05	<0.05	<0.05	<0.05	<0.05
Total Organic Carbon as C *	WLAB060	1.0	5.3	5.1	6.2	1.4
Total Coliform Bacteria / 100 mℓ	WLAB021	1 400	64	170	33	77
Faecal Coliform Bacteria / 100 mℓ *	WLAB021	1	4	30	0	0
E. coli / 100 mℓ	WLAB021	0	3	13	0	0
Heterotrophic Plate Count / mℓ *	WLAB021	13 000	77	70	33	1 800
ICP-MS Scan *	WLAB050	See Attached Report: 64529-A				
% Balancing *	---	91.6	93.9	86.5	99.2	91.3

E. Nkabinde

Technical Signatory

WATERLAB

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e-mail: matthysd@icloud.com
Telephone: 082 826 5468
Facsimile: -
Mobile: 082 826 5468

Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification**				
		Hydro-census BH5A 08/11/2016	**BH17 08/11/2016**	**Mun 1 08/11/2016**	**Mall BH1 08/11/2016**	**Mun 1 08/12/2016**
Sample Number		26387	26388	26389	26390	26391
pH – Value at 25°C *	WLAB065	6.4	6.1	6.5	6.7	6.5
Electrical Conductivity in mS/m at 25°C	WLAB002	28.6	14.1	92.4	13.9	76.1
Total Dissolved Solids at 180°C *	WLAB003	214	106	742	126	600
Colour in PtCo Units *	WLAB006	11	12	11	11	12
Odour in T.O.N *	WLAB038	<5	<5	<5	<5	<5
Turbidity in N.T.U	WLAB005	0.2	40	0.1	0.3	0.2
Chloride as Cl	WLAB046	21	12	27	2	23
Sulphate as SO_4	WLAB046	13	10	368	<2	260
Fluoride as F	WLAB014	<0.2	<0.2	0.5	<0.2	0.4
Nitrate as N	WLAB046	3.2	1.6	0.3	<0.1	0.5
Nitrite as N	WLAB046	<0.05	<0.05	<0.05	<0.05	<0.05
Total Organic Carbon as C *	WLAB060	<1.0	3.7	4.4	<1.0	4.0
Total Coliform Bacteria / 100 mℓ	WLAB021	0	1	0	1	3
Faecal Coliform Bacteria / 100 mℓ *	WLAB021	0	0	0	0	0
E. coli / 100 mℓ	WLAB021	0	0	0	0	0
Heterotrophic Plate Count / mℓ *	WLAB021	210	2 500	<10	3 200	140
ICP-MS Scan *	WLAB050	See Attached Report: 64529-A				
% Balancing *	---	90.4	98.2	98.2	99.2	98.9

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e-mail: matthysd@icloud.com
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Facsimile: -
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Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification**				
		Hydro-census BH5A 08/12/2016	**Hydro-census BH14 08/12/2016**	**BH2D 08/12/2016**	**BH1D 08/12/2016**	**BH17 08/12/2016**
Sample Number		26392	26393	26394	26395	26396
pH – Value at 25°C *	WLAB065	7.9	7.7	6.3	6.1	6.8
Electrical Conductivity in mS/m at 25°C	WLAB002	22.9	28.2	29.4	7.6	5.2
Total Dissolved Solids at 180°C *	WLAB003	164	206	230	62	74
Colour in PtCo Units *	WLAB006	5	9	9	98	22
Odour in T.O.N *	WLAB038	<5	<5	<5	<5	<5
Turbidity in N.T.U	WLAB005	2.1	1.5	252	137	12
Chloride as Cl	WLAB046	16	15	59	3	2
Sulphate as SO_4	WLAB046	12	38	<2	8	<2
Fluoride as F	WLAB014	<0.2	<0.2	<0.2	0.3	<0.2
Nitrate as N	WLAB046	2.6	3.2	0.2	<0.1	0.1
Nitrite as N	WLAB046	<0.05	<0.05	<0.05	<0.05	<0.05
Total Organic Carbon as C *	WLAB060	<1.0	<1.0	<1.0	1.5	<1.0
Total Coliform Bacteria / 100 mℓ	WLAB021	0	22	16	62	1
Faecal Coliform Bacteria / 100 mℓ *	WLAB021	0	0	0	0	0
E. coli / 100 mℓ	WLAB021	0	0	0	0	0
Heterotrophic Plate Count / mℓ *	WLAB021	150	120	1 800	1 300	11 000
ICP-MS Scan *	WLAB050	See Attached Report: 64529-A				
% Balancing *	---	98.2	95.2	94.6	95.8	94.4

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Technical Signatory

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Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification**					
		BH1S 08/12/2016	**BH4 08/12/2016**	**Stream A 08/12/2016**	**Stream B 08/12/2016**	**Stream C 08/12/2016**	**Mall BH1 08/12/2016**
Sample Number		26397	26398	26399	26400	26401	26402
pH – Value at 25°C *	WLAB065	6.2	6.6	6.0	7.1	6.3	7.4
Electrical Conductivity in mS/m at 25°C	WLAB002	21.4	96.3	31.6	33.4	34.3	18.5
Total Dissolved Solids at 180°C *	WLAB003	164	704	262	274	270	136
Colour in PtCo Units *	WLAB006	20	21	16	17	17	4
Odour in T.O.N *	WLAB038	<5	<5	<5	<5	<5	<5
Turbidity in N.T.U	WLAB005	91	62	0.9	1.0	1.7	0.3
Chloride as Cl	WLAB046	7	145	12	13	13	2
Sulphate as SO_4	WLAB046	43	219	97	101	100	<2
Fluoride as F	WLAB014	0.2	0.2	0.2	0.2	0.2	<0.2
Nitrate as N	WLAB046	1.3	1.4	0.1	<0.1	0.1	0.1
Nitrite as N	WLAB046	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total Organic Carbon as C *	WLAB060	3.2	13	3.0	3.0	3.4	<1.0
Total Coliform Bacteria / 100 mℓ	WLAB021	390	12	4 500	650	370	0
Faecal Coliform Bacteria / 100 mℓ *	WLAB021	0	2	36	78	30	0
E. coli / 100 mℓ	WLAB021	0	0	0	44	17	0
Heterotrophic Plate Count / mℓ *	WLAB021	>100 000	41 000	3 000	200	230	<10
ICP-MS Scan *	WLAB050	See Attached Report: 64529-A					
% Balancing *	---	95.3	87.7	97.8	92.4	99.4	92.5

E. Nkabinde

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Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification**					
		Stream A 15/01/2017	**Stream B 15/01/2017**	**Stream C 15/01/2017**	**Mun 1 15/01/2017**	**BH1D 15/01/2017**	**BH2D 15/01/2017**
Sample Number		26403	26404	26405	26406	26407	26408
pH – Value at 25°C *	WLAB065	6.4	6.1	6.3	6.5	6.3	6.2
Electrical Conductivity in mS/m at 25°C	WLAB002	47.1	45.0	44.1	86.4	13.3	31.7
Total Dissolved Solids at 180°C *	WLAB003	348	374	362	692	90	186
Colour in PtCo Units *	WLAB006	21	20	24	20	16	6
Odour in T.O.N *	WLAB038	<5	<5	<5	<5	<5	<5
Turbidity in N.T.U	WLAB005	1.1	1.4	3.4	0.2	545	33
Chloride as Cl	WLAB046	20	18	18	23	4	59
Sulphate as SO_4	WLAB046	129	128	122	299	15	<2
Fluoride as F	WLAB014	0.3	0.3	0.3	0.5	0.3	<0.2
Nitrate as N	WLAB046	<0.1	0.1	0.1	0.7	<0.1	<0.1
Nitrite as N	WLAB046	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total Organic Carbon as C *	WLAB060	3.9	3.7	3.8	4.1	1.8	1.0
Total Coliform Bacteria / 100 mℓ	WLAB021	39 000	14 000	46 000	0	21 000	1 100
Faecal Coliform Bacteria / 100 mℓ *	WLAB021	36	820	1 100	0	0	3
E. coli / 100 mℓ	WLAB021	26	460	820	0	0	2
Heterotrophic Plate Count / mℓ *	WLAB021		2 500	1 100	110	28 000	770
ICP-MS Scan *	WLAB050	See Attached Report: 64529-A					
% Balancing *	---	89.8	96.2	93.6	99.2	98.9	91.1

*** = Not SANAS Accredited**
Tests marked “Not SANAS Accredited” in this report are not included in the SANAS Schedule of Accreditation for this Laboratory.

Bacteriological parameters analyzed on: 2017-01-19

E. Nkabinde

Technical Signatory

The information contained in this report is relevant only to the sample/samples supplied to **WATERLAB (Pty) Ltd**. Any further use of the above information is not the responsibility of **WATERLAB (Pty) Ltd**. Except for the full report, part of this report may not be reproduced without written approval of **WATERLAB (Pty) Ltd**. Details of sample conducted by Waterlab (PTY) Ltd according to WLAB/Sampling Plan and Procedures/SOP are available on request.

WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSIS

Project Number : **215**
Client : **University of Pretoria**
Report Number : **64529-A**

Sample Origin	Sample ID	Ag (mg/L)	Al (mg/L)	As (mg/L)	Au (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Ca (mg/L)	Cd (mg/L)	Ce (mg/L)	Co (mg/L)
BH2D 20/10/2016	26382	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.437	< 0.010	< 0.010	13	< 0.010	< 0.010	< 0.010
Stream A 20/10/2016	26383	< 0.010	< 0.100	< 0.010	< 0.010	0.039	0.109	< 0.010	< 0.010	38	< 0.010	< 0.010	< 0.010
Stream B 20/10/2016	26384	< 0.010	< 0.100	< 0.010	< 0.010	0.028	0.091	< 0.010	< 0.010	20	< 0.010	< 0.010	< 0.010
Stream C 20/10/2016	26385	< 0.010	< 0.100	< 0.010	< 0.010	0.030	0.076	< 0.010	< 0.010	42	< 0.010	< 0.010	< 0.010
Hydro-census BH14A 08/11/2016	26386	< 0.010	< 0.100	< 0.010	< 0.010	0.037	0.063	< 0.010	< 0.010	38	< 0.010	< 0.010	< 0.010
Hydro-census BH5A 08/11/2016	26387	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.031	< 0.010	< 0.010	24	< 0.010	< 0.010	< 0.010
BH17 08/11/2016	26388	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.048	< 0.010	< 0.010	7	< 0.010	< 0.010	< 0.010
Mun 1 08/11/2016	26389	< 0.010	< 0.100	< 0.010	< 0.010	0.054	0.082	< 0.010	< 0.010	68	< 0.010	< 0.010	< 0.010
Mall BH1 08/11/2016	26390	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.040	< 0.010	< 0.010	10	< 0.010	< 0.010	< 0.010
Mun 1 08/12/2016	26391	< 0.010	< 0.100	< 0.010	< 0.010	0.044	0.066	< 0.010	< 0.010	51	< 0.010	< 0.010	< 0.010
Hydro-census BH5A 08/12/2016	26392	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.026	< 0.010	< 0.010	19	< 0.010	< 0.010	< 0.010
Hydro-census BH14 08/12/2016	26393	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.047	< 0.010	< 0.010	34	< 0.010	< 0.010	< 0.010
BH2D 08/12/2016	26394	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.394	< 0.010	< 0.010	15	< 0.010	< 0.010	< 0.010
BH1D 08/12/2016	26395	< 0.010	0.118	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	1	< 0.010	< 0.010	< 0.010
BH17 08/12/2016	26396	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.022	< 0.010	< 0.010	6	< 0.010	< 0.010	< 0.010
BH1S 08/12/2016	26397	< 0.010	< 0.100	< 0.010	< 0.010	0.019	0.060	< 0.010	< 0.010	11	< 0.010	< 0.010	< 0.010
BH4 08/12/2016	26398	< 0.010	< 0.100	< 0.010	< 0.010	0.016	0.079	< 0.010	< 0.010	72	< 0.010	< 0.010	< 0.010
Stream A 08/12/2016	26399	< 0.010	< 0.100	< 0.010	< 0.010	0.017	0.044	< 0.010	< 0.010	19	< 0.010	< 0.010	< 0.010
Stream B 08/12/2016	26400	< 0.010	< 0.100	< 0.010	< 0.010	0.020	0.057	< 0.010	< 0.010	14	< 0.010	< 0.010	< 0.010
Stream C 08/12/2016	26401	< 0.010	< 0.100	< 0.010	< 0.010	0.013	0.047	< 0.010	< 0.010	21	< 0.010	< 0.010	< 0.010
Mall BH1 08/12/2016	26402	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.041	< 0.010	< 0.010	6	< 0.010	< 0.010	< 0.010
Stream A 15/01/2017	26403	< 0.010	< 0.100	< 0.010	< 0.010	0.021	0.062	< 0.010	< 0.010	14	< 0.010	< 0.010	< 0.010
Stream B 15/01/2017	26404	< 0.010	< 0.100	< 0.010	< 0.010	0.025	0.067	< 0.010	< 0.010	22	< 0.010	< 0.010	< 0.010
Stream C 15/01/2017	26405	< 0.010	< 0.100	< 0.010	< 0.010	0.020	0.065	< 0.010	< 0.010	18	< 0.010	< 0.010	< 0.010
Mun 1 15/01/2017	26406	< 0.010	< 0.100	< 0.010	< 0.010	0.050	0.070	< 0.010	< 0.010	52	< 0.010	< 0.010	< 0.010
BH1D 15/01/2017	26407	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.017	< 0.010	< 0.010	2	< 0.010	< 0.010	< 0.010

BH2D 15/01/2017	26408	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.412	< 0.010	< 0.010	13	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	**Cr (mg/L)**	**Cs (mg/L)**	**Cu (mg/L)**	**Dy (mg/L)**	**Er (mg/L)**	**Eu (mg/L)**	**Fe (mg/L)**	**Ga (mg/L)**	**Gd (mg/L)**	**Ge (mg/L)**	**Hf (mg/L)**	**Hg (mg/L)**
BH2D 20/10/2016	26382	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	0.026	< 0.010	< 0.010	< 0.010	< 0.010
Stream A 20/10/2016	26383	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream B 20/10/2016	26384	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream C 20/10/2016	26385	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Hydro-census BH14A 08/11/2016	26386	< 0.010	< 0.010	0.016	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Hydro-census BH5A 08/11/2016	26387	< 0.010	< 0.010	0.017	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH17 08/11/2016	26388	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1 08/11/2016	26389	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mall BH1 08/11/2016	26390	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1 08/12/2016	26391	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Hydro-census BH5A 08/12/2016	26392	< 0.010	< 0.010	0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Hydro-census BH14 08/12/2016	26393	< 0.010	< 0.010	0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH2D 08/12/2016	26394	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	0.022	< 0.010	< 0.010	< 0.010	< 0.010
BH1D 08/12/2016	26395	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.155	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH17 08/12/2016	26396	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.050	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1S 08/12/2016	26397	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.049	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH4 08/12/2016	26398	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream A 08/12/2016	26399	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream B 08/12/2016	26400	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream C 08/12/2016	26401	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mall BH1 08/12/2016	26402	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream A 15/01/2017	26403	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream B 15/01/2017	26404	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream C 15/01/2017	26405	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1 15/01/2017	26406	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1D 15/01/2017	26407	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.059	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH2D 15/01/2017	26408	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	0.021	< 0.010	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	**Ho (mg/L)**	**In (mg/L)**	**Ir (mg/L)**	**K (mg/L)**	**La (mg/L)**	**Li (mg/L)**	**Lu (mg/L)**	**Mg (mg/L)**	**Mn (mg/L)**	**Mo (mg/L)**	**Na (mg/L)**	**Nb (mg/L)**
BH2D 20/10/2016	26382	< 0.010	< 0.010	< 0.010	2.2	< 0.010	< 0.010	< 0.010	10	1.19	< 0.010	13	< 0.010
Stream A 20/10/2016	26383	< 0.010	< 0.010	< 0.010	5.9	< 0.010	< 0.010	< 0.010	48	< 0.025	< 0.010	29	< 0.010

Stream B 20/10/2016	26384	< 0.010	< 0.010	< 0.010	6.1	< 0.010	< 0.010	< 0.010	37	< 0.025	< 0.010	22	< 0.010
Stream C 20/10/2016	26385	< 0.010	< 0.010	< 0.010	5.2	< 0.010	< 0.010	< 0.010	35	< 0.025	< 0.010	22	< 0.010
Hydro-census BH14A 08/11/2016	26386	< 0.010	< 0.010	< 0.010	4.9	< 0.010	0.012	< 0.010	23	< 0.025	< 0.010	23	< 0.010
Hydro-census BH5A 08/11/2016	26387	< 0.010	< 0.010	< 0.010	2.4	< 0.010	< 0.010	< 0.010	7	< 0.025	< 0.010	13	< 0.010
BH17 08/11/2016	26388	< 0.010	< 0.010	< 0.010	1.6	< 0.010	< 0.010	< 0.010	4	0.051	< 0.010	11	< 0.010
Mun 1 08/11/2016	26389	< 0.010	< 0.010	< 0.010	10	< 0.010	< 0.010	< 0.010	58	< 0.025	< 0.010	32	< 0.010
Mall BH1 08/11/2016	26390	< 0.010	< 0.010	< 0.010	1.4	< 0.010	< 0.010	< 0.010	5	0.000	< 0.010	9	< 0.010
Mun 1 08/12/2016	26391	< 0.010	< 0.010	< 0.010	8.8	< 0.010	< 0.010	< 0.010	43	< 0.025	< 0.010	25	< 0.010
Hydro-census BH5A 08/12/2016	26392	< 0.010	< 0.010	< 0.010	1.8	< 0.010	< 0.010	< 0.010	8	< 0.025	< 0.010	10	< 0.010
Hydro-census BH14 08/12/2016	26393	< 0.010	< 0.010	< 0.010	1.2	< 0.010	< 0.010	< 0.010	7	< 0.025	< 0.010	6	< 0.010
BH2D 08/12/2016	26394	< 0.010	< 0.010	< 0.010	1.9	< 0.010	< 0.010	< 0.010	12	1.42	< 0.010	13	< 0.010
BH1D 08/12/2016	26395	< 0.010	< 0.010	< 0.010	< 0.5	< 0.010	< 0.010	< 0.010	1	< 0.025	< 0.010	11	< 0.010
BH17 08/12/2016	26396	< 0.010	< 0.010	< 0.010	< 0.5	< 0.010	< 0.010	< 0.010	1	< 0.025	< 0.010	2	< 0.010
BH1S 08/12/2016	26397	< 0.010	< 0.010	< 0.010	2.3	< 0.010	< 0.010	< 0.010	6	0.233	< 0.010	15	< 0.010
BH4 08/12/2016	26398	< 0.010	< 0.010	< 0.010	7.5	< 0.010	< 0.010	< 0.010	25	0.055	< 0.010	53	< 0.010
Stream A 08/12/2016	26399	< 0.010	< 0.010	< 0.010	4.4	< 0.010	< 0.010	< 0.010	14	< 0.025	< 0.010	10	< 0.010
Stream B 08/12/2016	26400	< 0.010	< 0.010	< 0.010	4.6	< 0.010	< 0.010	< 0.010	16	< 0.025	< 0.010	12	< 0.010
Stream C 08/12/2016	26401	< 0.010	< 0.010	< 0.010	4.1	< 0.010	< 0.010	< 0.010	17	< 0.025	< 0.010	12	< 0.010
Mall BH1 08/12/2016	26402	< 0.010	< 0.010	< 0.010	1.4	< 0.010	< 0.010	< 0.010	5	< 0.025	< 0.010	9	< 0.010
Stream A 15/01/2017	26403	< 0.010	< 0.010	< 0.010	5.7	< 0.010	< 0.010	< 0.010	24	0.071	< 0.010	17	< 0.010
Stream B 15/01/2017	26404	< 0.010	< 0.010	< 0.010	5.5	< 0.010	< 0.010	< 0.010	22	0.028	< 0.010	16	< 0.010
Stream C 15/01/2017	26405	< 0.010	< 0.010	< 0.010	5.1	< 0.010	< 0.010	< 0.010	22	< 0.025	< 0.010	16	< 0.010
Mun 1 15/01/2017	26406	< 0.010	< 0.010	< 0.010	10	< 0.010	< 0.010	< 0.010	52	< 0.025	< 0.010	30	< 0.010
BH1D 15/01/2017	26407	< 0.010	< 0.010	< 0.010	0.7	< 0.010	< 0.010	< 0.010	2	0.302	< 0.010	19	< 0.010
BH2D 15/01/2017	26408	< 0.010	< 0.010	< 0.010	2.1	< 0.010	< 0.010	< 0.010	13	1.88	< 0.010	12	< 0.010

Sample Origin	Sample ID	**Nd (mg/L)**	**Ni (mg/L)**	**Os (mg/L)**	**P (mg/L)**	**Pb (mg/L)**	**Pd (mg/L)**	**Pr (mg/L)**	**Pt (mg/L)**	**Rb (mg/L)**	**Rh (mg/L)**	**Ru (mg/L)**	**Sb (mg/L)**
BH2D 20/10/2016	26382	< 0.010	0.022	< 0.010	0.023	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream A 20/10/2016	26383	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream B 20/10/2016	26384	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream C 20/10/2016	26385	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Hydro-census BH14A 08/11/2016	26386	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Hydro-census BH5A 08/11/2016	26387	< 0.010	< 0.010	< 0.010	0.177	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH17 08/11/2016	26388	< 0.010	< 0.010	< 0.010	0.049	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1 08/11/2016	26389	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mall BH1 08/11/2016	26390	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1 08/12/2016	26391	< 0.010	< 0.010	< 0.010	0.012	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010

Hydro-census BH5A 08/12/2016	26392	< 0.010	< 0.010	< 0.010	0.026	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Hydro-census BH14 08/12/2016	26393	< 0.010	< 0.010	< 0.010	0.036	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH2D 08/12/2016	26394	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1D 08/12/2016	26395	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH17 08/12/2016	26396	< 0.010	< 0.010	< 0.010	0.013	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1S 08/12/2016	26397	< 0.010	< 0.010	< 0.010	0.089	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH4 08/12/2016	26398	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream A 08/12/2016	26399	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream B 08/12/2016	26400	< 0.010	< 0.010	< 0.010	0.043	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream C 08/12/2016	26401	< 0.010	< 0.010	< 0.010	0.060	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mall BH1 08/12/2016	26402	< 0.010	< 0.010	< 0.010	0.087	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream A 15/01/2017	26403	< 0.010	< 0.010	< 0.010	0.078	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream B 15/01/2017	26404	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream C 15/01/2017	26405	< 0.010	< 0.010	< 0.010	0.067	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1 15/01/2017	26406	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1D 15/01/2017	26407	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH2D 15/01/2017	26408	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	**Sc (mg/L)**	**Se (mg/L)**	**Si (mg/L)**	**Sm (mg/L)**	**Sn (mg/L)**	**Sr (mg/L)**	**Ta (mg/L)**	**Tb (mg/L)**	**Te (mg/L)**	**Th (mg/L)**	**Ti (mg/L)**	**Tl (mg/L)**
BH2D 20/10/2016	26382	< 0.010	< 0.010	7.8	< 0.010	< 0.010	0.072	< 0.010	< 0.010	< 0.010	< 0.010	0.011	< 0.010
Stream A 20/10/2016	26383	< 0.010	< 0.010	3.3	< 0.010	< 0.010	0.196	< 0.010	< 0.010	< 0.010	< 0.010	0.048	< 0.010
Stream B 20/10/2016	26384	< 0.010	< 0.010	4.4	< 0.010	< 0.010	0.168	< 0.010	< 0.010	< 0.010	< 0.010	0.040	< 0.010
Stream C 20/10/2016	26385	< 0.010	< 0.010	3.5	< 0.010	< 0.010	0.150	< 0.010	< 0.010	< 0.010	< 0.010	0.038	< 0.010
Hydro-census BH14A 08/11/2016	26386	< 0.010	< 0.010	15.6	< 0.010	< 0.010	0.168	< 0.010	< 0.010	< 0.010	< 0.010	0.040	< 0.010
Hydro-census BH5A 08/11/2016	26387	< 0.010	< 0.010	18.2	< 0.010	< 0.010	0.094	< 0.010	< 0.010	< 0.010	< 0.010	0.015	< 0.010
BH17 08/11/2016	26388	< 0.010	< 0.010	11.8	< 0.010	< 0.010	0.032	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1 08/11/2016	26389	< 0.010	< 0.010	0.7	< 0.010	< 0.010	0.209	< 0.010	< 0.010	< 0.010	< 0.010	0.049	< 0.010
Mall BH1 08/11/2016	26390	< 0.010	< 0.010	21	< 0.010	< 0.010	0.039	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1 08/12/2016	26391	< 0.010	< 0.010	1.4	< 0.010	< 0.010	0.181	< 0.010	< 0.010	< 0.010	< 0.010	0.043	< 0.010
Hydro-census BH5A 08/12/2016	26392	< 0.010	< 0.010	15.3	< 0.010	< 0.010	0.078	< 0.010	< 0.010	< 0.010	< 0.010	0.012	< 0.010
Hydro-census BH14 08/12/2016	26393	< 0.010	< 0.010	14.5	< 0.010	< 0.010	0.091	< 0.010	< 0.010	< 0.010	< 0.010	0.026	< 0.010
BH2D 08/12/2016	26394	< 0.010	< 0.010	5.0	< 0.010	< 0.010	0.078	< 0.010	< 0.010	< 0.010	< 0.010	0.015	< 0.010
BH1D 08/12/2016	26395	< 0.010	< 0.010	0.5	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH17 08/12/2016	26396	< 0.010	< 0.010	13.6	< 0.010	< 0.010	0.022	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1S 08/12/2016	26397	< 0.010	< 0.010	7.9	< 0.010	< 0.010	0.054	< 0.010	< 0.010	< 0.010	< 0.010	0.011	< 0.010
BH4 08/12/2016	26398	< 0.010	< 0.010	7.3	< 0.010	< 0.010	0.160	< 0.010	< 0.010	< 0.010	< 0.010	0.061	< 0.010
Stream A 08/12/2016	26399	< 0.010	< 0.010	3.3	< 0.010	< 0.010	0.086	< 0.010	< 0.010	< 0.010	< 0.010	0.019	< 0.010

Stream B 08/12/2016	26400	< 0.010	< 0.010	4.1	< 0.010	< 0.010	0.092	< 0.010	< 0.010	< 0.010	< 0.010	0.018	< 0.010
Stream C 08/12/2016	26401	< 0.010	< 0.010	4.0	< 0.010	< 0.010	0.094	< 0.010	< 0.010	< 0.010	< 0.010	0.015	< 0.010
Mall BH1 08/12/2016	26402	< 0.010	< 0.010	22	< 0.010	< 0.010	0.041	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream A 15/01/2017	26403	< 0.010	< 0.010	3.6	< 0.010	< 0.010	0.121	< 0.010	< 0.010	< 0.010	< 0.010	0.022	< 0.010
Stream B 15/01/2017	26404	< 0.010	< 0.010	3.4	< 0.010	< 0.010	0.116	< 0.010	< 0.010	< 0.010	< 0.010	0.025	< 0.010
Stream C 15/01/2017	26405	< 0.010	< 0.010	3.5	< 0.010	< 0.010	0.115	< 0.010	< 0.010	< 0.010	< 0.010	0.023	< 0.010
Mun 1 15/01/2017	26406	< 0.010	< 0.010	0.8	< 0.010	< 0.010	0.188	< 0.010	< 0.010	< 0.010	< 0.010	0.047	< 0.010
BH1D 15/01/2017	26407	< 0.010	< 0.010	1.9	< 0.010	< 0.010	0.016	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH2D 15/01/2017	26408	< 0.010	< 0.010	5.0	< 0.010	< 0.010	0.081	< 0.010	< 0.010	< 0.010	< 0.010	0.014	< 0.010

Sample Origin	Sample ID	**Tm (mg/L)**	**U (mg/L)**	**V (mg/L)**	**W (mg/L)**	**Y (mg/L)**	**Yb (mg/L)**	**Zn (mg/L)**	**Zr (mg/L)**
BH2D 20/10/2016	26382	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.041	< 0.010
Stream A 20/10/2016	26383	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.021	< 0.010
Stream B 20/10/2016	26384	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.020	< 0.010
Stream C 20/10/2016	26385	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.019	< 0.010
Hydro-census BH14A 08/11/2016	26386	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.031	< 0.010
Hydro-census BH5A 08/11/2016	26387	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.022	< 0.010
BH17 08/11/2016	26388	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.046	< 0.010
Mun 1 08/11/2016	26389	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.029	< 0.010
Mall BH1 08/11/2016	26390	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.025	< 0.010
Mun 1 08/12/2016	26391	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.061	< 0.010
Hydro-census BH5A 08/12/2016	26392	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.038	< 0.010
Hydro-census BH14 08/12/2016	26393	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.062	< 0.010
BH2D 08/12/2016	26394	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.017	< 0.010
BH1D 08/12/2016	26395	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.021	< 0.010
BH17 08/12/2016	26396	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.023	< 0.010
BH1S 08/12/2016	26397	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.056	< 0.010
BH4 08/12/2016	26398	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.026	< 0.010
Stream A 08/12/2016	26399	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.017	< 0.010
Stream B 08/12/2016	26400	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.020	< 0.010
Stream C 08/12/2016	26401	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.016	< 0.010
Mall BH1 08/12/2016	26402	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.019	< 0.010
Stream A 15/01/2017	26403	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.019	< 0.010
Stream B 15/01/2017	26404	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.013	< 0.010
Stream C 15/01/2017	26405	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.019	< 0.010
Mun 1 15/01/2017	26406	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.054	< 0.010
BH1D 15/01/2017	26407	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.016	< 0.010
BH2D 15/01/2017	26408	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.013	< 0.010

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Testing Laboratory
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CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2017 - 02 - 13
Date completed: 2017 - 03 – 13
Project number: 215
Report number: 65056
Order number: 0000479885

Client name: University of Pretoria
Contact person: Mr. M. Dippenaar
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Telephone: 082 826 5468
Facsimile: -
Mobile: 082 826 5468

Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification:**			
		Stream A	**Stream B**	**Stream C**	**BH14A**
Sample Number		28105	28106	28107	28108
pH – Value at 25°C *	WLAB065	8.5	8.2	8.3	8.4
Electrical Conductivity in mS/m at 25°C	WLAB002	51.9	43.8	50.0	57.2
Total Dissolved Solids at 180°C *	WLAB003	428	384	410	502
Colour in PtCo Units *	WLAB006	24	31	31	5
Odour in T.O.N *	WLAB038	<5	<5	<5	<5
Turbidity in N.T.U	WLAB005	0.6	2.2	2.6	0.6
Chloride as Cl	WLAB046	22	17	19	53
Sulphate as SO_4	WLAB046	121	103	133	79
Fluoride as F	WLAB014	0.3	0.3	0.3	<0.2
Nitrate as N	WLAB046	<0.1	<0.1	<0.1	10
Nitrite as N	WLAB046	<0.05	<0.05	<0.05	<0.05
Total Organic Carbon as C *	WLAB060	4.8	4.3	4.6	1.7
Total Coliform Bacteria / 100 mℓ	WLAB021	42 000	>100 000	30 000	19
Faecal Coliform Bacteria / 100 mℓ *	WLAB021	160	230	290	14
E. coli / 100 mℓ	WLAB021	160	230	290	14
Heterotrophic Plate Count / mℓ *	WLAB021	>100 000	>100 000	>100 000	27
ICP-MS Scan (Dissolved)*	WLAB050	See Attached Report: 65056-A			
% Balancing *	---	96.1	99.1	98.6	95.1

A. van de Wetering
Technical Signatory

D.O. Mohlaloga
Technical Signatory

WATERLAB

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CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2017 - 02 - 13
Date completed: 2017 - 03 – 13
Project number: 215
Report number: 65056
Order number: 0000479885

Client name: University of Pretoria
Contact person: Mr. M. Dippenaar
Address: Private Bag X20, Geology Department, Hatfield, 0028
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Telephone: 082 826 5468
Facsimile: -
Mobile: 082 826 5468

Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification:**		
		BH2D	**Mun 1**	**Athlone Dam**
Sample Number		28109	28110	28111
pH – Value at 25°C *	WLAB065	8.1	8.3	7.8
Electrical Conductivity in mS/m at 25°C	WLAB002	32.2	85.2	44.9
Total Dissolved Solids at 180°C *	WLAB003	280	702	368
Colour in PtCo Units *	WLAB006	18	11	37
Odour in T.O.N *	WLAB038	<5	<5	<5
Turbidity in N.T.U	WLAB005	304	0.4	12
Chloride as Cl	WLAB046	67	24	14
Sulphate as SO_4	WLAB046	<2	292	144
Fluoride as F	WLAB014	<0.2	0.4	0.2
Nitrate as N	WLAB046	0.1	0.4	<0.1
Nitrite as N	WLAB046	<0.05	<0.05	<0.05
Total Organic Carbon as C *	WLAB060	1.3	4.3	5.4
Total Coliform Bacteria / 100 mℓ	WLAB021	6 400	0	>100 000
Faecal Coliform Bacteria / 100 mℓ *	WLAB021	21	0	92 000
E. coli / 100 mℓ	WLAB021	21	0	82 000
Heterotrophic Plate Count / mℓ *	WLAB021	12 000	<10	>100 000
ICP-MS Scan (Dissolved)*	WLAB050	See Attached Report: 65056-A		
% Balancing *	---	94.4	95.0	94.7

*** = Not SANAS Accredited**
Tests marked “Not SANAS Accredited” in this report are not included in the SANAS Schedule of Accreditation for this Laboratory.

Bacteriological parameters analyzed on: 2017-02-13

A. van de Wetering
Technical Signatory

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Technical Signatory

WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSIS

Project Number : 215
Client : University of Pretoria
Report Number : 65056-A

Sample Origin	Sample ID	Ag (mg/L)	Al (mg/L)	As (mg/L)	Au (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Ca (mg/L)	Cd (mg/L)	Ce (mg/L)	Co (mg/L)
Stream A	28105	< 0.010	< 0.100	< 0.010	< 0.010	0.021	0.087	< 0.010	< 0.010	35	< 0.010	< 0.010	< 0.010
Stream B	28106	< 0.010	< 0.100	< 0.010	< 0.010	0.021	0.063	< 0.010	< 0.010	32	< 0.010	< 0.010	< 0.010
Sttream C	28107	< 0.010	< 0.100	< 0.010	< 0.010	0.022	0.083	< 0.010	< 0.010	35	< 0.010	< 0.010	< 0.010
BH14A	28108	< 0.010	< 0.100	< 0.010	< 0.010	0.026	0.070	< 0.010	< 0.010	54	< 0.010	< 0.010	< 0.010
BH2D	28109	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.448	< 0.010	< 0.010	21	< 0.010	< 0.010	< 0.010
Mun 1	28110	< 0.010	< 0.100	< 0.010	< 0.010	0.053	0.069	< 0.010	< 0.010	60	< 0.010	< 0.010	< 0.010
Athlone Dam	28111	< 0.010	< 0.100	< 0.010	< 0.010	0.026	0.075	< 0.010	< 0.010	30	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	Cr (mg/L)	Cs (mg/L)	Cu (mg/L)	Dy (mg/L)	Er (mg/L)	Eu (mg/L)	Fe (mg/L)	Ga (mg/L)	Gd (mg/L)	Ge (mg/L)	Hf (mg/L)	Hg (mg/L)
Stream A	28105	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.034	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream B	28106	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Sttream C	28107	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.033	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH14A	28108	< 0.010	< 0.010	0.117	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH2D	28109	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	0.014	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1	28110	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Athlone Dam	28111	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.064	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	Ho (mg/L)	In (mg/L)	Ir (mg/L)	K (mg/L)	La (mg/L)	Li (mg/L)	Lu (mg/L)	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	Nb (mg/L)
Stream A	28105	< 0.010	< 0.010	< 0.010	6.5	< 0.010	< 0.010	< 0.010	28	0.816	< 0.010	20	< 0.010
Stream B	28106	< 0.010	< 0.010	< 0.010	5.3	< 0.010	< 0.010	< 0.010	25	0.028	< 0.010	18	< 0.010
Sttream C	28107	< 0.010	< 0.010	< 0.010	6.2	< 0.010	< 0.010	< 0.010	28	0.189	< 0.010	19	< 0.010
BH14A	28108	< 0.010	< 0.010	< 0.010	4.3	< 0.010	< 0.010	< 0.010	25	< 0.025	< 0.010	24	< 0.010
BH2D	28109	< 0.010	< 0.010	< 0.010	2.1	< 0.010	< 0.010	< 0.010	15	2.24	< 0.010	12	< 0.010
Mun 1	28110	< 0.010	< 0.010	< 0.010	10.9	< 0.010	< 0.010	< 0.010	52	< 0.025	< 0.010	29	< 0.010
Athlone Dam	28111	< 0.010	< 0.010	< 0.010	6.1	< 0.010	< 0.010	< 0.010	25	< 0.025	< 0.010	16	< 0.010

Sample Origin	Sample ID	Nd (mg/L)	Ni (mg/L)	Os (mg/L)	P (mg/L)	Pb (mg/L)	Pd (mg/L)	Pr (mg/L)	Pt (mg/L)	Rb (mg/L)	Rh (mg/L)	Ru (mg/L)	Sb (mg/L)
Stream A	28105	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream B	28106	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Sttream C	28107	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH14A	28108	< 0.010	< 0.010	< 0.010	0.024	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH2D	28109	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.014	< 0.010	< 0.010	< 0.010
Mun 1	28110	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.011	< 0.010	< 0.010	< 0.010
Athlone Dam	28111	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	Sc (mg/L)	Se (mg/L)	Si (mg/L)	Sm (mg/L)	Sn (mg/L)	Sr (mg/L)	Ta (mg/L)	Tb (mg/L)	Te (mg/L)	Th (mg/L)	Ti (mg/L)	Tl (mg/L)
Stream A	28105	< 0.010	< 0.010	4.1	< 0.010	< 0.010	0.125	< 0.010	< 0.010	< 0.010	< 0.010	0.026	< 0.010
Stream B	28106	< 0.010	< 0.010	5.5	< 0.010	< 0.010	0.108	< 0.010	< 0.010	< 0.010	< 0.010	0.021	< 0.010
Sttream C	28107	< 0.010	< 0.010	3.2	< 0.010	< 0.010	0.119	< 0.010	< 0.010	< 0.010	< 0.010	0.029	< 0.010
BH14A	28108	< 0.010	< 0.010	16.5	< 0.010	< 0.010	0.153	< 0.010	< 0.010	< 0.010	< 0.010	0.045	< 0.010
BH2D	28109	< 0.010	< 0.010	6.4	< 0.010	< 0.010	0.077	< 0.010	< 0.010	< 0.010	< 0.010	0.014	< 0.010
Mun 1	28110	< 0.010	< 0.010	1.0	< 0.010	< 0.010	0.178	< 0.010	< 0.010	< 0.010	< 0.010	0.055	< 0.010
Athlone Dam	28111	< 0.010	< 0.010	2.9	< 0.010	< 0.010	0.105	< 0.010	< 0.010	< 0.010	< 0.010	0.024	< 0.010

Sample Origin	Sample ID	Tm (mg/L)	U (mg/L)	V (mg/L)	W (mg/L)	Y (mg/L)	Yb (mg/L)	Zn (mg/L)	Zr (mg/L)
Stream A	28105	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.010	< 0.010
Stream B	28106	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.011	< 0.010
Sttream C	28107	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH14A	28108	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.140	< 0.010
BH2D	28109	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.013	< 0.010
Mun 1	28110	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.038	< 0.010
Athlone Dam	28111	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.012	< 0.010

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Testing Laboratory
T0391

CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2017 - 03 - 20
Date completed: 2017 - 04 – 07
Project number: 215
Report number: 65820
Order number: PO0000550559

Client name: University of Pretoria
Contact person: Mr. M. Dippenaar
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e-mail: matthysd@icloud.com
Telephone: 082 826 5468
Facsimile: -
Mobile: 082 826 5468

Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification:**				
		Stream A	**Stream B**	**Stream C**	**Athlone Dam**	**BH1D**
Sample Number		1264	1265	1266	1267	1268
pH – Value at 25°C *	WLAB065	7.4	7.6	7.7	7.1	6.8
Electrical Conductivity in mS/m at 25°C	WLAB002	37.2	36.4	38.0	35.8	14.1
Total Dissolved Solids at 180°C *	WLAB003	228	244	256	268	182
Colour in PtCo Units *	WLAB006	21	23	24	55	31
Odour in T.O.N *	WLAB038	<5	<5	<5	<5	<5
Turbidity in N.T.U	WLAB005	1.8	1.2	1.9	5.3	2 117
Chloride as Cl	WLAB046	23	23	22	11	8
Sulphate as SO_4	WLAB046	78	74	87	129	29
Fluoride as F	WLAB014	0.3	0.3	0.3	0.2	0.2
Nitrate as N	WLAB046	<0.1	<0.1	<0.1	<0.1	0.1
Nitrite as N	WLAB046	<0.05	<0.05	<0.05	<0.05	<0.05
Total Organic Carbon as C *	WLAB060	4.4	4.2	4.1	5.3	4.6
Total Coliform Bacteria / 100 mℓ	WLAB021	2 400	3 600	4 700	2 000	65 000
Faecal Coliform Bacteria / 100 mℓ *	WLAB021	68	200	870	48	13
E. coli / 100 mℓ	WLAB021	80	190	1 200	0	12
Heterotrophic Plate Count / mℓ *	WLAB021	12	1 200	910	170	57 000
Free & Saline Ammonia as N	WLAB046	<0.1	<0.1	<0.1	<0.1	<0.1
ICP-MS Scan (Dissolved)*	WLAB050	See Attached Report: 65820-A				

E. Nkabinde
Technical Signatory

D.O. Mohlaloga
Technical Signatory

WATERLAB (Pty) Ltd
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sanas Testing Laboratory
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CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2017 - 03 - 20
Date completed: 2017 - 04 – 07
Project number: 215
Report number: 65820
Order number: PO0000550559

Client name: University of Pretoria
Contact person: Mr. M. Dippenaar
Address: Private Bag X20, Geology Department, Hatfield, 0028
e-mail: matthysd@icloud.com
Telephone: 082 826 5468
Facsimile: -
Mobile: 082 826 5468

Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification:**			
		BH1S	**BH2D**	**BH4S**	**Mun 1**
Sample Number		1269	1270	1271	1272
pH – Value at 25°C *	WLAB065	6.7	6.8	6.9	7.7
Electrical Conductivity in mS/m at 25°C	WLAB002	19.6	46.0	110	69.0
Total Dissolved Solids at 180°C *	WLAB003	126	226	798	538
Colour in PtCo Units *	WLAB006	35	99	32	9
Odour in T.O.N *	WLAB038	<5	<5	<5	<5
Turbidity in N.T.U	WLAB005	168	125	96	0.1
Chloride as Cl	WLAB046	10	64	122	22
Sulphate as SO_4	WLAB046	40	<2	<2	279
Fluoride as F	WLAB014	0.2	<0.2	0.4	0.3
Nitrate as N	WLAB046	4.9	<0.1	<0.1	0.3
Nitrite as N	WLAB046	<0.05	<0.05	<0.05	<0.05
Total Organic Carbon as C *	WLAB060	3.3	22	16	3.4
Total Coliform Bacteria / 100 mℓ	WLAB021	5 600	310	5 900	0
Faecal Coliform Bacteria / 100 mℓ *	WLAB021	0	4	1	0
E. coli / 100 mℓ	WLAB021	2	83	0	0
Heterotrophic Plate Count / mℓ *	WLAB021	>100 000	11 000	76 000	140
Free & Saline Ammonia as N	WLAB046	<0.1	<0.1	<0.1	<0.1
ICP-MS Scan (Dissolved)*	WLAB050	See Attached Report: 65820-A			

*** = Not SANAS Accredited**
Tests marked "Not SANAS Accredited" in this report are not included in the SANAS Schedule of Accreditation for this Laboratory.

Bacteriological parameters analyzed on: 2017-03-20

E. Nkabinde
Technical Signatory

D.O. Mohlaloga
Technical Signatory

WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSIS

Project Number : **215**
Client : **University of Pretoria**
Report Number : **65820-A**

Sample Origin	Sample ID	Ag (mg/L)	Al (mg/L)	As (mg/L)	Au (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Ca (mg/L)	Cd (mg/L)	Ce (mg/L)	Co (mg/L)
Stream A	1264	< 0.010	< 0.100	< 0.010	< 0.010	0.024	0.092	< 0.010	< 0.010	26	< 0.010	< 0.010	< 0.010
Stream B	1265	< 0.010	< 0.100	< 0.010	< 0.010	0.018	0.079	< 0.010	< 0.010	24	< 0.010	< 0.010	< 0.010
Stream C	1266	< 0.010	< 0.100	< 0.010	< 0.010	0.023	0.077	< 0.010	< 0.010	25	< 0.010	< 0.010	< 0.010
Athlone Dam	1267	< 0.010	< 0.100	< 0.010	< 0.010	0.016	0.054	< 0.010	< 0.010	24	< 0.010	< 0.010	< 0.010
BH1D	1268	< 0.010	0.205	< 0.010	< 0.010	0.017	0.022	< 0.010	< 0.010	3	< 0.010	< 0.010	< 0.010
BH1S	1269	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.061	< 0.010	< 0.010	9	< 0.010	< 0.010	< 0.010
BH2D	1270	< 0.010	< 0.100	< 0.010	< 0.010	< 0.010	0.553	< 0.010	< 0.010	23	< 0.010	< 0.010	< 0.010
BH4S	1271	< 0.010	< 0.100	< 0.010	< 0.010	0.013	0.201	< 0.010	< 0.010	119	< 0.010	< 0.010	< 0.010
Mun 1	1272	< 0.010	< 0.100	< 0.010	< 0.010	0.033	0.063	< 0.010	< 0.010	56	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	Cr (mg/L)	Cs (mg/L)	Cu (mg/L)	Dy (mg/L)	Er (mg/L)	Eu (mg/L)	Fe (mg/L)	Ga (mg/L)	Gd (mg/L)	Ge (mg/L)	Hf (mg/L)	Hg (mg/L)
Stream A	1264	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.088	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream B	1265	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.034	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream C	1266	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.031	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Athlone Dam	1267	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.315	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1D	1268	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.092	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1S	1269	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.042	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH2D	1270	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	11	0.027	< 0.010	< 0.010	< 0.010	< 0.010
BH4S	1271	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.150	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1	1272	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.242	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	Ho (mg/L)	In (mg/L)	Ir (mg/L)	K (mg/L)	La (mg/L)	Li (mg/L)	Lu (mg/L)	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	Nb (mg/L)
Stream A	1264	< 0.010	< 0.010	< 0.010	6.1	< 0.010	< 0.010	< 0.010	15	< 0.025	< 0.010	18	< 0.010
Stream B	1265	< 0.010	< 0.010	< 0.010	5.7	< 0.010	< 0.010	< 0.010	15	< 0.025	< 0.010	18	< 0.010
Stream C	1266	< 0.010	< 0.010	< 0.010	5.8	< 0.010	< 0.010	< 0.010	16	< 0.025	< 0.010	18	< 0.010
Athlone Dam	1267	< 0.010	< 0.010	< 0.010	5.2	< 0.010	< 0.010	< 0.010	17	< 0.025	< 0.010	12	< 0.010
BH1D	1268	< 0.010	< 0.010	< 0.010	1.9	< 0.010	< 0.010	< 0.010	2	0.332	< 0.010	21	< 0.010
BH1S	1269	< 0.010	< 0.010	< 0.010	2.1	< 0.010	< 0.010	< 0.010	5	0.066	< 0.010	18	< 0.010
BH2D	1270	< 0.010	< 0.010	< 0.010	3.4	< 0.010	< 0.010	< 0.010	15	2.07	< 0.010	11	< 0.010
BH4S	1271	< 0.010	< 0.010	< 0.010	8.5	< 0.010	< 0.010	< 0.010	34	0.358	< 0.010	49	< 0.010
Mun 1	1272	< 0.010	< 0.010	< 0.010	10.7	< 0.010	< 0.010	< 0.010	32	< 0.025	< 0.010	20	< 0.010

Sample Origin	Sample ID	Nd (mg/L)	Ni (mg/L)	Os (mg/L)	P (mg/L)	Pb (mg/L)	Pd (mg/L)	Pr (mg/L)	Pt (mg/L)	Rb (mg/L)	Rh (mg/L)	Ru (mg/L)	Sb (mg/L)
Stream A	1264	< 0.010	< 0.010	< 0.010	0.046	< 0.010	< 0.010	< 0.010	< 0.010	0.010	< 0.010	< 0.010	< 0.010
Stream B	1265	< 0.010	< 0.010	< 0.010	0.017	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Stream C	1266	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Athlone Dam	1267	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1D	1268	< 0.010	< 0.010	< 0.010	0.026	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH1S	1269	< 0.010	< 0.010	< 0.010	0.208	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
BH2D	1270	< 0.010	0.110	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.011	< 0.010	< 0.010	< 0.010
BH4S	1271	< 0.010	0.011	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Mun 1	1272	< 0.010	0.019	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.014	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	Sc (mg/L)	Se (mg/L)	Si (mg/L)	Sm (mg/L)	Sn (mg/L)	Sr (mg/L)	Ta (mg/L)	Tb (mg/L)	Te (mg/L)	Th (mg/L)	Ti (mg/L)
Stream A	1264	< 0.010	< 0.010	1.7	< 0.010	< 0.010	0.117	< 0.010	< 0.010	< 0.010	< 0.010	0.026
Stream B	1265	< 0.010	< 0.010	2.3	< 0.010	< 0.010	0.114	< 0.010	< 0.010	< 0.010	< 0.010	0.019
Stream C	1266	< 0.010	< 0.010	2.3	< 0.010	< 0.010	0.117	< 0.010	< 0.010	< 0.010	< 0.010	0.024
Athlone Dam	1267	< 0.010	< 0.010	2.5	< 0.010	< 0.010	0.122	< 0.010	< 0.010	< 0.010	< 0.010	0.024
BH1D	1268	< 0.010	< 0.010	3.2	< 0.010	< 0.010	0.016	< 0.010	< 0.010	< 0.010	< 0.010	0.015
BH1S	1269	< 0.010	< 0.010	5.5	< 0.010	< 0.010	0.052	< 0.010	< 0.010	< 0.010	< 0.010	0.016
BH2D	1270	< 0.010	< 0.010	4.8	< 0.010	< 0.010	0.109	< 0.010	< 0.010	< 0.010	< 0.010	0.023
BH4S	1271	< 0.010	< 0.010	6.6	< 0.010	< 0.010	0.249	< 0.010	< 0.010	< 0.010	< 0.010	0.096
Mun 1	1272	< 0.010	< 0.010	1.9	< 0.010	< 0.010	0.202	< 0.010	< 0.010	< 0.010	< 0.010	0.045

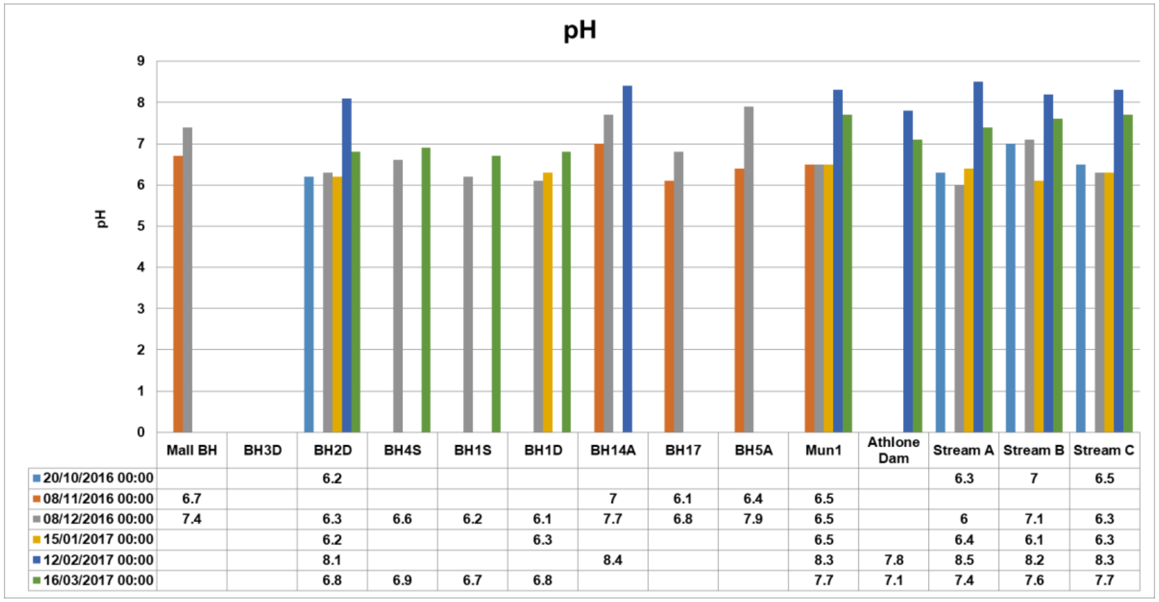
Sample Origin	Sample ID	Tl (mg/L)	Tm (mg/L)	U (mg/L)	V (mg/L)	W (mg/L)	Y (mg/L)	Yb (mg/L)	Zn (mg/L)	Zr (mg/L)
Stream A	1264	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.054	< 0.010
Stream B	1265	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.033	< 0.010
Stream C	1266	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.040	< 0.010
Athlone Dam	1267	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.039	< 0.010
BH1D	1268	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.047	< 0.010
BH1S	1269	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.219	< 0.010
BH2D	1270	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.043	< 0.010
BH4S	1271	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.071	< 0.010
Mun 1	1272	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.042	< 0.010

Appendix C2: Field Data and Data Quality Control

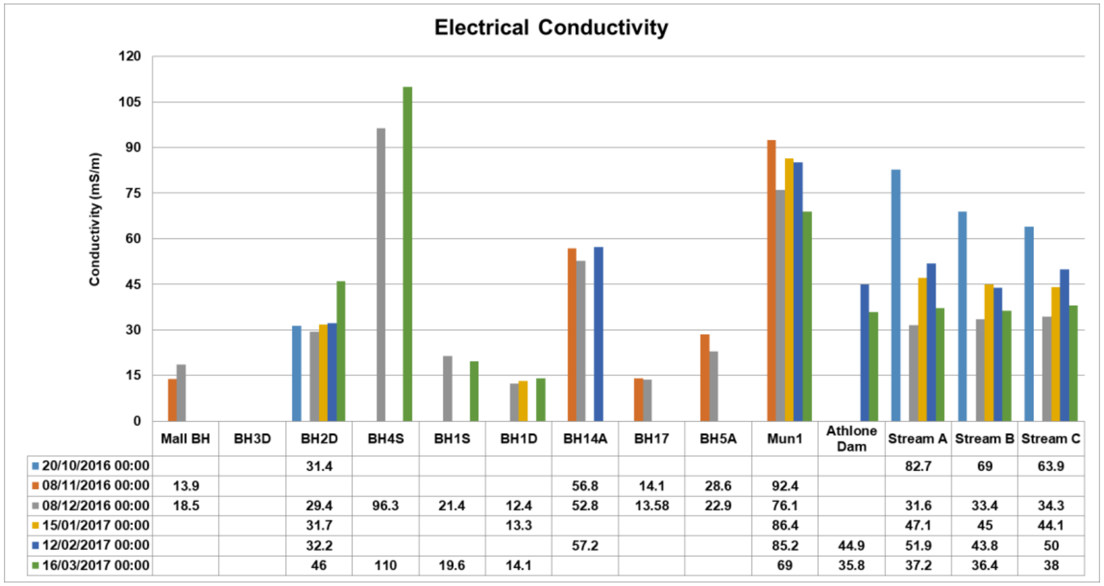
Sample name	Sampling date	Borehole Water level (mbgl) or stream depth (m)	Stream Width(m) or borehole depth (mbgl)	pH			EC (mS/m)			Temperature	DO (mg/l)	Eh (mV)
				Field	Lab	RPD	Field	Lab	RPD			
STREAMA	**20/10/2016**	0.13	6.96	6.97	6.3	10.1	81.8	82.7	1.09	23.7	3.5	143
STREAMB		0.5056	1.04	7.23	7.0	3.2	67.5	69.0	2.20	20.4	3.42	143
STREAMC		0.5055	1.40	7.25	6.5	10.9	63.4	63.9	0.79	21.1	5.70	148
BH2D		5.13		6.17	6.2	0.49	27.9	31.4	11.8	21.7	3.20	165
BH14A	**08/11/2016**			6.88	7.0	1.73	56.7	56.8	0.18	22.1	3.71	189
Mall BH				7.11	6.7	5.94	13.5	13.9	2.92	25.3	4.5	172
BH5A				7.28	6.4	12.9	28.9	28.6	1.04	24.1	3.72	176
BH17				6.95	6.1	13.0	15.8	14.1	11.4	23.2	3.88	152
Mun1					6.5			92.4				
RAIN 1	**Dec 2016**											
RAIN 2	**Jan 2017**											
RAIN 3	**Feb 2017**											
STREAMA	**08/12/2016**	0.37		6.95	6.0	14.7	33.3	31.6	5.2	25.7	3.33	141
STREAMB		0.42	1.6	7.23	7.1	1.81	33.4	33.4	0	26.1	3.67	148
STREAMC		0.81	2.33	7.5	6.3	17.4	33.8	34.3	1.47	24.6	4.5	151
BH1S		1.02	1.22	6.57	6.2	5.79	21.8	21.4	1.85	25.4	2.26	151
BH1D		1.01	1.12	7.72	6.1	23.4	12.40	7.6	48	23.8	1.96	148
BH2D		4.12	8.35	6.85	6.3	8.37	34.1	29.4	14.8	25.3	1.95	-9
BH4S		0.93	1.1	6.59	6.6	0.15	103.8	96.3	7.50	25.4	3.10	156
MUN1				7.54	6.5	14.8	72.3	76.1	5.12	23.8	3.65	142
BH14A				6.56	7.7	16.0	52.8	28.2	60.7	22.1	2.60	162
BH5A				7.10	7.9	10.7	28.9	22.9	23.2	24.0	3.92	129
BH17				7.20	6.8	5.71	13.58	5.2	89.2	22.0	4.40	116
MALL BH				7.22	7.4	2.46	13.89	18.5	28.5	25.3	4.3	130
STREAMA	**15/01/2017**	0.25		6.90	6.4	7.52	42.9	47.1	9.33	22.6	1.85	101
STREAMB		0.57		7.20	6.1	16.5	40.8	45.0	9.79	22.9	2.86	116
STREAMC		0.72		7.27	6.3	14.3	41.7	44.1	5.59	25.5	2.46	120
BH1D		0.796	2.02	7.77	6.3	20.9	12.94	13.3	2.74	25.3	1.55	86
BH2D		4.03	8.09	6.87	6.2	10.3	37.4	31.7	16.5	23.1	0.79	105
MUN1				7.35	6.5	12.3	84.0	86.4	2.82	24.6	2.84	115
STREAMA	**12/02/2017**	0.245		6.99	8.5	19.5	51.0	51.9	1.75	24.5	1.04	78
STREAMB		0.31	1.10	7.19	8.2	13.1	45.7	43.8	4.25	24.5	3.07	88

Sample name	Sampling date	Borehole Water level (mbgl) or stream depth (m)	Stream Width(m) or borehole depth (mbgl)	pH			EC (mS/m)			Temperature	DO (mg/l)	Eh (mV)
				Field	Lab	RPD	Field	Lab	RPD			
STREAMC		0.48	2.40	7.23	8.3	13.8	47.0	50.0	6.19	24.5	2.87	102
BH2D		4.19	8.11	6.95	8.1	15.3	38.8	32.2	18.6	26.3	1.66	-66
BH1D		2.14 (Water too little to sample)										
BH1S		Dry	1.19									
MUN1				7.90	8.3	4.94	83.1	85.2	2.50	25.1	2.02	63
BH14A				6.62	8.4	23.7	54.9	57.2	4.10	23.8		
ATHLONE DAM				7.04	7.8	10.2	45.4	44.9	1.11	28.8	3.01	96
STREAMA	**16/03/2017**	0.32		7.44	7.4	0.54	38.7	37.2	3.95	23.3	3.04	132
STREAMB		0.67	1.30	7.43	7.6	2.26	39.2	36.4	7.41	23.9	1.37	117
STREAMC		0.69	2.70	7.68	7.7	0.26	39.7	38.0	4.38		3.32	115
BH1S		1.03	1.19	6.44	6.7	3.96	20.3	19.6	3.51	24.1	0.75	101
BH1D		1.08	2.77	6.82	6.8	0.29	16.3	14.1	14.5	24.5	0.39	95
BH2D		3.54	8.10	7.15	6.8	5.02	52.8	46.0	13.8		0.11	109
BH3D		4.93	5.01									
BH4S		0.92	1.1	6.81	6.9	1.31	117.1	110	6.25		0.0	26
MUN1				6.53	7.7	16.4	70.2	69.0	1.72	22.6	0.00	190
ATHLONE DAM				7.10	7.1	0	41.1	35.8	13.8	24.2	2.17	137
BH1D	**03/06/2018**	1.37	2.76									
BH3D		4.99	4.99									
BH1S		0.86	1.28									
BH4S	**04/06/2018**	1.07	1.18									
BH2D		3.74	8.07									

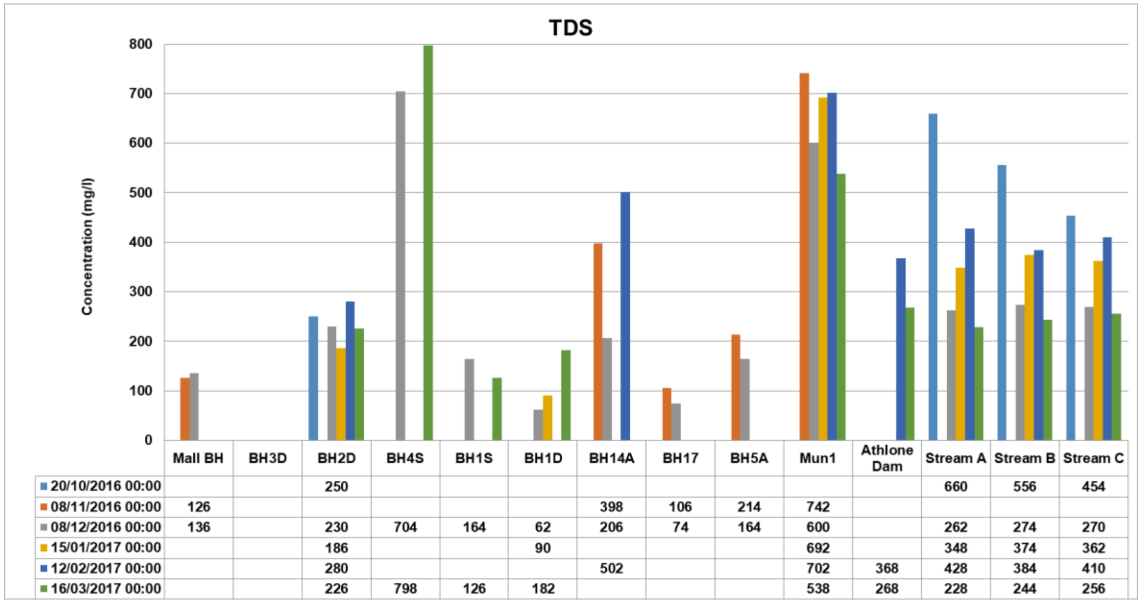
Appendix C3: Water Quality Time Series Charts



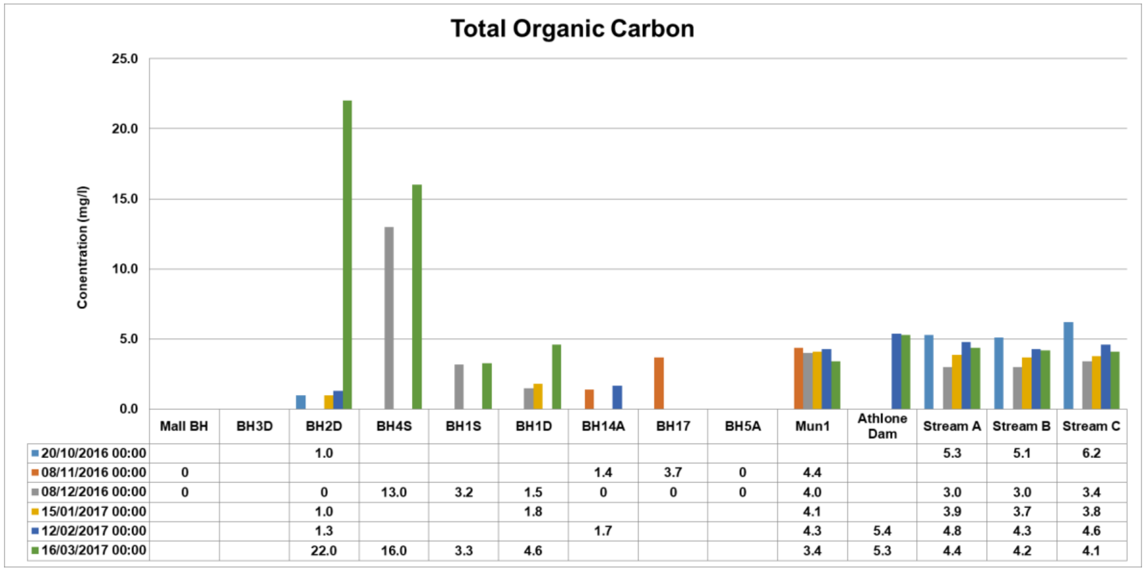
	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
■ 20/10/2016 00:00			6.2									6.3	7	6.5
■ 08/11/2016 00:00	6.7						7	6.1	6.4	6.5				
■ 08/12/2016 00:00	7.4		6.3	6.6	6.2	6.1	7.7	6.8	7.9	6.5		6	7.1	6.3
■ 15/01/2017 00:00			6.2			6.3				6.5		6.4	6.1	6.3
■ 12/02/2017 00:00			8.1				8.4			8.3	7.8	8.5	8.2	8.3
■ 16/03/2017 00:00			6.8	6.9	6.7	6.8				7.7	7.1	7.4	7.6	7.7



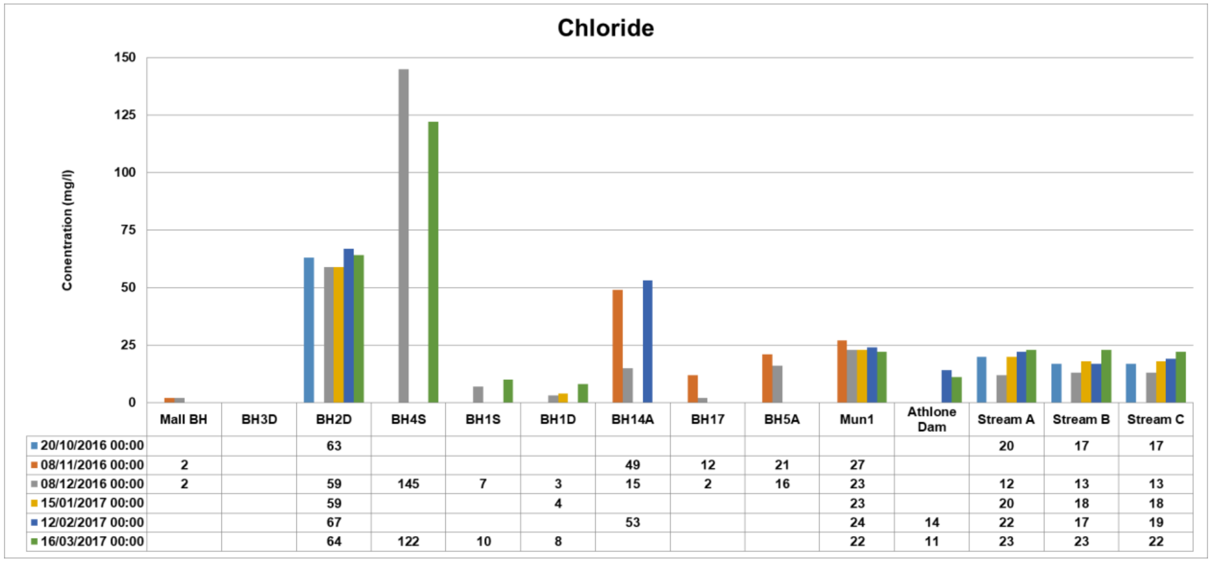
	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
■ 20/10/2016 00:00			31.4									82.7	69	63.9
■ 08/11/2016 00:00	13.9						56.8	14.1	28.6	92.4				
■ 08/12/2016 00:00	18.5		29.4	96.3	21.4	12.4	52.8	13.58	22.9	76.1		31.6	33.4	34.3
■ 15/01/2017 00:00			31.7			13.3				86.4		47.1	45	44.1
■ 12/02/2017 00:00			32.2				57.2			85.2	44.9	51.9	43.8	50
■ 16/03/2017 00:00			46	110	19.6	14.1				69	35.8	37.2	36.4	38



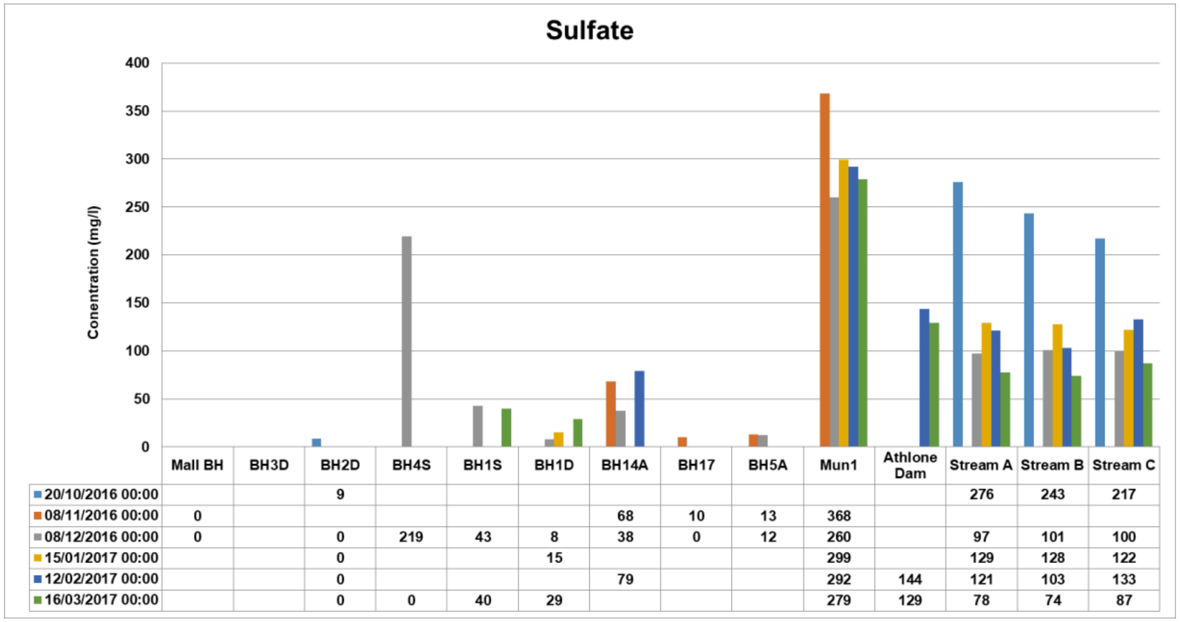
	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
■ 20/10/2016 00:00			250									660	556	454
■ 08/11/2016 00:00	126						398	106	214	742				
■ 08/12/2016 00:00	136		230	704	164	62	206	74	164	600		262	274	270
■ 15/01/2017 00:00			186			90				692		348	374	362
■ 12/02/2017 00:00			280				502			702	368	428	384	410
■ 16/03/2017 00:00			226	798	126	182				538	268	228	244	256



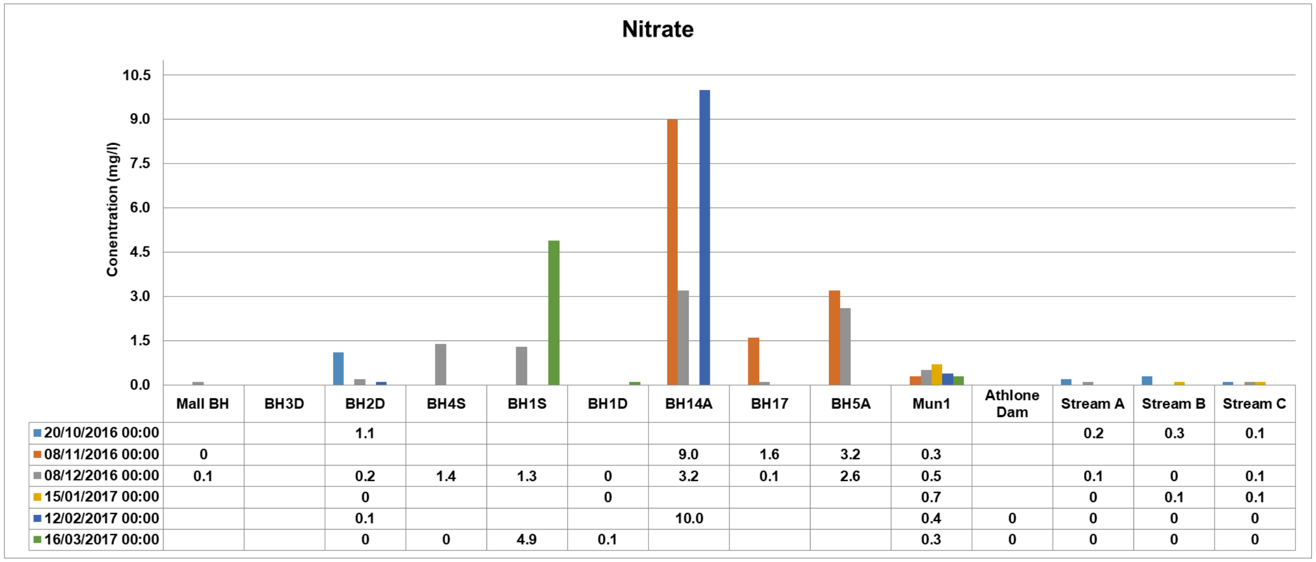
	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
■ 20/10/2016 00:00			1.0									5.3	5.1	6.2
■ 08/11/2016 00:00	0						1.4	3.7	0	4.4				
■ 08/12/2016 00:00	0		0	13.0	3.2	1.5	0	0	0	4.0		3.0	3.0	3.4
■ 15/01/2017 00:00			1.0			1.8				4.1		3.9	3.7	3.8
■ 12/02/2017 00:00			1.3				1.7			4.3	5.4	4.8	4.3	4.6
■ 16/03/2017 00:00			22.0	16.0	3.3	4.6				3.4	5.3	4.4	4.2	4.1



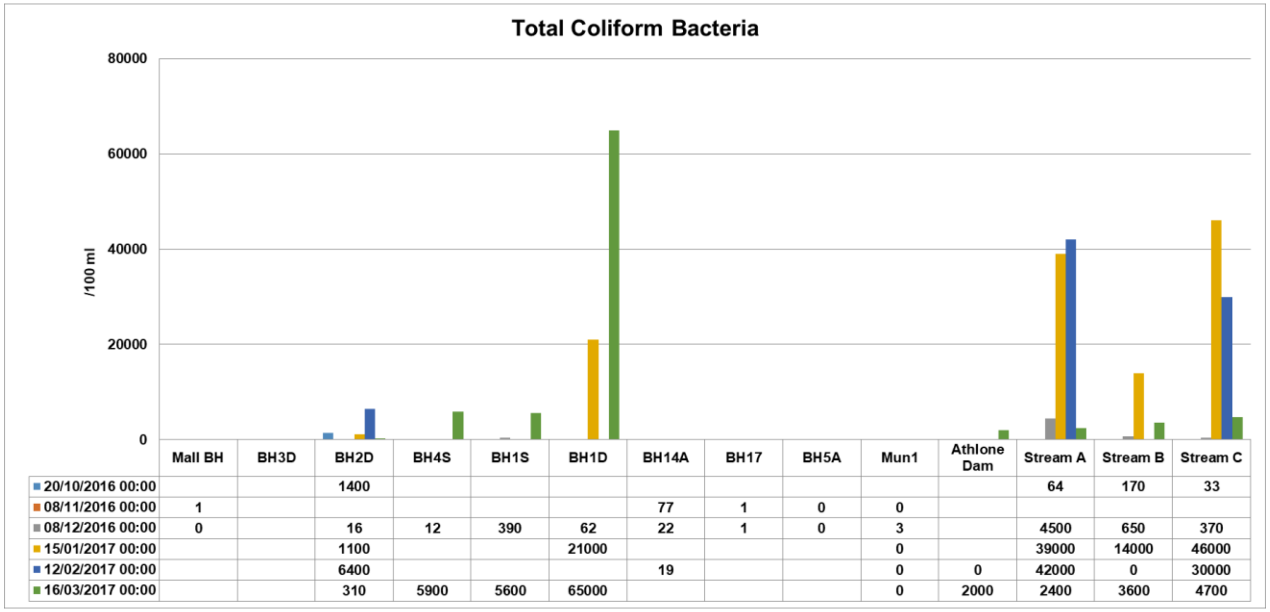
	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
■ 20/10/2016 00:00			63									20	17	17
■ 08/11/2016 00:00	2						49	12	21	27				
■ 08/12/2016 00:00	2		59	145	7	3	15	2	16	23		12	13	13
■ 15/01/2017 00:00			59			4				23		20	18	18
■ 12/02/2017 00:00			67				53			24	14	22	17	19
■ 16/03/2017 00:00			64	122	10	8				22	11	23	23	22



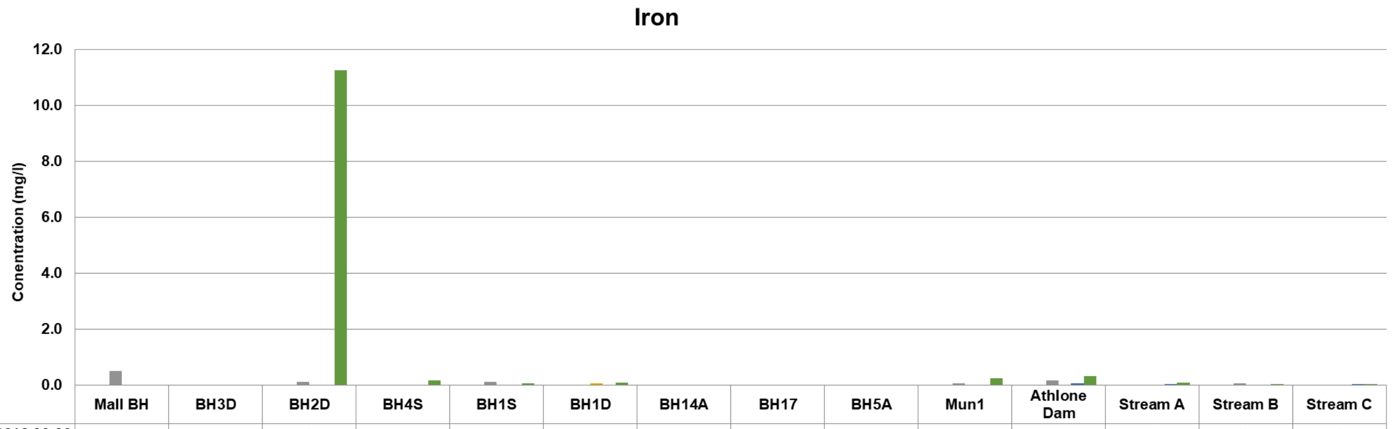
	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
■ 20/10/2016 00:00			9									276	243	217
■ 08/11/2016 00:00	0						68	10	13	368				
■ 08/12/2016 00:00	0		0	219	43	8	38	0	12	260		97	101	100
■ 15/01/2017 00:00			0			15				299		129	128	122
■ 12/02/2017 00:00			0				79			292	144	121	103	133
■ 16/03/2017 00:00			0	0	40	29				279	129	78	74	87



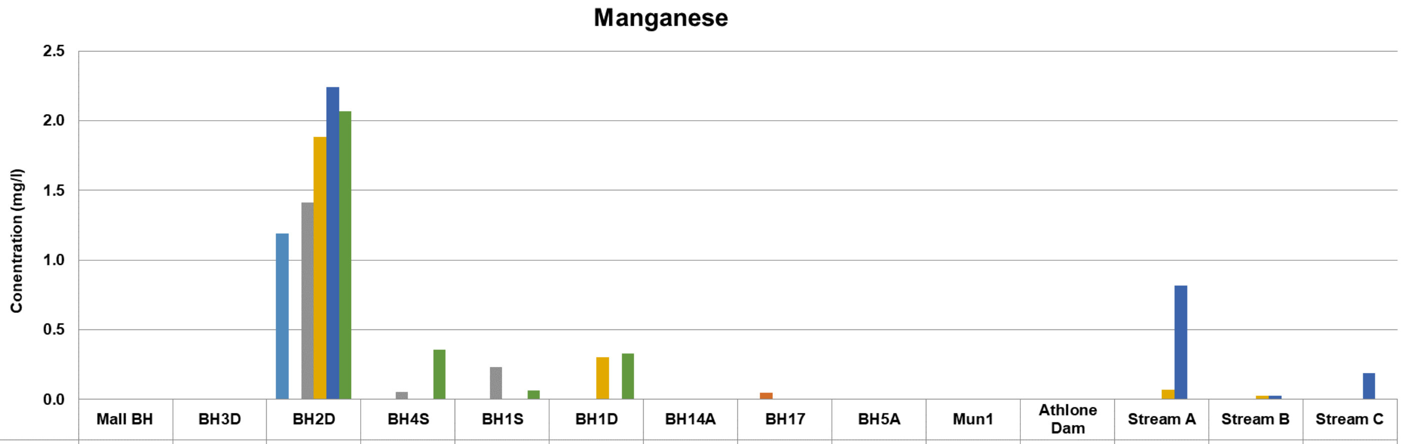
	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
20/10/2016 00:00			1.1									0.2	0.3	0.1
08/11/2016 00:00	0						9.0	1.6	3.2	0.3				
08/12/2016 00:00	0.1		0.2	1.4	1.3	0	3.2	0.1	2.6	0.5		0.1	0	0.1
15/01/2017 00:00			0			0				0.7		0	0.1	0.1
12/02/2017 00:00			0.1				10.0			0.4	0	0	0	0
16/03/2017 00:00			0	0	4.9	0.1				0.3	0	0	0	0



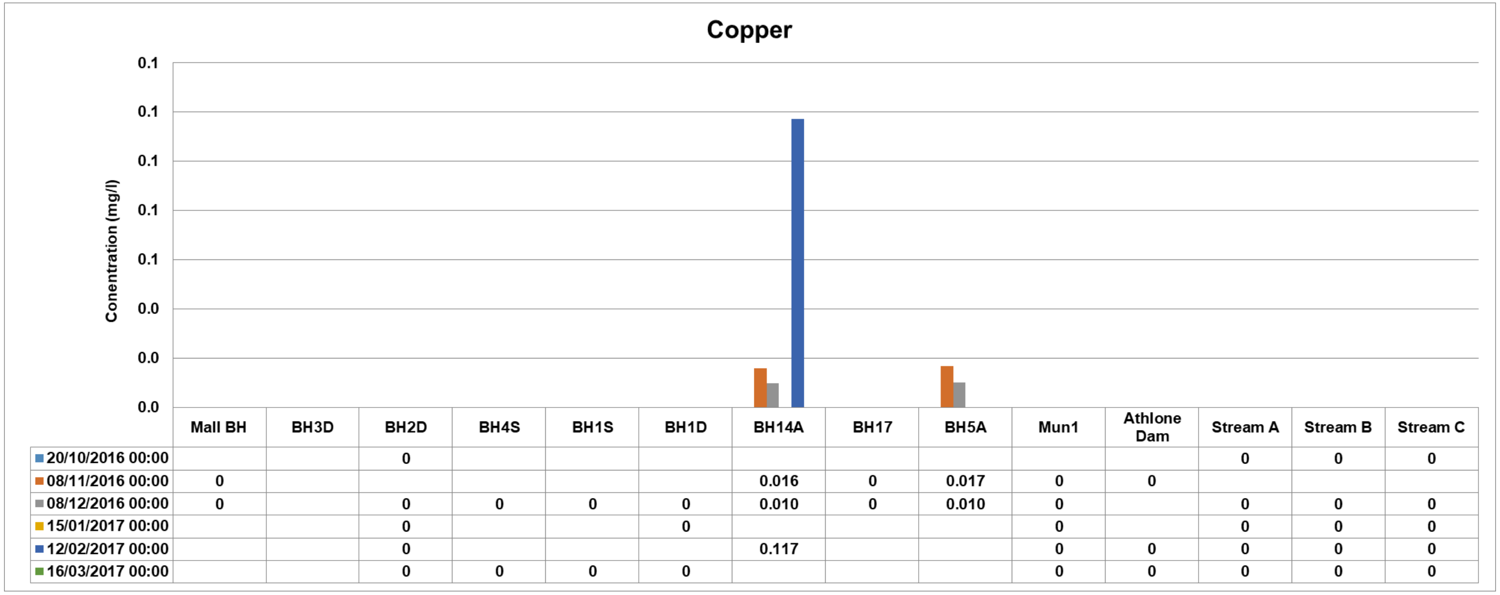
	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
20/10/2016 00:00			1400									64	170	33
08/11/2016 00:00	1						77	1	0	0				
08/12/2016 00:00	0		16	12	390	62	22	1	0	3		4500	650	370
15/01/2017 00:00			1100			21000				0		39000	14000	46000
12/02/2017 00:00			6400				19			0	0	42000	0	30000
16/03/2017 00:00			310	5900	5600	65000				0	2000	2400	3600	4700


Iron

	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
■ 20/10/2016 00:00			0									0	0	0
■ 08/11/2016 00:00	0						0	0	0	0				
■ 08/12/2016 00:00	0.5		0.1	0	0.1	0		0	0	0.05	0.16	0	0.05	0
■ 15/01/2017 00:00			0			0.06				0		0	0	0
■ 12/02/2017 00:00			0				0			0	0.06	0.03	0	0.03
■ 16/03/2017 00:00			11.26	0.15	0.04	0.09				0.24	0.32	0.09	0.03	0.03


Manganese

	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
■ 20/10/2016 00:00			1.19									0	0	0
■ 08/11/2016 00:00	0						0	0.05	0	0				
■ 08/12/2016 00:00	0		1.42	0.06	0.23	0	0	0	0	0		0	0	0
■ 15/01/2017 00:00			1.88			0.30				0		0.07	0.03	0
■ 12/02/2017 00:00			2.24				0			0	0	0.82	0.03	0.19
■ 16/03/2017 00:00			2.07	0.36	0.07	0.33				0	0	0	0	0



	Mall BH	BH3D	BH2D	BH4S	BH1S	BH1D	BH14A	BH17	BH5A	Mun1	Athlone Dam	Stream A	Stream B	Stream C
🟦 20/10/2016 00:00			0									0	0	0
🟧 08/11/2016 00:00	0						0.016	0	0.017	0	0			
⬜ 08/12/2016 00:00	0		0	0	0	0	0.010	0	0.010	0		0	0	0
🟨 15/01/2017 00:00			0			0				0		0	0	0
🟦 12/02/2017 00:00			0				0.117			0	0	0	0	0
🟩 16/03/2017 00:00			0	0	0	0				0	0	0	0	0

Appendix D: Isotope Analysis Results

Sample Name	**Sampling Date**	**δ²H Reportable Value (‰)**	**δ²H Standard Deviation (‰)**	**δ¹⁸O Reportable Value (‰)**	**δ¹⁸O Standard Deviation (‰)**	**d-Excess**	**Tritium (TU)**
StreamA	20/10/2016	12.86	0.61	3.23	0.1	-12.98	1.8 ± 0.3
StreamB		11.8	0.31	1.74	0.12	-2.12	2.2 ± 0.3
StreamC		11.33	0.78	0.79	0.22	5.01	1.7 ± 0.3
BH2D		-14.51	0.73	-3.07	0.22	10.05	1.5 ± 0.3
BH14A	08/11/2016	-9.26	0.58	-1.72	0.23	4.5	0.7 ± 0.2
Mall BH		-21.41	0.63	-3.61	0.07	7.47	0.0
BH5A		-14.13	0.77	-2.25	0.19	3.87	0.0
BH17		-10.35	0.2	-2.92	0.24	13.01	1.0 ± 0.3
RAIN 1	Dec 2016	1.74	0.84	0.12	0.13	0.78	
RAIN 2	Jan 2017	-14.90	1.07	-3.28	0.11	11.34	
RAIN 3	Feb 2017	-48.64	0.82	-8.37	0.13	18.32	1.1 ± 0.3
STREAM A	08/12/2016	-8.27	1.24	-2.18	0.09	9.17	
STREAM B		-7.74	0.57	-2.19	0.10	9.78	
STREAM C		-8.11	0.94	-2.46	0.13	11.57	
BH1S		-11.09	0.66	-2.96	0.11	12.59	
BH1D		-12.33	0.66	-4.08	0.14	20.31	
BH2D		-19.78	1.11	-5.13	0.06	21.26	
BH4S		-7.06	0.70	-2.52	0.06	13.1	
MUN1		4.86	1.06	-0.65	0.08	10.06	
BH14A		-12.20	0.99	-3.77	0.14	17.96	
BH5A		-16.84	0.56	-4.45	0.15	18.76	
BH17		-20.22	0.45	-5.05	0.09	20.18	
MALL BH		-24.29	0.54	-5.79	0.07	22.03	
STREAM A	15/01/2017	-4.48	1.35	-2.71	0.12	17.2	1.7 ± 0.3
STREAM B		-3.44	0.63	-2.69	0.08	18.08	1.8 ± 0.3
STREAM C		-3.63	0.59	-2.63	0.08	17.41	2.2 ± 0.3
BH1D		-13.20	1.18	-4.81	0.12	25.28	1.9 ± 0.3
BH2D		-19.74	0.88	-5.44	0.09	23.78	1.4 ± 0.3
MUN1		6.01	0.51	-1.20	0.09	15.61	1.6 ± 0.3
STREAM A	12/02/2017	0.31	0.64	-2.02	0.12	16.47	
STREAM B		-4.94	0.54	-2.85	0.18	17.86	
STREAM C		-0.67	0.74	-1.60	0.11	12.13	
BH2D		-19.10	0.72	-5.03	0.10	21.14	
MUN1		6.45	1.05	-0.22	0.21	8.21	
BH14A		-11.46	1.23	-3.32	0.08	15.1	
ATHLONE DAM		-1.28	0.73	-1.47	0.08	10.48	1.2 ± 0.3

Sample Name	**Sampling Date**	**δ^{2}H Reportable Value (‰)**	**δ^{2}H Standard Deviation (‰)**	**δ^{18}O Reportable Value (‰)**	**δ^{18}O Standard Deviation (‰)**	**d-Excess**	**Tritium (TU)**
STREAM A	16/03/2017	5.38	0.78	0.00	0.06	5.38	
STREAM B		4.41	0.90	-0.21	0.10	6.09	
STREAM C		4.31	0.74	1.27	0.03	-5.85	
BH1S		-8.43	0.81	-2.15	0.07	8.77	
BH1D		-13.44	0.89	-3.13	0.03	11.6	
BH2D		-16.47	0.48	-3.76	0.12	13.61	
BH3D		-14.58	0.32	-4.44	0.09	20.94	
BH4S		-17.37	0.68	-3.86	0.08	13.51	
MUN1		-6.07	0.62	-1.84	0.12	8.65	
ATHLONE DAM		-10.96	0.57	-3.14	0.04	14.16	
STREAM A	03/06/2017	-2.95	0.67	-1.33	0.09	7.69	1.6 ± 0.3
STREAM B		-6.92	0.57	-2.16	0.05	10.36	1.5 ± 0.3
STREAM C		-6.62	0.69	-2.23	0.06	11.22	1.3 ± 0.3
BH2D		-21.14	0.65	-5.43	0.07	22.30	1.6 ± 0.3
BH4S		-20.38	0.74	-4.85	0.08	18.42	
ATHOLE DAM		-17.69	0.79	-4.52	0.06	18.47	
BH3D		-22.86	0.64	-5.39	0.11	20.26	