Proposed Cemetery Development at Burnt Ground, Lots 47 and 48 Parish of Hanover, Jamaica

by Mr Boyd B. Dent PhD
on behalf of accessUTS

for Environmental Management Consultants (Caribbean) Ltd, Jamaica

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Project No: C06/62/004

accessUTS Pty Limited
PO Box 123
Broadway NSW 2007 Australia
Tel +61 2 9514 1916 Fax +61 2 9514 1433

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OVERVIEW

A report on site investigations of 31 January–2 February 2007, inspection of the district and nearby parts, considerations of the proposed cemetery development, analysis of risk to groundwater supply posed by the development, and other related matters

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Boyd B. Dent

Consultant, accessUTS Pty Ltd

INTRODUCTION

Our Consultant, Dr Boyd B Dent, was invited by Dr Ravidya Burrowes (the Principal Consultant) of Environmental Management Consultants (Caribbean) Ltd (*emc*[2]), to be part of the Project team for the preparation of an Environmental Impact Assessment (EIA) for the development of a cemetery at Burnt Ground, Hanover Parish, Jamaica.

The work tender by *emc*[2] was subsequently accepted by NEPA on behalf of the Government of Jamaica. Consequently *emc*[2] engaged the services of Dr Dent (through *accessUTS Pty Ltd*) in the capacity of a recognised expert on the geoscientific aspects of cemetery development.

Dr Dent's roles were to generally liaise on hydrogeological and geological inputs, review existing data and also new information as gathered, to advise on natural data collection and other data collection aspects, to assist in reviewing work done by others in the Project, but primarily to act as an international, independent expert on matters of cemetery development. Principally Dr Dent was to assess the potential impacts of the cemetery on the site, its soils and local and/or regional groundwater, and to address as many community concerns as were relevant to his expertise. He was to inspect the site and supervise such exploratory work there, and gather data from the district, to the extent possible in a limited visit time.

At the outset, it was noted that the proposed development is very controversial in the eyes of the surrounding communities and that there are widely held, genuine concerns about potential health risks or contamination of regional groundwater supplies due to the cemetery's activities and the nature of its development, and specifically about the use of formaldehyde used for embalming purposes. It was noted that the cemetery development had previously be approved to operate by Jamaican Local and National Government Authorities but that the work at site had subsequently been officially stopped and then this EIA process begun.

EIAs are normally undertaken, reviewed and approved, prior to developments commencing, so that the present situation is unusual. The evaluations of the site and proposed works are made a little more difficult by the fact that site development had already commenced; however, no interments had taken place in the cemetery prior to this evaluation.

As an independent expert on relevant matters Dr Dent is 'at large' to comment on, or review, any aspects or matters relevant to his expertise, learning or understandings concerning the proposed development and its site setting and district context.

Accordingly, it needs to be borne in mind that the findings made and conclusions presented herein, may be at variance with information or understandings or development directions to date, or contrary to 'perceived wisdom' or non-concordant with official or local or developer ideas. Nevertheless, the work in this report represents the Consultant's professional assessment of the proposed development and its context, unfettered by any relationship to the Project Manager, the local communities or the Jamaican Government.

This report includes specific conclusions and recommendations about the proposed cemetery site and some recommendations of a more general nature in relation to cemetery developments in Jamaica.

WORK DONE

The work undertaken by the Consultant consisted of:

1. Desk-top study of available information of the site's geological setting, the development proposals, regional hydrogeology, and relevant Government documents;
2. In Jamaica: site and district and other work as:
   a) 31st January 2007 – inspection of the site, visits to nearby cemeteries, discussion with nearby cemetery controllers, inspection of lands adjacent to the site;
   b) 31st January 2007 – an office meeting with site developer – Mr Dale Delapena for discussion concerning funeral and burial practices common to the district and proposed for the site;
   c) 1st February, 2007 – supervision of 7 exploratory backhoe pits; inspection of soils in the pits and sampling same; supervision of and participation in 4 percolation tests (Pits 1, 3, 4, 6) and measurement of water infiltration (Pit 7);
   d) 1st February 2007 - on site meeting with Mr Dale Delapena regarding site development proposals, intensive inspection of the site and measurement of site aspects;
   e) 2nd February, 2007 – completion of measurements for pit percolation tests running from previous day, measurement of water level in Pit 7;
   f) 2nd February, 2007 – oversee initial surface and Pit 7 water sampling at the site, as well as oversee sampling and inspect landforms and the site of Shettlewood Spring and The Great River;
   g) 2nd February, 2007 – inspection of 2 additional cemeteries – 1 church, 1 municipal in the Chester Castle area;
   h) 2nd February, 2007 – attendance at Public Meeting #1 (as per *emc²*) proposals, however, the planned presentation did not take place;
   i) 2nd February, 2007 – meeting to brief NEPA representatives of work done to date and preliminary findings;
   j) Frequent meetings and technical briefings with various *emc²* Project team members throughout the visit.
3. Post Jamaica visit: numerous email discussions with technical members of the *emc²* Project team; ongoing administrative liaison; review of results of soil and water testing, site drilling and district inspections; analysis, review and consideration of all data available, site inspection data, reports and documents;
4. Preparation of this report, review as necessary, and review or contribute to other parts of the total *emc²* report as requested.

WORD MEANINGS

For simplicity of expression in this report certain key words are given a fixed meaning, unless the context or sense is obviously different:

"aquifer" is used in its broadest sense to be one or more layers of earth material that readily permit the flow of groundwater but which may or may not provide a water resource of any kind; this term has several viable concurrent uses and usually needs to be qualified for greater understanding, the concept of amount of flow in an aquifer is variably interpreted.

"district" means the area of about 3.5 km radius about the site and includes the settlements of Miles Town, Copse, Shettlewood, Chester Castle, Ramble, Mount Ward, Haughton Grove, and others;

"groundwater" means strictly any water than is below the ground surface and within soil, regolith, fill or rock, and which may be pooled or perched, and includes interflow and saturated flows within the unsaturated zone, and, if verifiable, flowing subsurface water temporarily present in sinkholes (dolines) or other karst features or otherwise connected to a groundwater system;

"natural attenuation" means the overall process where leachate, drainage or seepage waters are incorporated into the natural hydrogeological setting; this comprises a number of mechanisms, pathways and reactions including dispersion, dilution, filtration and sorption (adsorption and absorption)

"NEPA" means the National Environment and Planning Agency of Jamaica

"region" means an area very much larger than the local district and would include Montpelier and can be a reference in any direction from the site;

"*site"* means the proposed cemetery development at Burnt Ground and the parcels of land intensively investigated on the ground;

"subsurface" means any point or matter or substance below the present-day natural or made surface;

"surface water" means streams, ponded and dammed water, temporary overland flows, groundwater that has exited as seeps or springs, water pooled in sinkholes (dolines) as a result of surface flow or rainfall;

"WRA" means the Jamaican Water Resources Authority

NATURE OF THE RISK

Numerous studies, worldwide, have consistently shown, and are strongly supportive of the idea, that cemeteries have a minimal impact on the environment: however, this conclusion needs to be heavily qualified. These aspects have been thoroughly examined by the Consultant (Dent 2002) and reviewed by peers and others in numerous worldwide forums.

If one designates "pollution", in the cemetery context, to be an unnaturally induced increase in some analyte of the representative natural environment's surface- or ground-waters and soils beyond the cemetery boundary, then this pollution can certainly be detected and quantified. However, the typical inorganic chemical loads imposed by cemeteries are very small. Often, groundwaters within cemeteries are chemically ‘cleaner’ than those without the cemeteries where they are severely impacted by other anthropogenic activities.

There are six main categories of decomposition products which need to be considered when delineating potential pollutants:

- pathogenic bacteria and viruses
- nutrients – N and P
- increased abundance of the ions – Na, Cl, Mg, SO4, Sr
- heavy metals including As
- a range of non-specific organic molecules, mostly low molecular weight acids
- formaldehyde (methanal).

The actual pollution from most cemeteries is minimal and is predominantly confined to some major ions and inorganic forms of N and P. However, the potential for contamination is considerable, particularly for bacterial and viral pathogens, if incorrect methods of cemetery location and operation are practised. Nonetheless, earth burial is an ecologically sustainable activity.

There are also other matters to consider, for example, the geomorphic activity of the site (particularly landslip and flooding potential), and it’s response to seismic or other hazards. Then finally, the interment and management practices of the site need to accord with the correct practices and policies for running and developing cemeteries which will satisfy the requirements of public health and mitigate any future ex-cemetery effects of the interment practices.

SITE DESCRIPTION AND PHYSICAL GEOLOGY

The accurate description of the site locality and its relationship to nearby communities is detailed elsewhere. The site generally occupies the south-western flank of a small ridge comprised of limestone bedrock and deep regolith and occupies the north-west corner of the intersection of the Shettlewood - Haughton Grove and Shettlewood - Copse roads, at Burnt Ground in Hanover Parish, Jamaica. The site comprises two Lots – 47 and 48; the interment area has been proposed only for the northern Lot - 48.

The site dips steeply from the north-east corner generally to the southern boundary. About the middle of the site on the eastern boundary is an east-west orientated spur dipping to the west until it reaches a topographic low adjacent to the western boundary. This spur effectively divides the site in two: a northern part and a southern part. The spur also roughly corresponds with the property boundary between Lots 47 and 48, although part of the middle of the site and on the spur has been redeveloped as a carpark.

The northern part hosts a clearly defined “central drainage line”, which begins near the boundary and terminates in a collapsed doline adjacent to the western boundary. The southern part also hosts a collapsed doline but receives drainage from the west, north and east; the northern flank being comprised of steep slopes. This area represents the lowest-most topography of the site, and being adjacent to the Shettlewood – Haughton Grove road also provides the front site boundary and principal access. Much of the site here has been alterred by road construction and redefinition of the sinkhole shape.

Above each of these low points the landform generally climbs modestly with typical side slopes of 7º - 9º, except in the vicinity of the central drainage line and immediately north of the front sinkhole. The effect of the central spur is to separate the two low points and effectively create two sub-catchments for the site. A third, very minor one is located in the NW corner and formed by a small divide about 50 m onto the site.

Surface runoff is retained on the site by the nature of the low points except in the most severe climatic events where the southern (front) pond may overtop to neighbouring lands, and, a small area in the NW corner may allow drainage off-site, via the over-topping of the small divide here.

Small, but improperly defined parts of the site have been reshaped by scraping and filling. Filled thickness don't appear to be large and where found are hard to distinguish from the natural regolith because of its very mixed nature. Filled areas are not expected to significantly alter surface drainage or groundwater percolation.

GEOLOGY AND REGOLITH (SOILS)

The site has been explored by pitting and engineering boreholes. 7 pits about 600 mm wide were excavated to about 3600 mm (Figure 1 and Appendix A). 3 boreholes (see separate report) were drilled with the primary intention of establishing the regolith thickness and continuity (Figure 1 and following). Samples retrieved during the pitting and drilling have been subjected to a wide range of laboratory analyses (Appendix B and separate reports).

The site is thought to be underlain by limestone bedrock of the Gibraltar - Bonny-Gate Limestone (possibly also referred to as Gibraltar-1 Limestone). This formation is generally described as cream-white or buff coloured limestone with lenses of gravel, not particularly karstic nor usually a significant aquifer. However, as a result of the present investigations there are now considerations that suggest that the bedrock may comprise a fault-bounded slither of another, older formation. This matter is discussed elsewhere and is thought to be evidenced in part by the substantial non-limestone-derived components of the regolith, the nature of the cherty cobbles, the non-conformable local landform and other aspects.

What is apparent is that the geomorphology of the site is a little different to that of the nearby district, and that the landforms here appear to be developed on a more erosion-resistant bedrock, which concomitantly is probably less fractured or porous than elsewhere.

A very thick regolith layer comprising yellow-brown and red-yellow-brown cobbly, pebbly silty clays, loams and clayey silts and clays is present over the whole site, and overlays a weathered limestone of unknown petrology and weathering state, but is likely to contain cherty gravel (cobbles and pebbles). The soil layer is at least 8m thick in the topographically high areas and of the order of 12–13 m thick in lower parts. Occasional cherty and/or clayey lenses and bands should be expected to be present, consistent with the combined - weathered and assumed transported - nature of the soils. Overall the soil profile is very uniform, horizons were infrequently observed.

Mineralogically and texturally the soils are quite uniform over most of the site – evidenced by their colour, physio-chemical properties and gradings. The mineral suite evidenced comprises those typical of well-weathered rocks – but not necessarily limestone but maybe including impure limestones, and primarily includes quartz, nacrite, dickite, kaolinite and some illite, with other minor clays including some unexpected ones of a metamorphic origin. There was a distinct absence of carbonate minerals, as might have been expected from a residual limestone regolith.

The presence of sandier parts in the loams and clays may be related to colluvial transport. However, it was also noted during the pitting explorations that some of the soils tended to have sand-sized peds, i.e. silt- and clay-sized particles clumped together: it is possible that this behaviour may have influenced the laboratory grading determinations (Appendix B) implying more sand is present in the soils that is actually the case. The soils are surprisingly quite acid (Appendix B) and some of the white coatings and dispersed grains seen are possibly precipitated silica. Accordingly there are few, if any, carbonate deposits as coatings and nodules, in the soils.

The clay mineral suite is not particularly noted for a swelling nature, although if they are desiccated they will lose substantial volume and crack. They are also not noted for their sorptive capacity of pollutant chemicals. However, the considerable quantity of clay present in the soils (Appendix B) fosters a soil with a suitable texture for development of a cemetery.

It has been determined (Dent 2002) that soils which can be classified with a Unified Soil Classification of "GC, SC, SM, ML and CL" generally represent "good to fair" conditions suitable for the development of a cemetery. Many of the site's soils (Appendix B) are within the range represented here and thus from considerations of drainage and workability are deemed suitable. Some site soils – mostly at depth, have a partial or complete classification of "MH or OH" (plastic silts and clays): these soils are not the best for cemetery development because they retard water infiltration and percolation and are often difficult to work with when wet. In the present case, however, these soils are associated with gravels which changes their workability and permeability so that they are at worst moderately deleterious to the development.

The soils contain variable amounts of charcoal, and large amounts of manganese. The former was observed in the exploratory pits but has not been readily detected in sample testing; however, its presence has led to two independent descriptions of some of the soils as being 'organic'. The latter is readily apparent as coatings on larger gravel and smaller sand-sized particles and coated particles. Charcoal is a useful adsorbent material for salts and organic compounds in groundwater. Manganese if mobilised in groundwater can stain monuments and concrete paths and surfaces. The disposition of manganese throughout the site is irregular; its presence apart from helping to characterise the soils, likely indicates deposition from very slow-moving percolating waters at irregular times.

The soils remain stable on pit sides when excavated, or even left to stand with water in their base; and are not expected to exhibit significant shrink or swell properties. Percolation tests to assess the site soils' drainage characteristics (discussed later), also suggest a considerable uniformity of soil properties and behaviour. Generally those results suggest groundwater percolation rates not unduly retarded by the nature of the soil fines.

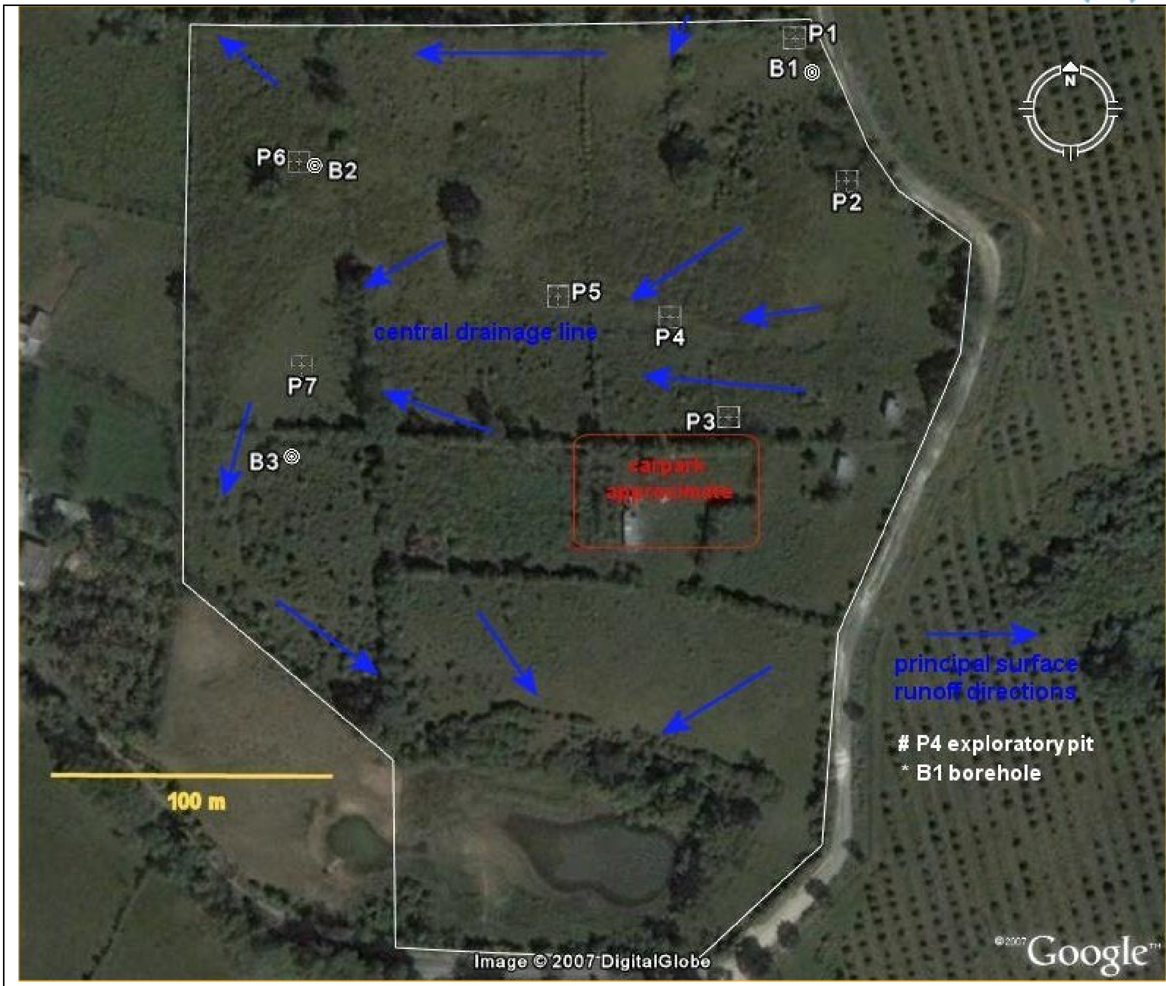


Figure 1: Site Drainage and Sub-Surface Investigation

HYDROGEOLOGICAL SETTING

Karstic terrain of all kinds is well known for its elements of non-regular and non-predictable hydrological behaviour. In the district of concern here the terrain shows some significant variations from a highly developed karts landscape, and it's likely that these will influence regional groundwater flow patterns and behaviour. Without comprehensive data including field mapping, borehole observations and records, any analysis must be substantially incomplete. Fortunately in the present situation, the location of major fault systems is known, the general nature of the rock formations is known, and the mapping of karst geomorphology is largely done.

Field observations made of the district did not indicate karst features like solution channels, pock-marked clifflines and caves expansively at the surface. The few outcrops visited showed the Gilbraltar-1 Limestone to be relatively homogeneous, bedded as expected for this kind of sedimentary rock, competent in cuttings and weathering as expected. It was also obvious that there are many collapsed dolines (sinkholes) in parts of the district, all of these were observed to be dry but clearly infilled with colluvium. At other places there appeared to be a thick regolith which gives an infilling and levelling effect to the landscape. Hills, and many ridgelines, are frequently rounded with steep sideslopes, yet are more severely dissected where associated with surface flows.

There is, unfortunately, an absence of sufficient official hydrogeological information for the immediate district in order to completely characterise the regional groundwater flow system. There are a few discontinuous records of bore water levels, partial descriptions of bores as well as incomplete descriptions of the regional hydrogeological setting. The regional geology is likely incompletely understood, although major fault systems and some structural geology of the district are known and located. An analysis of bore hydrographs and a re-interpretation of district structural elements have been made.

REGIONAL WATERTABLE

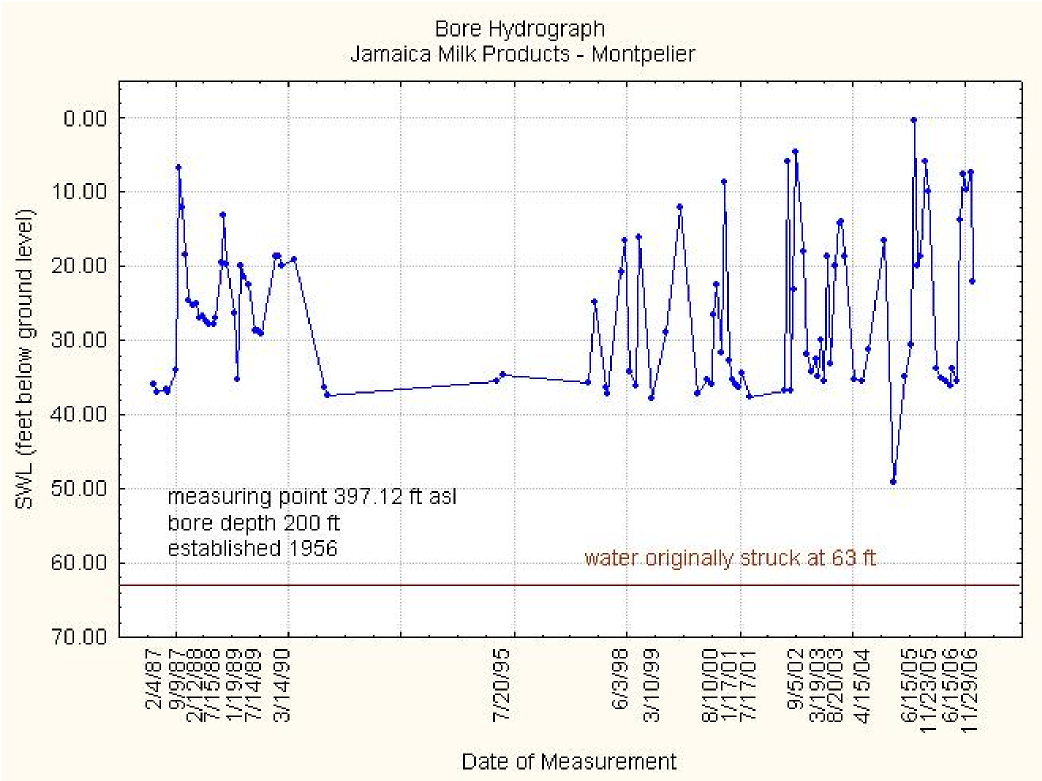
A compilation of all available nearby borehole data was made – Table 1. Special attention was given to eliciting information from borelogs and any reports on the presence and interception of permanent (regional) groundwater. An examination was also made of historic well water level data for nearby wells as an aid to understanding regional watertable behaviour (if any) and also any relationship to recharge. The amount of information available is scant and much is incomplete or unavailable. There are also some small difficulties with the quality of the data – mostly inconsistencies or absences - and this is noted in the following where appropriate.

The water level data for the Jamaica Dairy Products production bore and Cornwall Dairy #2 production bore at Montpelier were graphed, together with rainfall data for nearby Shettlewood (Figure 2 and 3). These hydrographs show that the piezometric surface in each well fluctuates between 20–30ft (6.1–9.1m) annually, and also show that the aquifer is behaving in a confined or semi-confined manner at this place. The hydrograph patterns are somewhat cyclical with low pressures generally apparent in the first half of the year and highs in the second half – this appears to be related to seasonal rainfall events (with a slight lag) or production pumping: it is not possible at this stage to separate out the effects of production pumping, but it seems likely that the regional aquifers are fairly quickly influenced by rainfall recharge events.

Another issue is that these wells are probably mostly related to the Montpelier Limestone aquifer system rather than that of the Gibraltar - Bonny-Gate Limestone. The situation, however, is unclear, and WRA records suggest that both formations may be involved: the top of the latter having been intersected. What is more, the latter formation is not thought to be a significant aquifer system or to be substantially karstified. Since it is thought that the Gibraltar – Bonny-Gate Limestone either underlies or surrounds the site, then the possible reflection on its potential behaviour might be important.

What can be said from this analysis is that the aquifer clearly responds to applied stresses (natural or anthropogenic) over a wide (but approximately constant with time) range of pressures. There appears to be no evidence of permanent dewatering, and at this stage the system would appear to adjust to, and be sustainable under, the applied stresses; that is, a ‘working equilibrium’ seems to apply. Accordingly there is every reason to believe that the aquifer system will continue to function in a relatively understandable manner unless the parameters of use, or the climate, change.

There are no surprises in these understandings however, they do affect the wider interpretation of regional groundwater flows. It suggests that the aquifer may be primarily recharged through discrete areas (perhaps outcrops) or pathways (perhaps dolines), and that much of the aquifer does not receive diffuse, regionally infiltrated rainwater. The presence of the thick colluvial soils generally in the district seems to support the idea that there is no widespread infiltration effect, and it is possible that this acts as a confining layer for the aquifer – thus causing elevated pressures. Accordingly, the cemetery site development is expected to have no impact in this matter.



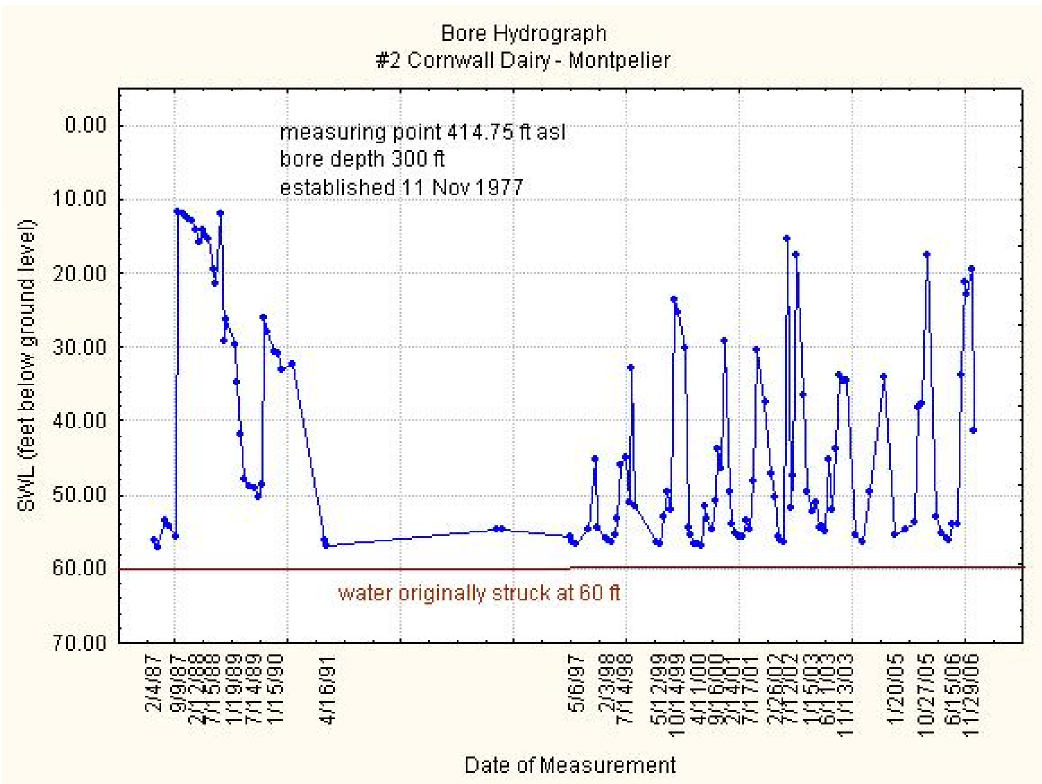


Figure 2: Hydrographs for Wells at Montpelier

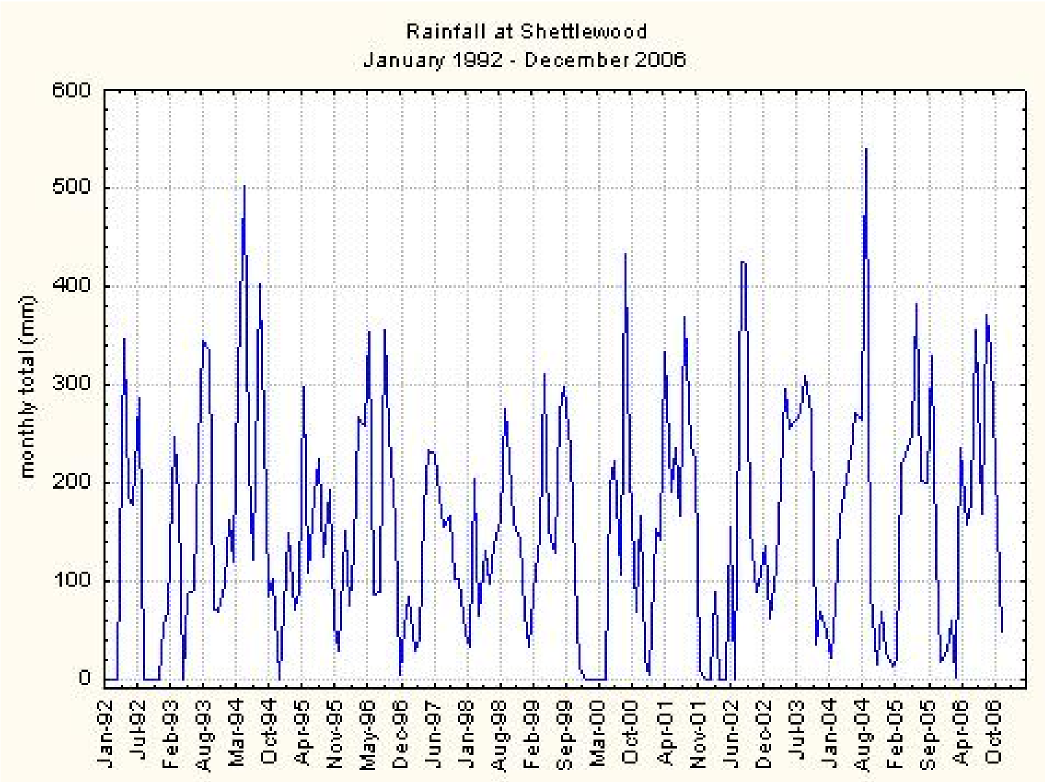


Figure 3: District Rainfall Data

In order to further consider any hydrogeological connection between the site and the Shettlewood Spring, an interpretation has been made of structurally related elements as they express themselves in the landscape – either as sinkhole patterns, ridgelines or controlled river and creek courses. This has been done on the district 1:50000 topographic map and the position of known faults (from a WRA map of hydrostratigraphy) has been added – Figure 4.

This analysis indicates that there are probably two major linearly directed structural elements that control the geomorphological development of the district landscape. These trends, generally NW-SE, and NNE-SSW: with possibly two minor trends closer to E-W and N-S, the latter particularly in the fault systems. In the absence of detailed structural information, the strikes of the NNW-SSE trending faults in the west of the district seem to suggest that they have a significant component of lateral shear, while the undoubted major fault strike is roughly orientated N-S. This all suggests that there have probably been two major stages of structural disruption here, giving rise to a complicated hydrostratigraphy.

Consequently, groundwater activity has favoured the development of karstic features in a controlled manner. This is very clear (Figure 4) for the area west and south-west of the site. To the north and east, although structural elements are clearly present and they strongly influence the course of the Great River, their inter-connectedness is less obvious. It is difficult from this analysis to pin-point the reasons for the emergence of the Shettlewood Spring. Likewise it is quite difficult to envisage the Springs relationship to the landscape to its south-west, that is, in the direction of the site.

There seems to be no obvious, direct connection of site to Spring. Accordingly, it is expected that any groundwater at the site reaching the regional groundwater system will not be preferentially directed towards the Spring. If anything, the regional groundwater system is enhanced to the west of the site and away from the Spring.

FLOW TO THE SHETTLEWOOD SPRING

In the absence of a great deal more hydrogeological data it is difficult to analyse regional groundwater flow in the district of the site. The site centre is of the order of 2.1 kilometres from the Spring, it sits above a deep regolith at least comprised of gravely clayey-silty and loam soils (about 8 - 12 m thick, Table 1), and hosts a relatively deep piezometric surface (cf watertable) in bedrock – of unknown depth but probably of the order of 25 m (61 ft) in the lower parts, but this increases as one moves into the north-east of the site (where the topography rises).

It is thus quite speculative to guess at how long water groundwater would take to move from the vicinity of the site to Shettlewood Spring – *if indeed it does so!*

Based on the most simplistic of speculations:

- If the typical elevation of the site is about 205 m asl;
- The elevation of Shettlewood Spring is about 150 m asl;
- The regional piezometric surface (watertable) is about 25 m beneath the site (i.e. about 180 m asl);
- The site is about 2.1 km from the Spring;
- Then the maximum regional watertable possible (if it were to exist in this manner) has a hydraulic gradient of about 30m/2100 m or 0.0143.

The immediate district appears to be only slightly to moderately karstic, having been affected and further modified by extensive colluvium deposition, and there is no evidence of major solution channels, cave structures or major terrain disruptions nearby. Hence, assuming an Hydraulic Conductivity (K) for the upper limestone of 1 x 10^{-5} m/sec and effective porosity of 30% (η_e) (Domenico and Schwartz 1990), and also assuming that Darcian flow prevails, then the minimum travel time (*t*) for groundwater from below site to Spring is given by:

$$t = d/v$$

where *(t)* is time, (*d*) the distance and (*v*) is the linear velocity, where

$$v = -\frac{K}{\eta_e} \times \frac{\delta h}{\delta l} \text{ (m/sec)}$$

thus for the pathway, on substitution:

$$t = d/v = 2100\text{m} / -(1 \times 10^{-5} \text{X } 0.0143/0.3) \text{ m/sec}$$

(the negative sign can be ignored) and the minimum travel time for the distance is: 141 years.

However, it needs to be stressed that, given the knowledge of the nature and hydraulics of any regional groundwater system, it would be unwise to rely on this simplistic model for further calculations. It is considered that the pathway of any infiltrated water molecule at the site to the Spring – even if it occurs - would be extremely tortuous and long. It will be longer than the 141 years above because it must move through the deep soils to the watertable. The dilution which would occur when factoring in concomitant infiltration and percolation over the 2100 m distance would be extremely large so as to render the likelihood of tracing such a molecule pathway non-sensical.

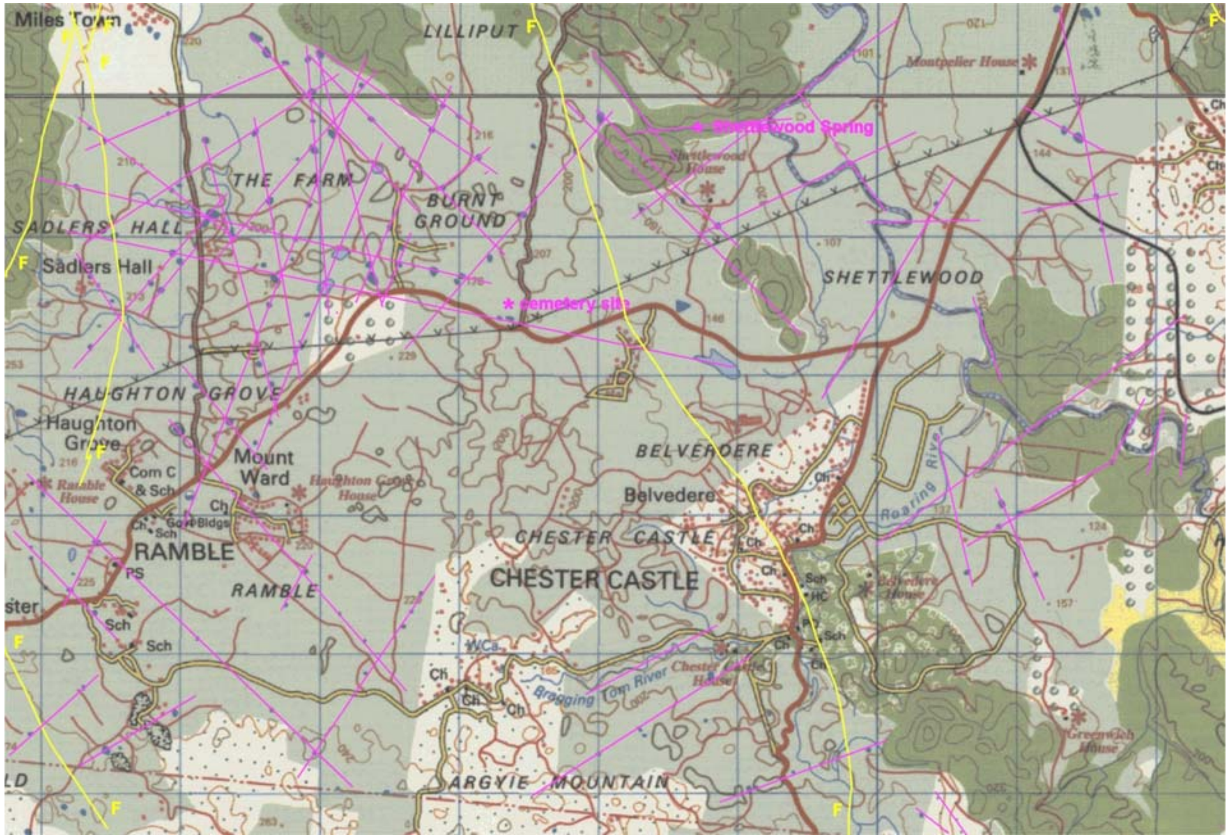


Figure 4: Interpretation of Structural Elements Associated with Hydrostratigraphy

adapted from 1:50000 topographic and WRA maps; scale not shown; North at top edge; pink lines interpreted joint, ridge or channel structure; yellow (F) – mapped faults by others (position approximately transposed to this figure)

Part A: District Localities

Well ref	General locality	Date completed	Well surface level *(1)*	Completed depth (ft)	Initial water level (ft bsl) *(2)*	Aquifer or formation description from well logs	Approx distance from centre of site (km) (miles)	Well purpose
Jamaica Milk Products	Montpelier	1956	397.12	200	63	limestone	5.0 (3.11)	production
Knockalva	Knockalva	April 30, 1971	unknown	492	420 approx	limestone	3.9 (2.42)	abandoned, no supply
Cornwall Dairy Test Bore	Montpelier	July 1977	unknown	200	36 *(3)*	limestone	5.1 (3.17)	investigation bore
Cornwall Dairy #2	Montpelier	Nov 11, 1977	414.75	300	60	limestone	5.2 (3.23)	production bore
Shettlewood Spring	Shettlewood			elevation about 492 (150 m) *(4)*			2.1 (1.30)	spring outlet dammed for water supply

Table 1: Key Water and Investigative Well and Spring Data for the District

(data obtained from official WRA database, and reports and records by Mr B. Young and Hill-Betty (Engineers) Ltd.)

Notes:

1) Refers to the ruling datum of the day; not corrected for any changes in height or location datum
2) bsl = below surface level (unclear if measured from, or corrected for, a well collar)

3) Official notes that the water levels in this well are similar to those in the Jamaica Milk Products' production bore about 100 yds away are confusing. They may relate to SWL or when the water was originally encountered. The level of original interception is not consistent with the new production bore – Cornwall Dairy 32 which was sunk nearby. Insufficient data, e.g. surface levels, is available to undertake complete analysis, but the water first encountered in the Cornwall dairy Test Bore may represent a perched watertable.

4) There is conflicting information as to the elevation of the Shettlewood Spring; this level is a working level considered to be close to the real value; however a minimum of those available is 475 ft (145 m) but seems to refer to the water supply dam or streambed below it.

Part B: Community Investigation in respect of the site by Mr B. Young, General Locality - Hanover

Well ref	Location	Date completed	Well surface level (ft)	Completed depth (ft) *(4)*	Groundwater encountered (at initial depth - ft) (m)	SWL *54)* shortly after completion (ft)	Groundwater rise (ft)	Depth of clay regolith over bedrock (ft) (m)	Bedrock
BH 1	Shettlewood Baptist Church	March 15, 2006	na	50; to be continued to 100 by NX coring	46 in bedrock (14.0)	38	7	about 40 (12.2)	limestone
BH 2	Haughton Grove	March 25, 2006	na	57; to be continued to 100 by NX coring	48 in bedrock (14.6)	46	2	about 45 (13.7)	limestone
BH 3	Burnt Ground - opposite the site	March 30, 2006	na	55; to be continued to 100 by NX coring	53 in bedrock (16.2)	34 (April 2, '06)	19	about 30 (9.1)	limestone with flint
BH 4	Martin's Property, Ramble	March 30, 2006	na	*(4)*	more than 30 (unknown)	na	na	more than 30 (9.1)	*(4)*
BH 5	Wright's Property, Haughton Grove –	May 1, 2006	na	60; to be continued to 100 by NX coring	56 in bedrock (17.1)	unknown	unknown	about 0.5 (0.15)	limestone

	Saddler's Hall								

<u>Notes</u>: na = information not available or not recorded on borelogs

4) full borelogs were never made available; it is unclear whether the proposed coring ever took place

5) SWL = static or standing water level; the water level in the bore at the time of measurement – reported either in feet below the surface (or measuring point/collar) or as an RL.

Part C: Site Investigations – February 2007

Well ref	Location	Date completed	Well surface level	Completed depth (m) (ft)	Groundwater encountered (at initial depth – m) (ft)	Depth of silty-clayey regolith over definite bedrock (m) (ft)	Bedrock
BH 1	NE corner, topographic high	nr	nr	9.1 (29.9)	nil	~ 8.1 (~26.6)	? cream/brown limestone
BH 2	NW corner area	nr	nr	12.2 (40.0)	nil	~11.1 (~36.4)	? cream/brown limestone
BH 3	adjacent central drainage line, to SW, close to west boundary	nr	nr	13.7 (45.0)	6.1 (20.0) perched	~12 (~39.4) unclear	weathered limestone (?)

Notes: nr = not reported

PERCOLATION TESTS

During the field investigations the opportunity was taken to evaluate the manner in which water will enter the site soils at depth. This work was designed to understand the specific site situation where water might make its way into the backfilled grave space from the surface, possibly interact with the interred remains, and then enter the undisturbed soils at the grave invert (base).

This type of investigation is usually performed near the surface and is referred to as infiltration measurement. The experimental technique and analysis of field data in such situations is relatively well understood although there are a number of contentious matters raised in respect of interpreting the results. It should be noted that the great variations exhibited in the texture and micro-structures of soils makes their testing complicated.

In the present case, the testing was done at the base of the exploratory pits used for examining the soil profile and within a short time of each excavation (Appendix A). Consequently, this testing more likely emulates 'percolation' within the soil profile. That is, a stage after infiltration where water continues to move through the soil. As such the data are probably superior for interpretative purposes than any infiltration measurement. They have also been done on a bulk scale, an unusual situation but more representative of what may happen in the grave.

There are severe limitations to the methodology and interpretation. The method comprised quickly, and with absolute minimum spill and splash, tipping clean tap water into the base of the pit. The depth of water remaining in the pit as it enters the soil over time, was then measured from a fixed reference point at the surface. Initially, measurements of residual water level in the pit are taken quite frequently, but then the interval between successive measurements is allowed to grow; a final measurement being taken the morning after the testing was begun (Appendix C).

The percolation testing, *can at best*, be regarded as indicative of some soil behaviour. The test suffers from irregularities in the size and shape (floor-smoothness) of the pits, the amount and chemistry of water used, any degree of smearing of clays over the lower walls of the pit, total time available for observations, the fact that there is head (pond) of water at atmospheric pressure in the pit, potential losses due to evaporation and other matters. On the other hand, the test has the potential to interact with a large area of natural soil including typical heterogeneities of the profile, e.g. tree roots, rocky lenses, facies variations, macropores and other aspects. Overall, the water percolation behaviour can be indicative of what might be expected for the site. Relative and generalised interpretations can be made; although absolute and precise quantitative data cannot be obtained.

The analysis of the test results is broadly consistent with that used for the infiltration test, but with the following variations. Because the 'infiltratable area' and the pond depth are not controlled (as opposed to the constant head infiltration test), the water losses are converted to a value of loss with time and area available for initial infiltration. The area available can only be estimated: this can be done by assuming that in each measurement time period, only half the area of the pit wall would be available (whilst fully ponded, the pit floor area is always available). The pit dimensions at its base are approximately estimated from measuring the axial lengths at 'mid-side'. In the situation of the site and at the time of the investigation, losses due to evaporation are thought to be extremely small and are thus ignored.

Various graphical interpretations, including the standard water loss with time of test are used to assist in assessing the interpretation of data. These representations show periods of irregular percolation and capillary action by pores or drainage into macropores and/or spurts in waterfront movement, as well as the effect of the progressive wetting-up of the soil. Consistent with standard understandings of unsaturated soil behaviour, i.e. that infiltration rate decreases with time, is also observed (Figures 5, 7, 9, 11). With the aid of general graphical descriptions a representative rate of percolation as "volume/time/area" (L/min/m^2) is determined and used for broad comparative purposes (Figures 6, 8, 10, 12).

Other soil data, e.g. the grading analyses, and understanding of the mineralogy and textural features (Appendix B), is used to support or compliment the percolation test interpretations.

During the site drilling investigations, percolation testing of the soil-bedrock boundary was requested. However, the methodology of this testing was very poor and didn't consider the discrete interval required: any results obtained (reported separately in the drilling report) could not, and should not, be used for further analysis. It also needs to be borne-in-mind that the top of the bedrock was not precisely identified by the drilling but has been inferred from the borehole logs and drilling reports.

PERCOLATION TEST – GRAPHICAL ANALYSES

Analysis of the data for Pit 1 suggests a working result of 0.3 L/min/m^2, this is equivalent to

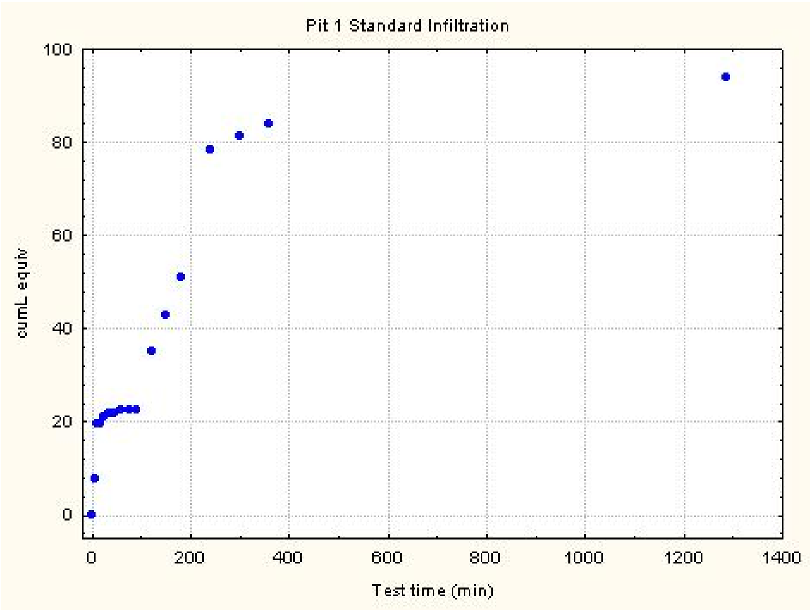


Figure 5 Pit 1 Standard presentation of cumulative infiltration style

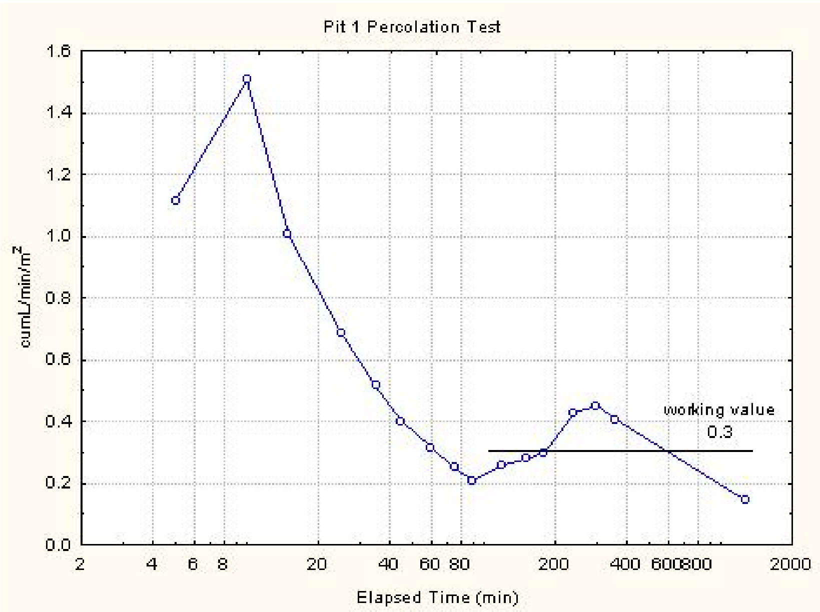


Figure 6 Pit 1 Percolation Analysis

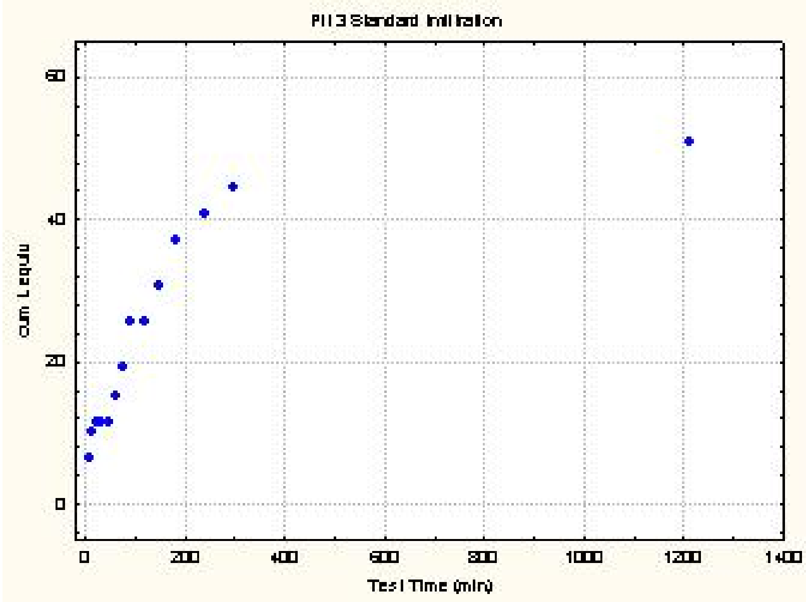


Figure 7: Pit 3 Standard presentation of cumulative infiltration style

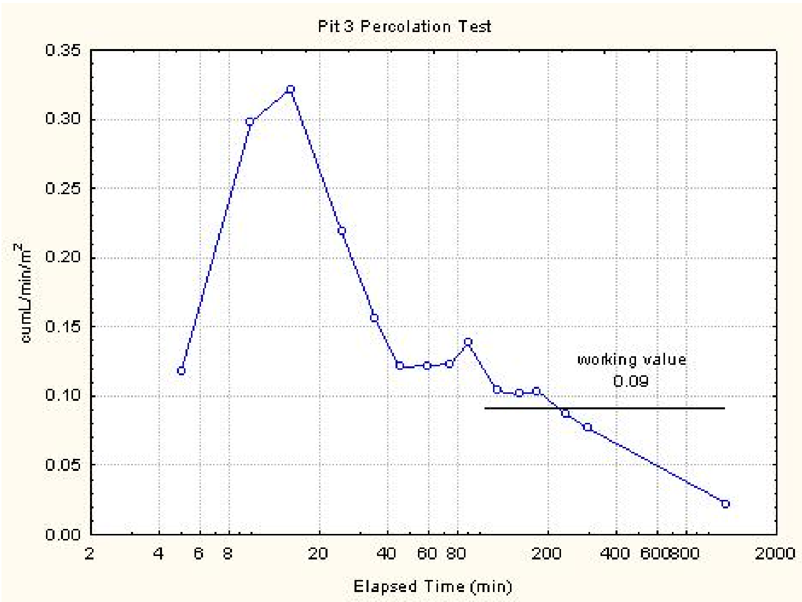


Figure 8: Pit 3 Percolation Analysis

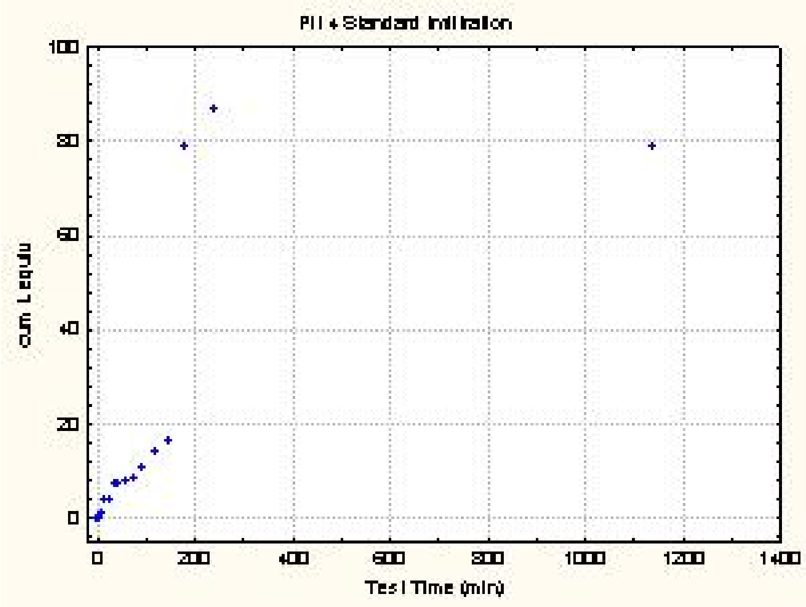


Figure 9: Pit 4 Standard presentation of cumulative infiltration style

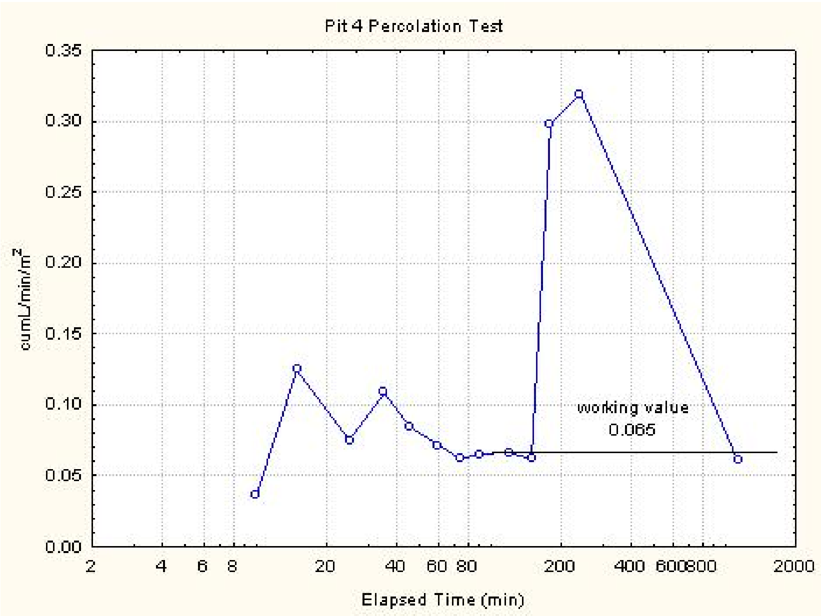


Figure 10: Pit 4 Percolation Analysis

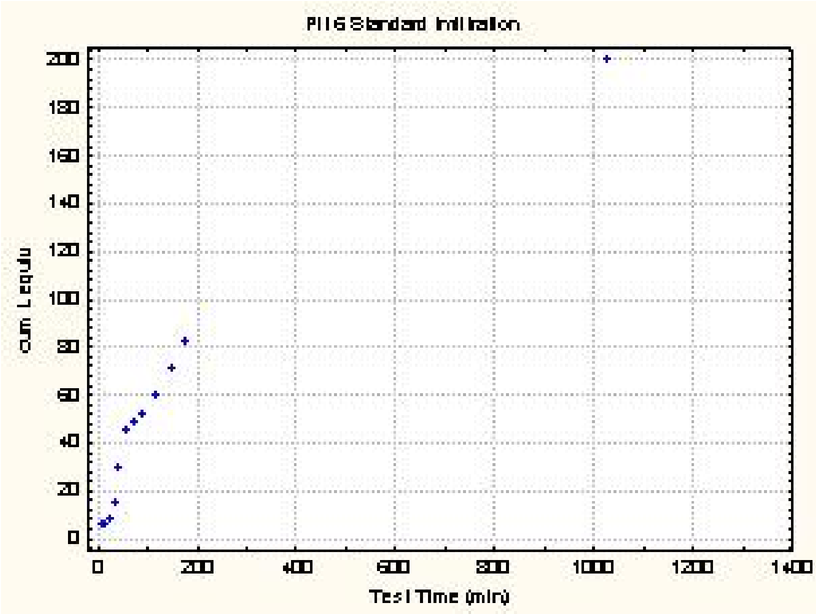


Figure 11: Pit 6 Standard presentation of cumulative infiltration style

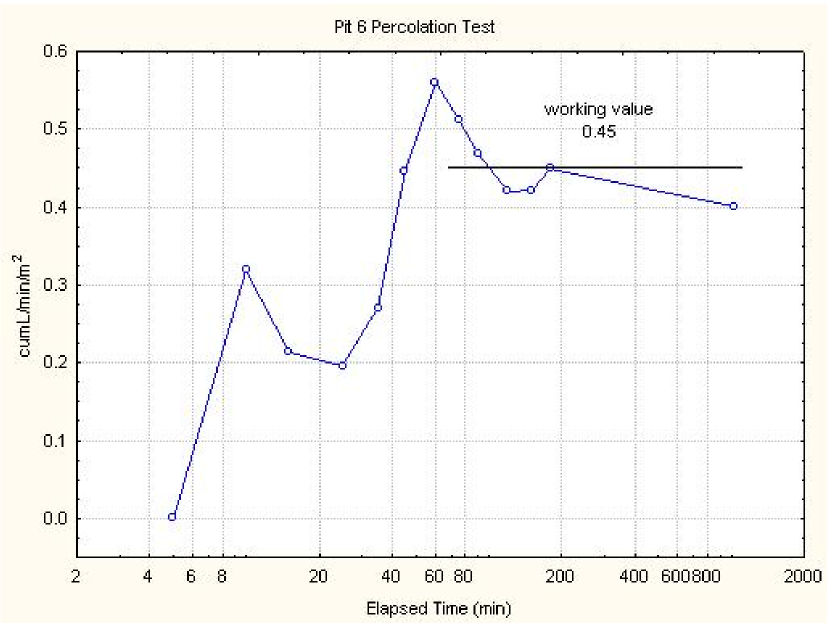


Figure 12 Pit 6 Percolation Analysis

SUMMARY OF SOIL PERCOLATION DATA

From the raw percolation value interpreted by graphical analysis an equivalent saturated Hydraulic Conductivity (Ks) is devised; these results are summarised in Table 2, while Figure 13 illustrates the overall patterns of the percolation results. This soil property is used for further development of considerations of the water flow within the soils; and is compared to the Hydraulic Conductivity for aquifers.

Table 2: Representative Soil Percolation Properties

Pit #	raw value cumL/min/m²	equivalent percolation K_s m/sec	equivalent infiltration rate mm/hr	interpretation (after Hazelton & Murphy 2006)
1	0.3	5.0×10^{-6}	18	moderate rate of infiltration and low rate of percolation
3	0.09	1.5×10^{-6}	5.4	moderate to low rate of infiltration and very low rate of percolation
4	0.065	1.1×10^{-6}	3.9	slow rate of infiltration and very low rate of percolation
6	0.45	7.5×10^{-6}	27	moderately rapid rate of infiltration and moderate rate of percolation

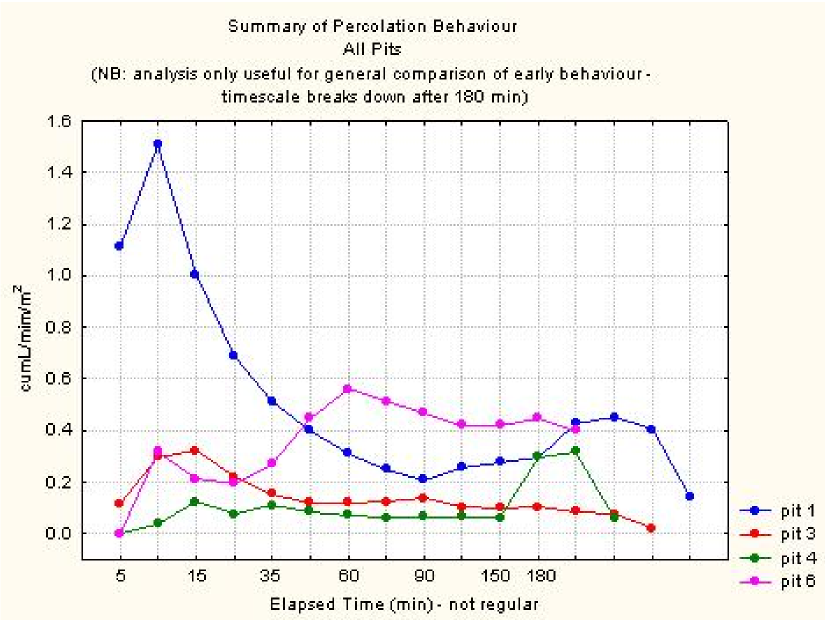


Figure 13: General Percolation Patterns

The percolation patterns (Figure 13) illustrate some of the natural variation likely within the site soils. At some time close to the beginning of the test, a sudden spurt of water loss occurs probably as larger macropores, lens partings and variable facies' lenses are filled following on from the immediate capillarity effects in the walls of the pit. Thereafter, percolation rates generally fall, but this rate can be variable – compare Pits 1 and 4. At some later stage, and this timeframe is also variable, an additional spurt of water loss can occur as the diffusing wetting front encounters more macropores or variable compaction conditions. Generally speaking, the percolation patterns exhibit no unusual or unpredictable behaviour given the nature of the site's colluvial soils; and all indicate a relatively uniform rate over the longer term within a narrow range.

The values of K_s determined from the field percolation tests are in the range 1.1 x 10^{-6} – 7.5 x 10^{-6} m/sec; which is very narrow and consistent for a natural physical parameter. This is indicative of the generalised understanding, noted above, that the site soils are quite uniform in character and behaviour. This range of Hydraulic Conductivity is entirely consistent with published representative data ranges for the clayey loam – loamy clay – till type of soils e.g. see Freeze and Cherry (1979) who report values from 5 x 10^{-8} to 8 x 10^{-4} m/sec, and Fetter (2001) who reports values from 1 x 10^{-11} to 2 x 10^{-5} m/sec.

WORST CASE TRAVEL TIME

The movement of cemetery decomposition products (from bodies, caskets and artefacts) is retarded in soil, as for any other type of soil- or water-borne pollutant, by dispersion, adsorption, entrapment, filtration and reaction. The worst case situation covering their normal, natural movement is where they quickly enter a saturated aquifer with a steep hydraulic gradient – thus permitting their rapid sub-surface movement and spread.

Such a situation requires:

a) The saturated condition,

b) Ready access to a shallow watertable,

c) Constant flow along a steep pathway,

d) Materials which are not naturally sorptive and which facilitate spread through open pores, macropores, partings or other fissures and planes.

The only other situation facilitating spread and which could be relevant here is where there is open channel, fissure or solution channel flow and Darcian flow does not apply; for example, where there is immediate access to karstic solution channels in soil or bedrock.

As noted previously – this situation does NOT apply at the site, and the site materials and hydrogeological setting are entirely inconsistent with the scenario necessary for rapid sub-surface movement (see also Appendices A and B). Nevertheless, it is necessary to examine the potential for the greatest risk of sub-surface migration.

Assuming that all the previously noted criteria (a – d) applied without restriction, that the hydraulic gradient ($\delta h/\delta l$) was very steep at 5% (0.05), and that a representative effective porosity (η_e) for the site materials was 40%, and that Hydraulic Conductivity (K) was 7.5 x 10^{-6} m/sec; then the linear velocity of travel of a water molecule (v) can be given using Darcy's Law as below. Treating the material as a conductive sediment means that it is not strictly necessary to correct for effective porosity (Fetter 2001), but this can be done to enhance the worst case situation which would then have the effect of speeding flow.

$$v = -\frac{K}{\eta_e} \times \frac{\delta h}{\delta l} \text{ (m/sec)}$$

Thus for the site, on substitution:

$$v = -\ (7.5 \times 10^{-6} X\ 0.05/0.4)\ (m/sec)$$

That is:

$$v \approx 9.4 \times 10^{-7}\ m/sec \quad \text{(the negative flow sign can be ignored)}$$

Which means, that for the absolute worst case:

- *In 100 days^ water will travel approximately 8.1 m*
- *In 1 year water will travel approximately 29.6 m*
- *For water to travel 100 m will take approximately 3.4 years.*

^ The 100 days travel time is consistent with detailed analyses (Dent 2002) that show that after this time the risk from bacterial or viral infection which might have been percolated in the soil or groundwater, is insignificant.

In reality, flow in the unsaturated zone – that is, as in the site soils, is not linear, and regular; even if it was only ultimately connected with interflow, or perched watertables, its direction would initially be curvilinear under advection flow conditions as it seeks to recharge groundwater, and it would be strongly influenced by soil inhomogeneities. The mathematical analysis of such situations is considerably imprecise and is initially handled by use of the Richard's Equation. That methodology takes into account the volumetric water content of the soil pores (akin to effective porosity assuming full saturation) plus other aspects effecting the site like rainfall events and infiltration rates, seasonality, depth of plant roots and type of vegetation. To proceed further on this matter would require an extensive gathering of additional site information and climatic data, and be very time-consuming and costly with only a marginal benefit. The outcome is likely to produce results one to three orders of magnitude slower (i.e. less conducive to flow) than the present analysis and is considered beyond what is necessary for evaluation of the site.

Soil water percolation at the site – generally - is considered to be well within acceptable criteria for sanitary flow – that is, a minimum 100 travel time days from a grave and before leaving the cemetery boundary or entering possible drainage pathways (Dent, 2002).

PERCHED WATER IN PIT 7

After a substantial amount of excavation of Pit 7 had occurred, to a level (about 2.65 m) normally below expected interment depths at the site, perched groundwater was struck. The soil conditions here are different to elsewhere on the site; they are much more clayey and this facies change has prevented downward groundwater percolation over an unknown distance. The feature is associated with the lowest drainage point on the central drainage line and likely the infill of a sinkhole.

The presence of the groundwater and the very damp soil and surface conditions (noticeably lush vegetation present) at this part of the site suggest that general drainage here is retarded. This is an area where site overland flows are ponded and the circumstances suggest that the surface water is retarded in its journey into the soil and away from the site.

Figure 14 illustrates the effect of the water ingress into the pit (Appendix C) but there are insufficient measurements to permit calculation of percolation rates here. When first struck the groundwater entered very quickly on about 3 levels down to about 3.0 m, and at some time overnight the water level in the pit stabilised at a level about 0.09 m above where it was first encountered. This is a small rise indicating that the perched table zone is confined.

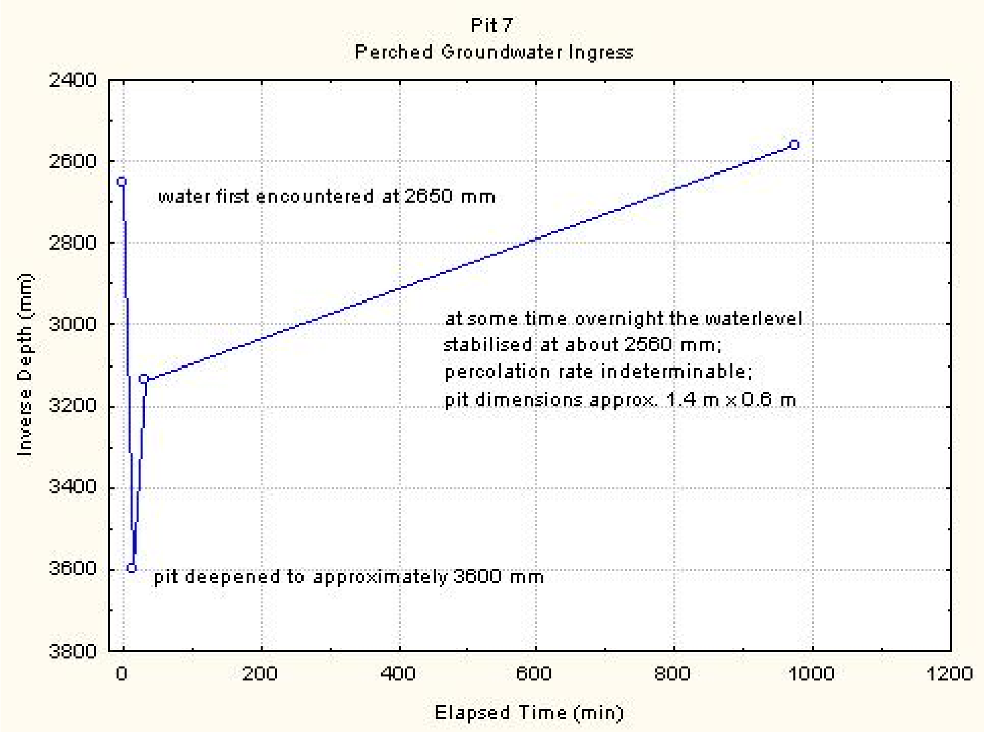


Figure 14: Water Ingress in Pit 7

FORMALDEHYDE

The chemical formaldehyde (systematic name – methanal, molecular formula - CH_20) is often discussed in the context of cemeteries and their development. The natural chemical is a clear gas with a pungent odour at standard temperature and pressure; in the present context it is usually considered in its form when dissolved in water. The discussions and considerations are usually controversial and often over-emotive. In the cemetery context, formaldehyde is used as a preservative for deceased remains (generally used in one of two ways – arterial or full visceral) and is sometimes also present in the resins and paints of made-timber coffins and caskets.

Formaldehyde is readily dissolved in water up to about 55 % by weight, and is also soluble in alcohols and other polar substances, but is most common as 'formalin' which is a water-based solution of about 30 – 40 % by weight. When in water it undergoes a range of reactions like hydration (usually to form a glycol of formula $CH_2(OH)_2$ sometimes called 'methylene glycol') and polymerization; consequently most of it will change its form and this is likely to be more common where it is in low concentrations.

Formaldehyde is ubiquitous in the environment; both from natural degradation processes of vegetation (combustion and oxidation) and from oxidation of volatile organic compounds of many kinds (including phyto-oxidation); as well as from anthropogenic sources like fuel combustion (including poorly running motor vehicles), industrial processes, resinous construction materials.

Formaldehyde is also considered to be ubiquitous in almost all living organisms e.g. as an intermediate metabolite, and also from processes of respiration and is common in surface water in small amounts. It is present in rainwater up to 1-2 mg/kg (i.e. about 1 ppm). In humans it is breathed-in daily in different amounts depending whether the person is mostly outdoors or indoors (higher amounts) and their level of exposure to fires, decaying vegetation, furnishings that give off the gas, and whether they smoke. Humans typically also ingest small amounts daily in their food. The body breaks down formaldehyde in the human to methanoic (formic) acid and then ultimately to carbon dioxide and water.

The degradation processes of formaldehyde in the natural environment have been extensively, but not completely researched; in particular how it adsorbs to sediment or soil, which specific micro-organisms break it down and in what timeframe, need more study. Because of its molecular nature, formaldehyde is thought to not adsorb strongly to soil particles. Its fate in groundwater has been incompletely studied. But it is known that it breaks down quite quickly in most environments (within 1 to 2 days), e.g. one long pathway reported is up to 40 hours breakdown in seawater. The likely end products are organic acids, carbon dioxide and water. The chemical is very susceptible to bacterial decomposition. Where the formaldehyde molecules will experience long residence time in soils then they are very likely to be degraded quickly and close to where they are released.

There are many written articles and discussions about formaldehyde readily available in libraries and via internet services; these vary greatly in the quality of their discussion and bias of presentation. Comprehensive technical discussions and information are available from sources such as: the environment agency of Canada (Environment Canada 2001), World Health Organisation (WHO 2005), Danish Environmental Protection Agency (Larson 1998).

CEMETERY STUDIES OF FORMALDEHYDE

In respect of cemeteries, this Consultant is aware of only 2 documented studies of formaldehyde in cemetery-related groundwaters. Both of these studies are reported in the Environment Canada (2001) document; they have also been independently assessed: the most widely cited one is by Soo Chan et al., 1996. Neither study is exhaustive, and both involve new approaches and thoughts about the detecting of formaldehyde with respect to cemeteries.

The investigation by Soo Chan et al. sampled groundwaters from six domestic irrigation wells, down hydraulic gradient from, and associated with, municipal cemeteries in Ontario, Canada. The hydrogeology represented was comprised of shallow sandy aquifers with sampling points from 3 to 24 m below ground. It needs to be noted that these kind of hydrogeological conditions are most suitable for this kind of research – that is, deliberately trying to detect formaldehyde in the groundwater. These hydrogeological conditions are markedly different to those at the site – subject of this investigation - which are much less conducive to the transmission of groundwater. Their testing (on duplicate samples) was relative to a very low reporting limit of 20 micrograms/L (i.e. 20 ppb). Their work also included examination for nitrate and some simplistic modelling for likely loads from the decomposing cadavers.

Soo Chan et al. found only one set of samples where the low value of formaldehyde (avg. 0.0230 ppm) was greater than their background test value of 0.0073 ppm. They concluded that cemeteries were not significant contributors of formaldehyde for groundwater. They also noted the commonplace status that formaldehyde has as a chemical breakdown product and commented on how groundwater dilution would work to reduce any possible impact in aquifers.

The other Canadian study by BEAK Consultants (1992), concentrated on looking for formaldehyde in soils, perched and regional watertables within an area of Mount Pleasant Cemetery (Ontario, Canada) where it was reasonably expected that they would find formaldehyde if it was present. The soils were described as sandy-silts, silt till and interbeds of fine and medium sand; with levels of testing at the ppm level (detection level: 10 micrograms/gram for soils, or 0.2 mg/L for groundwater). All their samples returned results below the detection levels.

The BEAK study concluded that there doesn't appear to be an elevated presence of formaldehyde in the soils or groundwaters at the cemetery.

FORMALDEHYDE MODELLING AT THE SITE

Investigations by *emc*^{2} have indicated that common practice in Jamaica with respect to embalming of the deceased is to prepare the body with a cosmetic amount of embalming fluid so as to allow body viewing for a short period of time – several days – after death. In general practice this is not a full visceral embalming, but rather the replacement of a portion of the blood with embalming fluid. After a short time, the casket (the general burial container in use in Jamaica as opposed to a coffin) is closed and interment practices proceed as normal.

The widely published information about the human body indicates that there are between 4.7 and 5 L of blood (about 1.10 imp gal) in the average cadaver. This is about 8 % by weight of the reference man (70 kg) (ICRP 1975).

Investigations by *emc*^{2} have indicated that it is common practice in Jamaica to use embalming fluid with a trade name similar to 'Power 36' or referred to as 'Index 36'; this generally means that this is approximately a 36% formalin solution or that approximately 36% of the solution is formaldehyde. This kind of embalming fluid is readily promoted by supply companies as being a high quality arterial fluid: for cavity embalming, generally fluids with a lower index of about '25', meaning 25% formalin solution, are promoted. About 1–1.5 pt (0.57-0.85 L) of stock fluid (probably made up into a watery solution) are used per body.

It is possible to develop a conceptual percolation model for the embalming fluid – but only representing an extreme position and with many assumptions. The model depends upon the parameters already developed in the discussions concerning percolation. The overview here attempts to indicate the effects of dispersion of the potential contaminant - essentially a volume of formaldehyde-laden blood (up to 5L) from a 2.3m^2 surface (the grave invert) into a larger volume with time. It needs to be stressed that the true effect in the soil will be dependent on true initial loadings, soil mineralogy and textural consistency, moisture conditions, biodegradation effects, time and more. The model parameters used here are those most favourable to the persistence and percolation of formaldehyde. In reality it will disperse and degrade as it percolates in the soils. The deep soils of the site are favourable to the delay of the percolation.

- A representative body (70 kg) with all blood (5L) replaced by embalming fluid made up with 1.5 pt (0.85 L) of 36 index fluid would contain about 307 g of formaldehyde or a concentration of about 61 g/L.
- It is difficult to say how quickly and how much of this formaldehyde is decomposed in the body by its intrinsic bacteria at work during the decomposition process, but presuming the rate is low and slow – then for modelling purposes assume that 55g/L is interred with the body.
- The way in which this chemical is released by the decomposing body is also unknown, but as an extreme example assume the unrealistic situation that all the embalming fluid is instantaneously released all-over the floor of the casket and then immediately reaches the grave invert (floor), where it does not further degrade.
- The area of the excavated grave available is about 7ft x 3.5ft (24.5ft^2) or about 2.3m^2 (2.13 m x 1.07 m) (this is further discussed following).
- For the formaldehyde to enter the environment it dissolves in, or reacts with, the groundwater present either in the grave or in the soils immediately beneath the grave invert. (If it reacts with, or is dissolved in, an excess of water e.g. if the grave was full of water, then its concentration is reduced as it is further diluted.)
- Using the indicative average field moisture content of the site soils (Appendix B results by X-Ray Crystallography Facility, University of West Indies) of 30%, and assuming this is free moisture (which is unlikely), and assuming a typical effective pore space for the soils of 40 %, so that all water is thus available; then for the 1m depth immediately beneath the grave the maximum concentration if the formaldehyde was to instantly occupy this space (which is unlikely) would be: 55 g x 5 per 30% x 2.3 m^2 x 1 m or *about 400 mg/L*.
- Further analysis is now highly speculative:
- It has been shown earlier that the typical saturated soil linear velocity for the site is equivalent to about 8.1m per 100 days. Assuming that further percolation is

essentially within a pillow-like bulb of about 8.1 m radius which encapsulates the grave invert (or volume not fully definable but say of the order of 1000 m^3 – probably much more), then this concentration is diluted into 40% of 1,000,000 L or a volume of 400,000 L; thus giving a maximum possible concentration of about 1 x 10^{-3} mg/L (*0.001 mg/L)* expected after 100 days of the catastrophic formaldehyde release event postulated earlier.

- This is the maximum likely concentration in soil pore water.
- The percolation fronts deriving from any one grave will doubtlessly overlap with others nearby; however, all the available grave spaces will not instantaneously fill. Should there be more than 30% moisture in the soils, or a perched watertable be present, then the concentration will be much more reduced.

Extending the model to 100 bodies, e.g. a possibility following a natural disaster, and assuming that all the deceased are treated the same way, and that they all instantaneously decompose in the same way as the previous, then:

- The space now occupied would be about 270 m^2, a little extra (about 17% more) is consumed for pathways and grave separations. Consequently more soil is present and this aids advection and reduces percolation; that is, further mitigating the movement of formaldehyde.
- The embalming fluid concentrations are the same; at the floor of the graves a concentration of formaldehyde of 120 g/m^3 is now percolated into 30% of the volume roughly 270 m^2 x 8.1 m deep and bulbous at the sides.
- Thus in the 1m of soil below grave floor level, the formaldehyde concentration is about 340 mg/L, and in the soil volume now utilised, using the same concept before of a pillow-like bulb per interment, this gives a maximum final concentration of about: 0.85 x 10^{-3} mg/L (*0.00085 mg/L*) after 100 days.
- This is the maximum likely concentration in soil pore water.
- The increased volume of soil around the interments is now having an effect in reducing the concentration.

The situation described by the 100 interment model is beginning to show some of the effects seen in a real cemetery – particularly at this site. The increasing volume of soil available, where there is no obvious pathway for the formaldehyde to exit the thick soils present, only aids this chemical's mitigation.

In addition, it is quite unreasonable to assume that all the bodies will be:

a) Treated exactly the same – e.g. they will differ in weight, age and condition at burial;

b) They will all decompose at the same rate,

c) They will all be interred in the same timeframe; and

d) Probably (but not necessarily) that they will be interred at different places in the cemetery.

The decomposition product loading is thus spread temporally and spatially. This is the way that a functioning cemetery operates: the aspect of (d) above depending on management practices. In addition to the inhomogeneities of the physical interment conditions, there are many more variables to be considered; for example, the lining of the casket, type of casket, breakdown rates of the casket, the presence of funereal artefacts and clothing, the exact size of the grave void, the nature of the backfill and its compaction, the surface completion of the grave, the depth of interment and whether there is more than one interment in the grave space.

Whole of Cemetery Considerations

In reality, it is possible to have many combinations of the values of the parameters: grave space, interment ratios, depths of burial, size of bodies, masses of caskets/coffins and much more; they are simply sensible values in a model.

Research in the United Kingdom, Germany, Italy, and Australia, as well as other anecdotal evidence, suggests that coffinated remains will essentially decompose to skeletons in about 10 -12 years, and that there will be little of the body or its container left after 50 years in a wide range of soils types and environments. Obviously there are many gross exceptions to these findings (e.g. bones in deserts), but they are useful 'rules of thumb'. Soft tissue, in standard interments, can in extreme environments survive 800 years (in North Germany) or longer if frozen.

The above figures generally apply for temperate or cooler conditions. For tropical settings, the data is more scant but clearly indicates that the decomposition rate for standard interments is much higher and that soft tissue is rapidly decomposed. The natural soil environment is as important as the climate and other factors, and in acidic soils the rates are higher than for alkaline soils. In terms of assisting this understanding; a studied cemetery in South Australia, in semi-arid climate and comprised of alkaline silty soil, has consistently shown virtually nothing left after 100 years (for hundreds of grave spaces exhumed and re-used). In the present case, the site soils are acidic, the climate is tropical.

In a later section of this report, considerations are made for a total cemetery development at the site permitting the interment of up to 3000 sets of remains over 30 years (at a typical rate of 100 per year), including double interments. This is a low rate of interment and the space available is very large.

In the decomposition process the soft tissues yield very quickly, and hence body and embalming fluids are quickly released – say within a couple of weeks of interment, but it is not an instantaneous effect. Thus as bodies are interred, say at the rate of 2 per week, then there is a progressive, but slightly delayed, release of formaldehyde to the grave space; moreover, some bodies will release there fluid more quickly than others. Thus looked at overall, the picture of availability of any formaldehyde left at the floor of the graves is quite irregular and complicated.

If 100 bodies are interred per year (i.e. 2 per week) then any formaldehyde which percolates beyond the individual grave will not be in greater concentration than has already been illustrated for the 100 interment model preceding where it was assumed that all bodies instantaneously released their fluids (that is, not greater than 0.00085 mg/L in the soil pore water).

It is also important to re-iterate that interments in a working cemetery are not always in contiguous spaces. For many reasons the individual interments can be well separated from each other, although it is also true that small sections or rows of grave spaces are filled consecutively. The spatial and temporal patterns are very variable and unique to any cemetery. The aspect of double interments further complicates matters because the second interments in grave spaces are even more irregularly dispersed, and they do not occur at a constant rate within the overall usage pattern of the cemetery.

As cemetery operations proceed, the area of space consumed by grave sites and related access pathways, roads and simple open spaces, increases quite significantly; but again, uniquely for any cemetery. Accordingly, the volume of soil into which any remnant formaldehyde percolates is similarly increasing very substantially. In the case of the present site – a 100-day working volume of soil close to 1000 m^3 is brought into consideration with each interment. Where interments are contiguous then these working volumes overlap and a ‘slug’ or ‘pulse’ type effect might possibly be seen as temporally-related formaldehyde releases make their way into the soil volume. In any case, the maximum likely in-soil concentration established already will apply.

The amount of formaldehyde that might possibly leave the individual grave space is relatively low: its rapid attenuation in the site’s soils will ensure that there is an extremely low risk of it reaching any watertable: the amount of risk is likely to be unquantifiable above background values. The development of the site with attention to interments in permitted areas only, suitable buffer zones and other best-practice protocols, will virtually ensure that any formaldehyde possibly percolating in the soils, for example by shallow groundwater interflows, is likely to biodegrade before reaching the cemetery boundary.

CEMETERY DEVELOPMENT PRACTICES

The developments proposed for the site should be permitted with attention to suitable guidelines consistent with World’s best-practice as discussed in the following. The most important matters from a geoscientific perspective are considered within the context of the nature of the site’s soils – particularly their thickness and composition, and the very considerable depth to any regional watertable. Overall there is a low potential impact of the cemetery. These physical matters mitigate against the likely flow of body decomposition products from the site in any significant concentration and with any direct connection to regional water supply. Accordingly, precise development proposals or conditions of development should be reflective of, and harmonious with, these aspects rather than being necessarily restrictive or disconnected.

The general development of the site, in accordance with the ideas developed herein, is set out in Figure 15.

BURIAL DENSITY

The original development proposals reviewed by this Consultant state that approximately 2.43 ha will be available for burial purposes, and that it is proposed to develop the cemetery at the rate of 100 vaults per 0.2 ha, with a typical vault being 33 in x 92 in – that is, 1.96 m^2; with an indicative development of 3000 vaults. It is not clear how many of these will be doubles or if the 3000 figure included provisioning for this. As such this was a proposed maximum interred space ratio of about 24%, but could be a lot less.

At some time during the approval process, the development conditions were altered and in Permit 2004-09017- EP00157 (under the Natural Resources Conservation Authority Act) the conditions granted for the development state: the same vault load and size as the proposal, but conclude that the development will comprise about 1215 vaults, but does not specify how many of these will be doubles. If 20% of these are doubles, this gives a potential indicative interment load of 1458 bodies. The potential maximum interment space under this scenario is about 10%.

Observations of typical vault construction practices in the district indicate that vaults in nearby churchyards are more likely to be 40 in x 88 in internally, or allowing for the concrete blocks, closer to a typical grave space of 4 ft x 8 ft (or 1.2 m x 2.4 m = 2.88 $m^{2)}$. As such these are consistent with the traditional sizes seen in the rural areas for example of: UK, Australia, USA and Germany, where space is less pressured. The smaller proposed sizes are more consistent with space-pressured sites in cities. However, it should be recognised that the smaller vaults are probably easier to construct, particularly given the floor and capping specifications in the Permit, and hence make sense in that context.

Both the originally proposed, and subsequently 'Permitted', burial densities are very low; considerably below the capacity of the site, and may potentially limit the usefulness of the site for future generations. However, the quantification in the proposal and permit can be questioned.

In accordance with the considerations herein, approximately 29000 m^2 (2.9 ha) is suitable for development for interments. Consistent with the idea that vault containment of interred remains is neither necessary nor desirable (discussed following), then it would be very satisfactory if grave spaces were created on the basis of 2.88 m^2 per grave. There are useful practical reasons for this sizing when no block walls are included, to wit, that in most soils the whole space is never totally excavated leaving a suitable earth wall between the actual burials.

The remaining issue in this context is how quickly will the dedicated space be consumed. If, on average, 2 interments per week occur – or 100 per year, then the primary space permits about 12.5 years' operation, and with double interments – about 15 years. In terms of the original proposal, about 30 years.

BUFFER ZONES

The use of a buffer zone to separate a waste disposal activity (and many other high-impact activities, for example quarrying) from other urban land use has been widely practised since the 1960s and nowadays is generally incorporated as a planning tool before approvals are given. In the case of cemeteries the use of this tool is quite specific and is not related to hiding the activity, controlling dust or noise. Rather the buffer zones on cemeteries are an essential aid in the attenuation of any decomposition products leaving the cemetery boundary.

In the buffer zone a further effort should be made to attenuate groundwater flow by removing it naturally, that is, through evapotranspiration with suitable vegetation – one of the forms of phytoremediation. The planting of deep-rooting, locally adapted, native vegetation is likely to provide the best type of planting, although there are many cases where other species have proved effective in a particular use.

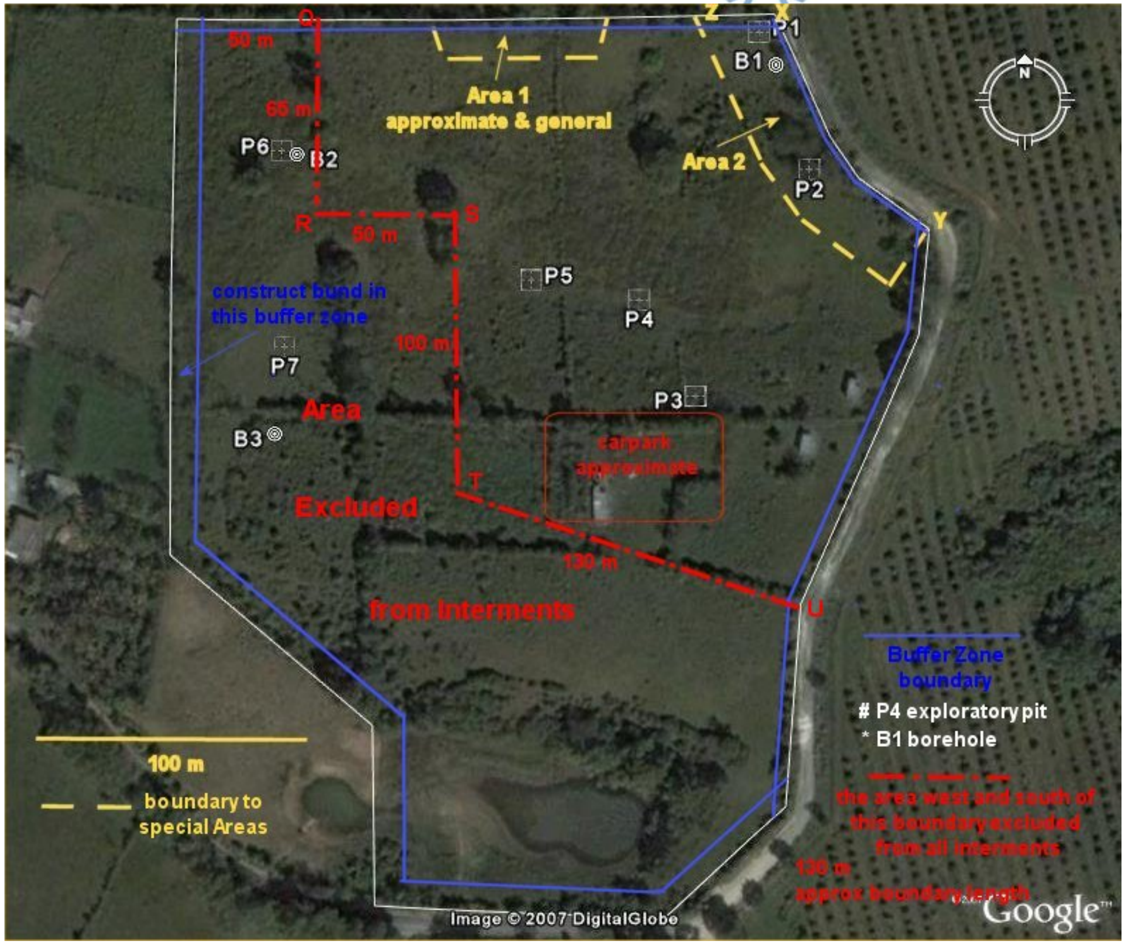


Figure 15: Site Development Plan

It is considered that the following buffer zone allowances should be provided at the site:

- 5m wide parallel to the north boundary (and will include part of Area 1 – see following);
- At least 2.5 m wide parallel to the north-east boundary (taking in part of Area 2 – see following) but enlarging on the lower eastern slopes of the site to 5 m;
- 10m wide parallel to all other boundaries.

Where buffer zones intersect the widest dimension shall always apply, Figure 15.

The buffer zones may include general service tracks and access routes, but generally these should be completed so as to be free-draining, except, if necessary on main entrance roads. Buffer zones may be used for the scattering of cremated remains (as provided below) and small shelter and decorative/commemorative structures, however, they are not generally the place for administrative and service buildings, or significant parking areas.

Cremated remains can be disposed by scattering or shallow burial in buffer zones provided that they are at least 2 m from any boundary and that it is not possible for them to be washed past the boundary by surface runoff. Hence small drainage works, bunds, spoon drains or the like may be necessary to prevent the slopewash in the designated areas. At this site, cremated remains should not be disposed of in any buffer zones within the Area Excluded from Interments (see later).

On the site's main western boundary, there is the potential for runoff and leachate from nearby farming operations to come onto the site. If such a situation were to occur it may unnecessarily prejudice the cemetery operations and contribute deleterious water-born chemistries to the site. Accordingly an impermeable bund of heaped earth, not less than 1 m in height, should be built adjacent, and parallel to the boundary, within the buffer zone here. Any waters trapped against the bund should be able to freely drain to the front pond on the adjacent property.

DEVELOPMENT AREA AND RELATED MATTERS

At the time of the fieldwork in early 2007 the site had been considerably altered from its previous farmland status. There had been cutting adjacent to the north boundary and commencement of vault construction (Area 1 on Figure 15); as well as, levelling and construction of a carpark on the central spur of the site; possible filling in parts of the lower central drainage line and elsewhere.

Area 1 is partly within the proposed buffer zone for the north boundary. The cutting here is considered too steep for longer term stability and should be remediated by either refilling the slope toe or benching (including by filling), or else benching with the aid of free-draining retaining walls e.g. crib-block type. The constructed vaults could be completed and finished as planned or abandoned and infilled. Surface drainage needs to be led from above and behind here, well away from the steep slopes and towards the central drainage line.

Area 2 (defined following) – the highest land of the site and adjacent to the north-east boundary, is problematic for use without further shaping and construction. An important issue to be taken into account here is the potential for the development of shallow groundwater flow systems which may emerge further down the side slopes of the central drainage line; this happens if the invert of graves is too elevated relative to the steepness of the slope. Site reshaping which takes account of this need could be achieved by careful use of crib-block (or similar) retaining walls and moderately wide benching; backfilling behind the walls with free-draining adsorptive materials e.g. clay loam and charcoal would be beneficial.

Area 2 definition: For simplicity this area is defined as a polygon being 25 m perpendicular at all points from the north-east boundary between reference marks X and Y on Figure 15, and 15 m perpendicular to the northern boundary between reference marks X and Z, where mark Z represents a small obvious drainage depression at the northern boundary approximately 25 m from X, so that all the part adjacent to the northern boundary is likely to be fully encompassed in the former, but if necessary at intersections, all wider dimensions have priority.

The space available for interments at the site is controlled by the Buffer Zone and exclusions areas. A large amount of the western and southern parts of the site are unsuitable for interments because of their association with the topographical lowest areas and the need to provide for natural surface drainage as well as ponding of stormwater runoff. The area is shown on Figure 15 and is defined as follows, provided also that boundary lengths may need to be adjusted for practical purposes only apparent on site, but to be done so as to not generally reduce the excluded area.

Area Excluded from Interments definition: All the area west and south of a line starting at mark Q 50 m from the north-west corner along the northern boundary, a line parallel to the western boundary for 65 m (to mark R), then perpendicularly for 50 m to the east and parallel with the northern boundary (to mark S), then perpendicularly south for 100 m parallel with the western boundary (to mark T), then on an angle to join the external south-east boundary (at mark U) where the second boundary inflexion point from the southern boundary road occurs – a distance of about 130 m.

FLOODING

During the Community investigations by *emc*[2] the concern that the lower part of the site, or perhaps the site generally, floods, also presumably in major storm events, was raised. Information to hand suggests, that prior to the initial site development works now seen, the roadway at the southern edge of the site (parochial road to Knockalva) did have some flooding in storm events associated with the low point and infilled sinkhole here. The Community has been particularly mindful of the major climatic event in June 1979 (discussed elsewhere) wherein extensive parts of the region were flooded.

It is understood that this southernmost low point has now been considerably modified and that the flooding issue has eased during the last couple of years. This low point on the site must ultimately take the greatest concentration of surface flows if they continue from the other depressed area to the north (in the vicinity of Pit 7 – previously discussed) (see also Figure 1 site plan and earlier discussions on site geomorphology).

It is very difficult to conceive that flooding except associated with these low points can occur at any time: ultimately if surface flood levels rose the water would flow over the road and well to the south east or leave the north-east corner of the site at about 630 ft. Thus, any interments with inverts above these levels is extremely unlikely to be flooded. This matter has been addressed in the proposed Site Development Plan (Figure 15) wherein all low-lying areas are excluded from interments.

Generally speaking, the grave when backfilled presents a pathway for easier infiltration of surface water into the soil. In times of intense storm or high surface flows or over-irrigation, the grave backfill soils become saturated, and free water can accumulate in the grave (the bucket effect). This impounded water takes time to drain, and if associated with early-time decomposition products, facilitates the movement of these into the soils, but at the same time the excess water generally dilutes them. Excess water in the grave may possibly foster the survival of pathogens. Proper management of graves at the surface requires that any settlement of the backfilled grave soils be continually topped-up, and that where possible the land be reshaped to shed surface runoff.

The other problems for cemeteries associated with flooding are scour - if the flooding causing erosion of banks, or removes grave backfill; and if excess infiltrated floodwater flows back out graves onto the surface - this can assist in spreading pathogens. The latter situation is mainly of concern on floodplains (not at the site), whilst the former situation usually relates to clear regional drainage pathways such as creeks, rivers, channels, and may also apply at lake and sea shorelines (again not this site).

With attention to development in designated areas, flooding is not expected to be an issue related to interments at the site.

INTERMENT CONTAINMENT

The current development proposals for the site include a provision that interments shall be within concrete block vaults founded on concrete strip footings and that these must have a 4 inch thick concrete floor.

The use of vault burials is not a primary method of interment in the World. It seems to be a practice more related to a few European cemeteries with difficult development conditions, the desires of some cultural groups, and some practices in the USA. It is occasionally utilised in Australia as standard practice by some minor religio-cultural groups or in unstable ground. This Consultant’s experiences, as on-site inspections, research and wide correspondence, suggest, that where possible, interments should be intimately connected to the cemetery soils. The primary reasons behind this are:

- The fostering of natural attenuation in the decomposition process; this is achieved through seepage, mixing and transport of decomposition products with groundwater, and bacterial action: a process directly comparable to many types of municipal landfills;
- The conceptualisation of a rapid decomposition of the remains back to the primary elements frequently associated with human existence – “a dust to dust” concept;
- The prevention of flooding and water retention in the vaults: sealed construction restricts the outward flow of decomposition products encouraging remanent bacterial survival and concentration of decomposition fluids. Very few below-ground vault and/or crypt constructions remain free of groundwater seepage and at some time they act as a restrictive bucket for these fluids.
- Reduction of costs in the development and operation of the cemetery (and presumably this is passed along to the consumer);

- Allowance for variation of interment practices: e.g. one versus two or three interments per grave without extensive modification being required; or ready enlargement of certain sections of cemeteries devoted to burying persons of certain religious affiliations; or changes in the orientation of interments; and other reasons.

Even in locations where side walls are desirable for support during the interment process, floors of these structures are usually left open. Thus groundwater and decomposition products pass into the environment where they can be naturally attenuated. The above arguments also hold true for the use of non-biodegradable plastic coffin liners, or coffins, or body-bags, and to the extent possible for sanitary dealing with the deceased, the use of plastic sheet/liner materials should be restricted.

In other cemetery developments where the interment level is created by raising the ground level with filling, some unique concrete cell-like constructions with open floors have been utilised. In such cases the drainage of the grave fluids (groundwater and decomposing remains) is initially directed through a drainage layer of appropriate gravel. This ensures an even drainage process applies where the natural or prepared site might otherwise have been unsuitable. In some other cemeteries, organic materials and/or sand are placed on the grave floor prior to interment to assist in drainage, odour control and seepage control (from neighbouring graves). This aspect can be artificially enhanced and the development of a floor lining e.g. a 50:50 mixture of 10 – 20 mm diameter gravel and like-sized charcoal pieces, about 70 mm thick could be emplaced before interment. This could help to ensure an even grave floor, thus assisting drainage, and possibly assisting some adsorption and forced attenuation of short-term decomposition products (e.g. fluid containing formaldehyde, liquefying fats and proteins).

The experience of the site investigation by pitting at this site (see Appendix A) has indicated that the soils are quite suitable to be left unsupported for the time taken to dig a grave and then inter remains – of the order of a few days. At this site there is the additional aspect of the tropical climate. It is considered that it would be beneficial to encourage rapid decomposition and incorporation of decomposition products into the soil matrix; and this would be best done by direct earth-contact interments.

SEISMIC DESIGN CONSIDERATIONS

Another Community concern detailed by *emc*^{2} is the matter of the seismic stability of the proposed burial vaults. The concerns correctly related to the potential release of body fluids and vault contents to the soil as a result of vault cracking. The seismic hazard report prepared by Wiggins-Grandison (2006) suggests that at some time, structural damage to concrete block masonry is likely. It is difficult to predict the extent of potential damage in below-ground vaults, but it is likely to include cracking, minor displacement of blocks, possible warping of the concrete floor and loss of seal against fluid ingress or egress.

Given that most concrete structures of the kind envisaged permit fluid movement in and out anyway, then it makes sense to not be prescriptive in their use or design. Once interment has occurred it is generally of little concern if the wall structures collapse except in the case where they are to be used for above-ground masonry construction, that is memorialisation or monumental construction. The free flow of fluids to the environment is to be encouraged, as discussed above. The surface finish of the grave areas should be maintained against settlement in any case and so fostered to shed surface run-off wherever possible.

DISPOSAL OF CREMATED REMAINS

The chemical composition of cremated remains is sparsely documented and not fully known; they are also predicted to vary widely between different populations and geographic regions. The essential components are a calcium phosphate base rich in metals. It is the likely concentration of any deleterious trace metals that may cause a pollution issue. However, if disposed of in a suitable soil, and in a manner so as to prevent their removal from the cemetery by slopewash, they are not expected to cause a pollution issue. Soils rich in clays are advantageous for cremated remains' disposal because of the adsorption of the metal ions to the clays.

The interment of ashes should take place below the subsoil – at about a depth of 1m, and needs to be at least 1 m above any level to which a watertable can rise, and be in soil not affected by ephemeral or perched watertables. The interments should not take place into unlined chambers constructed in fractured rock. However ashes can also be scattered at the surface without major concerns.

High density scattering, at a rate say of about 25 times the standard burial space density ought to be possible without leading to an extreme accumulation of metals in the near surface. This has been modeled for an area of 25m2 (Dent 2002). In addition the extra loads of calcium and phosphorus, possible if all of these elements from the average set of remains are included, are shown.

The evaluation needs to be set against a 'pollution' standard for contaminated land. Using the Australian background values for contaminated sites and the 1983 Netherlands A values for triggering clean-up events (ANZECC 1992), it has been shown that at the modeled level (about 250 sets of remains per 25 m2) do not suggest a significant problem for the metals – Zn, Cu, Pb, Cd, Ni and Cr. However, at higher densities of scattering the elements zinc and cadmium begin to be of concern.

The cremated remains can be disposed of in buffer zones, but ideally should be at least 2.5 m from any boundary; they need to be prevented from washing off the site by drainage ditches and furrows or similar.

CONCLUSIONS AND FINDINGS

1. The site comprising cleared agricultural land now mostly covered with grasses and partially developed for the proposed cemetery, is located on a hillside with various side-slopes from 2º-22º. A thick colluvial and residual regolith lies above a slightly to moderately karstic limestone bedrock. Most site slopes are less than 9º. There is no bedrock outcrop on, or in the vicinity of, the site.
2. No groundwater discharges onto the surface of the site. The regional groundwater piezometric surface ('watertable') is likely to be at least 25 m below the average site surface, but deeper under the topographically higher points.
3. It is estimated that over 90% of the site's surface drainage remains on the site in normal climatic conditions. In the most severe hurricane conditions water may overtop the front pond area and the small divide in the NW corner.

4. Generally off-site surface water will not enter the site, except for minor amounts from the road ridge adjacent to the eastern boundary, and severe slopewash from the adjoining western property.

5. Karst erosional features are present as general landform expressions and it is likely that small collapsed, but infilled dolines occupy the topographic lows of the site.
6. The thick regolith layer comprising uniform, yellow-brown and red-yellow-brown cobbly, pebbly silty clays, loams and clayey silts and clays is present over the whole site, and overlays a weathered limestone of unknown petrology. The soil layer is at least 8 m thick in the topographically high areas and of the order of 12 – 13 m thick in lower parts.
7. Mineralogically and texturally the soils are quite uniform over most of the site. The mineral suite evidenced comprises those typical of well-weathered rocks – but not necessarily limestone, and primarily includes quartz, nacrite, dickite, kaolinite and some illite, with other minor clays including some unexpected ones of a metamorphic origin.
8. The soils contain variable amounts of charcoal, and large amounts of manganese. The latter is readily apparent as coatings on larger gravel and smaller sand-sized particles and coated particles. The disposition of manganese throughout the site is irregular; its presence apart from helping to characterise the soils, likely indicates deposition from very slow-moving percolating waters at irregular times. The quantity of charcoal is insignificant.
9. The soils remain stable on pit sides when excavated, or even left to stand with water in their base; and are not expected to exhibit significant shrink or swell properties. Percolation tests to assess the site soils' drainage characteristics were made. The results again suggest a considerable uniformity of soil properties and behaviour and imply an overall saturated hydraulic conductivity of about 4 x 10-6 m/sec, which is entirely consistent with the descriptions of the soils. These data imply that the lateral 100-day groundwater percolation rate is not more than 8.1 m.
10. Groundwater, as a series of perched watertables over a depth of about 500 mm, was observed in the exploratory pit (Pit 7) in the topographic lows, together with a similar occurrence, albeit at least twice as deep, in the nearby borehole (BH3). The nature of the landform and the clearly wetter soil conditions where these explorations were made (evidenced by lush vegetation) suggests that this is not an unexpected or unusual finding. It would be expected that surface water ponds here and slowly infiltrates the ground or is evaporated. The presence of a significant clay facies in Pit 7 exacerbates the slow water drainage here.
11. The issue of the existence and nature of the regional groundwater surface has not been resolved by this investigation or research. A bore drilled by Community interests (BH #3) adjacent to the site suggests that groundwater occurs here in the bedrock at about 17 m depth. This borehole location is well below the general site level, and when this is considered together with the geology, it is concluded that under the site the groundwater could be somewhat deeper – maybe 25m or more, else the local hydraulic gradient would be excessively steep.
12. There are incomplete understandings of the regional hydrogeological setting. A combination of information analyses, site and context interpretation and the measured evidence suggest that:

a) irrespective of the formal identification of the limestone bedrock, that it may host a confined to partially confined aquifer;

b) groundwater flow is within the bedrock, but the hydraulic gradient appears very low;

c) regional recharge is through bedrock exposure or discrete pathways (maybe unfilled dolines), not diffuse land surface;

d) there is no obvious connection between the site groundwater system, or even the immediate district's groundwater system, and Shettlewood Spring;

e) on the basis of the most simplistic groundwater model for potential movement between the site and Shettlewood Spring (a model of potentially limited applicability), groundwater once it had percolated through the site's soils would take over 140 years to make the journey.

13. The whole of the Lots 47 and 48 together are considered to comprise the proposed development site which is better treated as one entity free of artificial land boundaries and previous developmental design. A large part of the site, up to 2.9 ha, is suitable for development as a cemetery with negligible risk to surface- or ground- waters. Interments have not commenced at the site. The ratio of interred space to open space within the permissible area could be reduced. On the basis of large grave spaces (2.4 m x 1.2 m), 20% doubles and 20% access provision, there is sufficient space for the proposed and/or permitted number of grave spaces.

14. Some existing site development works are considered to be unsatisfactory for future development aspects and require modification and/or rectification; particularly areas adjacent to the north and east boundaries. Parts of the site – generally to the west and south and the topographically lower areas - are unsuitable for interments. The site should host buffer zones around the whole perimeter.

15. Consideration has been given to the risks from natural hazards, particularly seismic shaking and flood events. The former is considered to impose no risk but might lead to isolated settlement of grave fill; the latter is not a hazard if development is conducted in ways to mitigate against excess water infiltration to graves and erosion; graves need to be kept filled, that is topped-up after settlement, and the competed surface designed to shed water. No slope or soil instability was observed on the site.

16. Consideration has been given to the potential risk of formaldehyde, deriving from use as a component of embalming fluid, leaching into the soils and/or possibly entering the regional groundwater system. The decay rate of formaldehyde solution in the ground is unknown but is considered to be fast, with little effective chemical remaining after a very short time. The nature of the site soils - in terms of composition, texture, uniformity and thickness - should ensure very slow percolation of any body fluids containing, or water which will mobilise, formaldehyde. Groundwater seepage has been demonstrated to be very slow, with a conservative 100-day travel time of at least 8.1 m. Any chemical remaining intact after this time will be very widely attenuated (dispersed) a process that will continue as it moves (if it does) in the environment. The overall cemetery interment loadings and rates of loading are low and the large volume of site-soil

available to ‘process’ moving formaldehyde (if it does) will ensure its rapid decomposition and keep it well on-site.

17. Many options for interment style are suitable and sustainable at the site. These include use of earthen graves, vaults, crypts and mausoleums. There is no justification for insisting that bottom-sealed vaults be used. There is no reason to preclude burials without coffins/caskets. The decomposition processes in cemeteries function best if associated with natural attenuation.
18. The site, where designated as permissible, is suitable to receive cremated remains either scattered, buried in or out of urns, or placed in memorial walls or structures.

RECOMMENDATIONS

There are no overall geoscientific impediments to the development of a cemetery at the site, but there are relevant matters that need to be considered. The proposed development should be allowed with attention to the following matters which are summarised here and discussed in detail within the report. The site for these purposes is regarded as the sum of Lots 47 and 48 together.

BUFFER ZONES

Buffer zones from 2.5 – 10 m width should be developed parallel and adjacent to all boundaries. These are shown in Figure 15. Buffer zones should be planted out with deep-rooting locally acclimatised vegetation. The buffer zone on the western boundary should be supplemented with an earthen bund to prevent slopewash from the neighbouring property.

DEVELOPMENT AREA

Generally the western and southern parts of the site should be excluded from interments. This is shown on Figure 15 and generally described as all the area comprising the topographic lowland of the site. A developable area of about 2.9 ha remains.

INTERMENT DEPTH AND COMPLETION

The uppermost interment should be covered with 1 m of well compacted sandy clay, clayey sand, clay loam, or loamy clay style soils. Site soils sieved of cobbles and generally pieces larger than 30 mm gravel are suitable for the primary filling, but probably not for the surface finishing.

The minimum invert level for various numbers of interments should be:

- For one – 1.5m (about 5 ft);
- For two – 2.3m (about 7.5 ft);
- For three – 3m (about 10 ft).

A minimum compacted soil layer of 0.3 m (about 1 ft) should be made to fully cover between each interment.

In order to have 3 interments in a grave the immediate site soils need to be quite deep. At this site a minimum soil depth of 11 m would be satisfactory.

Wherever possible, graves should be completed at the surface so that they shed surface water. Settled grave-fill should be topped-up regularly.

SPACE PROVISION AND INTERMENT METHOD

Consideration should be given to creating grave spaces for earthen burial on the basis of 2.88 m^2 per grave. It is not necessary to have burials in concrete block vaults. If, however, this method of interment is retained, then the existent sizes specified are satisfactory. In any case the floor of concrete vaults should be left earthen to allow free drainage of decomposition products and infiltrated groundwater.

Consideration should be given to the provision of a drainage and sorptive layer on the invert base of earthen-floored graves. This could be comprised of a 50:50 mixture of 10 – 20 mm diameter gravel and like-sized charcoal pieces, about 70 mm thick.

SITE RECTIFICATION WORKS

In the Areas delineated 1 and 2 on Figure 15 certain restoration works or careful construction and development works should be implemented. Attention needs to be paid at all times to direction of surface drainage away from restorative and new work and into recognised natural drainage lines.

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APPENDIX A: PIT LOGS

PIT LOGS: PROPOSED CEMETERY AT BURNT GROUND

Summary logs of 7 exploration pits excavated by backhoe with 600 mm bucket on Friday, Feb 1, 2007.

Logged: all by Boyd B Dent

Site weather: fine, warm, humid isolated small white clouds; increasing heat and humidity from midday.

Samples were collected (in duplicate) as indicated, and subjected to a range of tests by others, and which are summarised in Appendix B.

Percolation tests, described separately, were conducted in Pits 1, 3, 4, and 6; while groundwater ingress into Pit 7 was also recorded.

Locations are shown approximately in Figure 15

Pit 1

Location: at approximately highest point on site, adjacent to NE corner and eastern boundary.

Commenced: 09:40 hr

Avg. surface dimensions: 2500 mm x 700 mm

Avg. dimensions at base: 1300 mm x 600 mm

Representative depth: 3600 mm; floor is not even

Disposition: orthogonal to slope which is very steep here (about 22º generally to the WSW) (Fig A.1)

Hard digging, quite dry, no sign of groundwater, soils very uniform and only moderately damp from about 1m, more pedal towards the base giving the impression of sandier material. Below a minor grassy and topsoil layer not more than about 100 mm thick; soil comprises a uniform profile of, yellow-brown, occasionally red-brown and beige, cobbly, pebbly clayey silt and silty clays; no developed horizons. Appears to be rich in charcoal within the lowest-most 1m (Fig A.2). Probable stains of manganese on various cobbles; cobbles and pebbles are well-rounded of mostly red-brown chert with clayey or calcareous coatings or combinations of these. No sign of lensing or banding within the profile.

Percolation test conducted commencing after excavation of Pit 2 (Fig A.3). The pit shows no sign of collapse and except for the topsoil and uppermost rim material is stable, and remains open overnight. On re-inspection at 09:08 hr the following day some water from the percolation test remained in the bottom; no sign of collapse.

Samples:

- from base
- from 1m above base

- from 2m above base

Figure A.1: Pit 1 Located at north-eastern corner

Figure A.2: Pit 1 charcoal in lowest-most 1m

Figure A.3: Pit 1 after percolation test commences

Pit 2

Location: adjacent to eastern boundary, downslope to the south from Pit 1

Commenced: 10:50 hr

Avg. surface dimensions: 1856 mm x 950 mm

Representative depth: 3250 - 3400 mm

Disposition: parallel to slope which is moderately steep here (about 9.5º generally to the WSW; 7º to SSE) (Fig A.4)

Dry, no sign of groundwater, soils very uniform and only moderately damp from about 1m, noticeably harder digging in lowest-most 1m. Below a minor grassy and topsoil layer not more than about 100 mm thick; soil comprises a uniform profile of, yellow-brown, occasionally red-brown and beige, cobbly, pebbly clayey silt and silty clays; no developed horizons. A great deal of black staining (possibly manganese deposits) and/or charcoal is present in the lower half (to 1.7 m from base) and particularly associated with chert cobbles (Fig A.5). No sign of lensing or banding within the profile.

No percolation test; pit immediately backfilled.

Samples:

- 2-1 from base
- 2-2 from 1m above base
- 2-3 from 2m above base

Figure A.4: Pit 2 Location adjacent to north-eastern boundary – gentle slopes

Figure A.5: Pit 2 First appearance of black staining

Pit 3

Location: adjacent to upper end of made carpark towards the centre of the site

Commenced: 12:05 hr

Avg. surface dimensions: 2600 mm x 700 mm

Avg. dimensions at base: 1400 mm x 600 mm

Representative depth: 3150 mm

Disposition: roughly parallel to slope which is gentle here (about 7.0º generally to the N; 2º to W) (Fig A.6)

Dry, no sign of groundwater, soils uniform with noticeably much less charcoal and black staining. There were minor lateral variations in the distribution of cobbles, pebbles and more pedal (sandier) sections but no distinct stratigraphic variation or lensing. Below a minor grassy and topsoil layer not more than about 150 mm thick; soil comprises a mostly uniform profile of, yellow-brown and beige, cobbly, pebbly clayey silt and silty clays; no developed horizons.

Percolation test conducted commencing immediately after excavation of pit (Fig A.7). The pit shows no sign of collapse and except for the topsoil and uppermost rim material is stable, and remains open overnight. On re-inspection at 09:04 hr the following day some water from the percolation test remained in the bottom; no sign of collapse.

Samples:

- 3-1 from base
- 3-2 from 1m above base
- 3-3 from 2m above base

Figure A.6: Pit 3 general location.

Figure A.7: Pit 3 water immediately after emplacement for percolation test; also shows test measuring point

Pit 4

Location: in the main drainage gully generally north of Pit 3

Commenced: not recorded; complete before 13:55 hr

Avg. surface dimensions: 1850 mm x 600 mm

Avg. dimensions at base: 1400 mm x 600 mm

Representative depth: 3350 mm

Disposition: roughly parallel to slope which is gentle here (about 2.0º generally to the W) (Fig A.8)

Soils here noticeably host fewer chert cobbles and pebbles; the profile is damper, but there is no sign of groundwater. The excavation is stable with no sign of collapse or spillage. At 1200 mm depth there is evidence of a former land surface – tree roots, charcoal and darker soils (Fig A.9). Overlying is likely to be colluvium. Otherwise the soil is uniform and comprised of yellow-brown pebbly clayey silt and silty clays with occasional cobbles.

A percolation test was run after logging this pit. At 09:03 hr the following morning there was still water in the pit; no sign of collapse.

Samples:

- 4-1 from base
- 4-2 from 1 m above base

- 4-3 from 2 m above base

Figure A.8: Pit 4 location in major drainage area; soils noticeably damper

Figure A.9: Pit 4 former land surface at 1200 mm, darker soil and tree roots

Pit 5

Location: towards the middle of the central drainage pathway, downhill from Pit 4

Commenced: 14:12 hr

Avg. surface dimensions: 2300 mm x 700 mm

Representative depth: 3050 mm

Disposition: roughly parallel to slope which is gentle here (about 10º generally to the W).

The location of this pit suggests that it might continue the features seen above in Pit 4; however, it was noticeably drier, more difficult to excavate, with an overlying topsoil (dark brown 0.6-0.7 m thick) which may be related to filling. Below the topsoil layer, the soil was noticeably more cobbly than in other parts and comprised a yellow-brown, pebbly cobbly clay and /or silty clay. Chert cobbles and nodules frequently covered with what appears to be carbonate (?) coatings. There was a marked absence of black deposits and/or charcoal; no stratigraphic variations seen in pit walls, but this difficult excavation was terminated on a cobbly chert layer.

No percolation testing; pit immediately backfilled.

Samples:

- 5-1 from base
- 5-2 from 1 m above base
- 5-3 from 2 m above base

Pit 6

Location: towards the NW corner, atop small surface divide, but low in site topography

Commenced: 14:55 hr

Avg. surface dimensions: 2100 mm x 650 mm

Avg. dimensions at base: 1800 mm x 600 mm

Representative depth: 2030 mm

Disposition: roughly perpendicular to slope which is gentle here (about 2.0º generally to the SW) (Fig A.10)

Very difficult to excavate from the outset, many cherty cobbles close to surface (Fig A.11).

Soil is dry, no evidence of groundwater. Below a layer of brown topsoil about 60 mm thick, soil comprises yellow-brown, very cobbly pebbly silty clays and clayey silts. No evidence of stratification but evidence of lensing cherty bands. Excavation halted on very hard cobbly cherty lens.

Percolation test immediately following excavation. The excavation is very stable no signs of collapse or spalling. At 08:52 hr the following morning the pit was found to be fully drained of test water and a muddy sludge remained on the bottom.

Samples:

- 6-1 from base
- 6-2 from 1m above base

Figure A.10: Pit 6 General location

Figure A.11: Pit 6 Large chert cobble

Figure A.12: Pit 6 completed on hard cobbly layer

Pit 7

Location: close to western boundary in lowest-most part of central drainage area.

Commenced: 15:55 hr

Avg. surface dimensions: 2600 mm x 650 mm (variable)

Representative depth: complete at about 3600 mm with irregular floor; excavation suspended due to water inflow; this also prevented logging the pit form within – observations made at surface.

Disposition: parallel to drainage path, surface is almost flat (slopes about 0.5º – 1.0º generally to the SW) (Fig A.13)

The ground is damper here; no free surface water evident but ground hosts lush vegetation. Excavation is relatively easy, the ground is noticeably soft and quite different to elsewhere on site. Relatively thick topsoil to about 200 mm, underlain by a series of horizons including:

- From about 0.4–1.2 m damp composite beige and grey clay;
- From about 1.2–1.85 m damp, composite yellow-brown and grey clays, sometimes mottled, some pebbles;
- From about 1.85–2.65 m occasionally mottled red-brown and grey clays with minor pebbles of chalky limestone;
- From about 2.65–3.60 m mottled yellow-brown clay with some chalky nodules.

Perched groundwater was encountered at about 2.65 m and flowed in from several parts of the pit (Fig A.14). Further excavation encountered several more horizontal flow paths within the next 500 mm approximately (Fig A.15); with water flowing-in rapidly at 3.0 m. Below this the soil was relatively dry. Excavation terminated at about 3600 mm due to difficulties of excavation in flooded pit.

Except for the topsoil (which became irregularly shaped) the pit did not cave of slough during the excavation. When inspected the following day at 08:49 hr there had been no collapse of the sides and the waterlevel had stabilised at 2560 mm

The pit was left open overnight and the height to which the incoming groundwater rose, was monitored (reported in Appendix C).

Samples were taken from the spoil heap or excavator bucket from material representing the various horizons seen (Fig A.16):

- 7-1 from 0.4-1.2 m

- 7-2 from 1.2–1.85m
- 7-3 from 1.85 – 2.65 m
- 7-4 from 2.65 – 3.6 m

Figure A.13: Pit 7 General location

Figure A.14 Pit 7 groundwater inflow about 2.65 m

Figure A.15: Pit 7 Groundwater inflow continues as perched watertables struck within next 0.5 m; water level rises

Figure A.16: Pit 7 Mottled yellow-brown and grey clay excavated at base of pit below perched watertables

APPENDIX B: SUMMARY OF SOIL TEST DATA

SUMMARY OF SOIL PROPERTIES

PART A: Data from Pitting Investigations in 2007

Sample #	sample description (1)	colour (Munsell)	field moisture content (wt %) (2)	field moisture content (wt %) (3)	pH (units) (4)	EC (µS/cm)	presence Mn (mg/kg)	whole mineralogy (5)	grading (wt %) (6)				UCSC (7)
									G	S	M	C	
1-1	Yellow brown clay with hard white substances throughout	10YR 4/6	30.9	48.3	4.27	71.2	2937	quartz, nacrite, kaolinite, dickite, illite (?), clinochlore	53	20	27	nd	GM
1-2	Yellow brown clay with hard white substances throughout	10YR 5/6	27.4	41.0	4.17	14.6	1778	quartz, nacrite, kaolinite, dickite, illite (?), clinochlore	56	?	?	nd	
1-3	Yellow brown clay with hard white substances throughout	10YR 5/6	29.0	nd	nd	nd	nd	quartz, nacrite, kaolinite, dickite, illite, clinochlore	nd	nd	nd	nd	
2-1	Dark brown clay with small black and small white particles throughout	10YR 3/6	27.0	39.2	4.09	9.87	8793	quartz, nacrite, kaolinite, dickite, illite (?), clinochlore	?	?	43	nd	
2-2	Dark brown with small black particles throughout.	10YR 4/6	37.8	36.3	4.19	11.4	5988	quartz, nacrite, kaolinite, dickite, illite (?), clinochlore	?	?	?	nd	

2-3	Yellow brown clay with soft white substances throughout	10YR 6/8	31.3	37.4	4.19	21.3	440	quartz, nacrite, kaolinite, dickite, illite (?)	?	?	?	nd	
3-1	Soft grey material coated brownish yellow.	1 for Gley 8/10Y	31.7	38.3	4.06	8.02	254	quartz, nacrite, kaolinite, dickite, illite (?)	43	8	49	nd	GM
3-2	Yellow brown clay with hard white substances throughout	10YR 5/8	26.6	31.9	4.70	24.7	1674	quartz, nacrite, kaolinite, dickite, illite (?)	59	?	?	nd	
3-3	Dark brown clay with few white particles	10YR 3/6	30.2	nd	nd	nd	nd	greenalite, goethite, quartz	nd	nd	nd	nd	
4-1	Yellowish clay with few white particles	10YR 5/8	27.2	37.6	4.50	3.51	197	quartz, nacrite, kaolinite, dickite, illite (?)	?	?	76	nd	
4-2	Yellowish brown clay with few white particles	10YR 5/8	27.5	37.8	5.80	29.2	261	quartz, nacrite, kaolinite, dickite, illite (?)	?	?	76	nd	
4-3	Dark brown clay with few small black and small white particles throughout	10YR 3/4	30.4	31.5	5.80	22.7	5087	quartz, nacrite, kaolinite, dickite, illite (?)	?	?	69	nd	
5-1	Pale brownish yellow clay with soft grey particles and a few white particles	10YR 6/6	28.0	40.6	4.30	6.95	43.24	quartz, nacrite, kaolinite, dickite, illite (?)	24	?	?	nd	

	throughout												
5-2	Brownish yellow clay with hard white substances throughout	10YR 6/8	27.5	25.9	4.29	41.2	149.6	quartz, nacrite, kaolinite, dickite, illite (?)	15	27	58	nd	MH
5-3	Brownish yellow clay with hard white substances throughout	10YR 5/8	26.7	37.3	4.40	11.6	58.3	quartz, nacrite, kaolinite, dickite, illite (?)	13	?	?	nd	
6-1	Yellowish brown with hard white substances throughout	10YR 5/8	29.8	46.6	4.31	3.39	487	quartz, nacrite, kaolinite, dickite, illite (?)	43	10	47	nd	GM
6-2	Yellowish brown with hard white substances throughout	10YR 5/8	30.4	43.6	4.41	31.8	nd	quartz, nacrite, kaolinite, dickite, illite (?)	?	?	?	nd	
7-1	Light yellowish clay	2.5Y 6/3	27.5	nd	4.33	7.45	24.5	quartz, nacrite, kaolinite, dickite	?	?	82	nd	
7-2	Yellow clay	2.5Y 6/8	35.0	50.9	5.42	12.8	nd	quartz, nacrite, kaolinite, dickite, illite (?)	?	?	?	nd	
7-3	Grey clay coated with yellow particles. A few hard white substances throughout	1 for Gley 7/10Y	30.5	nd	4.44	15.0	27.1	quartz, nacrite, kaolinite, dickite	?	?	?	nd	

7-4	Grey clay coated with pale yellow clay.	2.5Y 6/2	32.6	nd	nd	nd	nd	quartz, nacrite, kaolinite, dickite	nd	nd	nd	nd	

Key to Symbols and Notes:

nd = test not done or not reported

1) soil description, occasionally abbreviated, provided by X-Ray Crystallography Facility, University of West Indies
2) soil moisture wt % measured by X-Ray Crystallography Facility, University of West Indies
3) soil moisture wt % measured by the Mines and Geological Survey Division Laboratory.
4) pH using a $CaCl_2$ solution was not measured
5) measurements were made of the floatables wt% wherein they may have represented loose charcoal – however none was found; gross and clay mineralogy has been assessed by XRD and is reported separately
6) G = gravel, S = sand, M = mud/silt – combined measurement, C = clay % not determined
7) Unified Soil System Classification developed from grading information

PART B: Data from Borehole Samples in February 2007

Sample #	Gross description (1)	Depth sampled (m)	Unified Soil Classification System				SPT (N blows) (total)	LL	PI (4)
			% gravel	% sand	% fines	UCS (2) (3)			
Borehole 1									
1-1	Light brown gravel and organic clay	0.8 - 1.2	24	30	36	GC-SC fines MH-OH	8, 10 (18)	64.2	20.7
1-2	Light brown sandy organic clay with some gravel	1.5 – 2.0	19	30	51	MH	12, 13 (25)	66.0	19.2

1-3	Cream brown sandy gravel	2.3 – 2.7	39	30	31	GM/GC – SM/SC	17, 24 (41)	nd	nd
1-7	Light brown clayey sandy gravel	7.6 – 8.1	48	22	30	GC fines MH-OH	48, 51 (99)	72.4	27.4

Borehole 2									
2-1	Light brown gravely silty sand	0.8-1.2	21	58	21	SM fines MH	10, 11 (21)	55.1	15.7
2-3	Light brown sandy silt with trace gravel	2.25 – 2.7	nd	nd	nd	MH	19, 28 (47)	57.8	13.0
2-5	Light brown silty sand with some gravel	4.6 – 5.0	20	54	26	SM	27, 32 (59)	nd	nd
2-6	Light brown sand and gravel with some clay	6.1 – 6.6	36	48	16	SM Fines MH-OH	31, 34 (65)	61.2	15.2

Borehole 3									
3-1	Light brown silty sand with trace gravel	0.8 – 1.2	6	62	32	SM	4, 5 (9)	nd	nd
3-2	Light brown clayey silt with some sand	1.5 – 2. 0	nd	nd	nd	SM fines MH	4, 5 (9)	55.8	16.4
3-8	Light brown silty gravely sand	9.1 – 9.6	24	42	34	SM	26, 30 (56)	nd	nd

Notes:

1) The descriptions given by Hill Betty (Engineers) Ltd. In their report are open to interpretation – see separate report. It seems likely that the drilling and sampling techniques used may have favoured collection of sand and gravel over fines (silt and clay). Their report for example, has no mention of the substantial cobbles embedded in the upper site soils at least. The gravel is likewise not described lithologically so its origins and relationships are not immediately clear.

2) This classification is sometimes a re-interpretation of the results reported. In the Unified Soil Classification Scheme, particles larger than 75 mm diameter are ignored

3) A great deal of fine material is reported as 'organic' in tests but not in borelogs: the reason for or nature of the 'organic' descriptor is not explained

4) Field moisture content – not reported

APPENDIX C: PERCOLATION TEST DATA

Percolation Test Results, Feb 1 2007: PIT #1

		Time Frames	time interval	elapsed time min	sq root time	Depth to water / m	height of water	cum % ht lost	L lost in time step	cum L equiv	new area available for infiltration	effective area available for infiltration	cumL/m2	cumL/m2/min
Start depth to base:	3.780 m		0	0	0	3.605	0.175	0	0	0	1.445	1.445	0	0
Start depth to water:	3.605 m	5mins	5	5	2.24	3.615	0.165	5.71	7.83	7.8	1.362	1.404	5.58	1.115
Base of pit (LxW):	1.3 m x 0.6 m	5mins	5	10	3.16	3.63	0.15	14.29	11.74	19.6	1.239	1.301	15.05	1.505
Initial Water Volume:	137 L; minor spillage	5mins	5	15	3.87	3.63	0.15	14.29	0	19.6	1.239	1.301	15.05	1.003
Start time	10:04 hr	10mins	10	25	5	3.632	0.148	15.43	1.57	21.1	1.222	1.23	17.18	0.687
Effective initial water depth	0.175 m	10mins	10	35	5.92	3.633	0.147	16	0.78	21.9	1.214	1.218	18	0.514
Effective initial infiltratable area	1.445 m2	10mins	10	45	6.71	3.633	0.147	16	0	21.9	1.214	1.218	18	0.4
		15mins	15	60	7.75	3.634	0.146	16.57	0.78	22.7	1.206	1.21	18.77	0.313
		15mins	15	75	8.66	3.634	0.146	16.57	0	22.7	1.206	1.21	18.77	0.25
		15mins	15	90	9.49	3.634	0.146	16.57	0	22.7	1.206	1.21	18.77	0.209

30mins	30	120	10.95	3.65	0.13	25.71	12.53	35.2	1.073	1.139	30.92	0.258
30mins	30	150	12.25	3.66	0.12	31.43	7.83	43.1	0.991	1.032	41.72	0.278
30mins	30	180	13.42	3.67	0.11	37.14	7.83	50.9	0.908	0.95	53.59	0.298
1hr	60	240	15.49	3.705	0.075	57.14	27.4	78.3	0.619	0.764	102.5	0.427
1hr	60	300	17.32	3.709	0.071	59.43	3.13	81.4	0.586	0.603	135.07	0.45
1hr	60	360	18.97	3.712	0.068	61.14	2.35	83.8	0.561	0.574	145.97	0.405
9:08am next day	926	1286	35.86	3.725	0.055	68.57	10.18	93.9	0.454	0.508	184.99	0.144

Percolation Test Results, Feb 1 2007: PIT #3

		Time Frames	time interval min	elapsed time min	sq root time	Depth to water / m	height of water	cum % ht lost	L lost in time step	cum L equiv	new area available for infiltration	effective area available for infiltration	cumL/m2	cumL/m2/min
Start depth to base:	3.150 m		0	0	0	2.82	0.33	0	0	0	2.16	2.16	0	0
Start depth to water:	2.820 m	5mins	5	5	2.24	2.821	0.329	0.3	1.28	1.3	2.153	2.157	0.59	0.118
Base of pit (LxW):	1.4m x 0.6m	5mins	5	10	3.16	2.825	0.325	1.52	5.1	6.4	2.127	2.14	2.98	0.298
Initial Water Volume:	421 L	5mins	5	15	3.87	2.828	0.322	2.42	3.83	10.2	2.108	2.117	4.82	0.321
Start time	12:53 hr	10mins	10	25	5	2.829	0.321	2.73	1.28	11.5	2.101	2.104	5.46	0.218
Effective initial water depth	0.330 m	10mins	10	35	5.92	2.829	0.321	2.73	0	11.5	2.101	2.104	5.46	0.156

Effective initial infiltratable area	2.160 m2	10mins	10	45	6.71	2.829	0.321	2.73	0	11.5	2.101	2.104	5.46	0.121
		15mins	15	60	7.75	2.832	0.318	3.64	3.83	15.3	2.081	2.091	7.32	0.122
		15mins	15	75	8.66	2.835	0.315	4.55	3.83	19.1	2.062	2.072	9.24	0.123
		15mins	15	90	9.49	2.84	0.31	6.06	6.38	25.5	2.029	2.045	12.47	0.139
		30mins	30	120	10.95	2.84	0.31	6.06	0	25.5	2.029	2.045	12.47	0.104
		30mins	30	150	12.25	2.844	0.306	7.27	5.1	30.6	2.003	2.016	15.19	0.101
		30mins	30	180	13.42	2.849	0.301	8.79	6.38	37	1.97	1.987	18.62	0.103
		1hr	60	240	15.49	2.852	0.298	9.7	3.83	40.8	1.951	1.96	20.82	0.087
		1hr	60	300	17.32	2.855	0.295	10.61	3.83	44.7	1.931	1.941	23.01	0.077
		9:04am next day	911	1211	34.8	2.86	0.29	12.12	6.38	51	1.898	1.915	26.65	0.022

Percolation Test Results, Feb 1 2007: PIT #4

		Time Frames		elapsed time min	sq root time	Depth to water / m	height of water	cum % ht lost	L lost in time step	cum L equiv	new area available for infiltration	effective area available for infiltration	cumL/m2	c
Start depth to base:	3.360 m													
Start depth to water:	3.080 m		0	0	0	3.08	0.28	0	0	0	1.92	1.92	0	
Base of pit (LxW):	1.4 m x 0.6 m	5mins	5	5	2.24	3.08	0.28	0	0	0	1.92	1.92	0	
Initial Water Volume:	200 L	5mins	5	10	3.16	3.081	0.279	0.36	0.71	0.7	1.913	1.917	0.37	
Start time	13:55 hr	5mins	5	15	3.87	3.085	0.275	1.79	2.86	3.6	1.886	1.899	1.88	
Effective initial water depth	0.280 m	10mins	10	25	5	3.085	0.275	1.79	0	3.6	1.886	1.899	1.88	
Effective initial infiltratable area	1.920 m2	10mins	10	35	5.92	3.09	0.27	3.57	3.57	7.1	1.851	1.869	3.82	
		10mins	10	45	6.71	3.09	0.27	3.57	0	7.1	1.851	1.869	3.82	
		15mins	15	60	7.75	3.091	0.269	3.93	0.71	7.9	1.845	1.848	4.25	
		15mins	15	75	8.66	3.092	0.268	4.29	0.71	8.6	1.838	1.841	4.66	
		15mins	15	90	9.49	3.095	0.265	5.36	2.14	10.7	1.817	1.827	5.86	
		30mins	30	120	10.95	3.1	0.26	7.14	3.57	14.3	1.783	1.8	7.94	
		30mins	30	150	12.25	3.103	0.257	8.21	2.14	16.4	1.762	1.773	9.27	
		30mins	30	180	13.42	3.19	0.17	39.29	62.14	78.6	1.166	1.464	53.67	
		1hr	60	240	15.49	3.201	0.159	43.21	7.86	86.4	1.09	1.128	76.62	

9:03am next day	898	1138	33.73	3.19	0.17	39.29	-7.86	78.6	1.166	1.128	69.66

Percolation Test Results, Feb 1 2007: PIT #6

Start depth to base:	2.310 m	**Time Frames**		**elapsed time min**	**sq root time**	**Depth to water / m**	**height of water**	**cum % ht lost**	**L lost in time step**	**cum L equiv**	**new area available for infiltration**	**effective area available for infiltration**	**cumL/m2**
Start depth to water:	2.080 m		0	0	0	2.08	0.23	0	0	0	1.654	1.654	0
Base of pit (LxW):	1.3 m x 0.6 m	5mins	5	5	2.24	2.08	0.23	0	0	0	1.654	1.654	0
Initial Water Volume:	200 L	5mins	5	10	3.16	2.086	0.224	2.61	5.22	5.2	1.611	1.632	3.2
Start time	15:44 hr	5mins	5	15	3.87	2.086	0.224	2.61	0	5.2	1.611	1.632	3.2
Effective initial water depth	0.230 m	10mins	10	25	5	2.089	0.221	3.91	2.61	7.8	1.589	1.6	4.89
Effective initial infiltratable area	1.654 m2	10mins	10	35	5.92	2.097	0.213	7.39	6.96	14.8	1.532	1.561	9.47
		10mins	10	45	6.71	2.114	0.196	14.78	14.78	29.6	1.409	1.471	20.1
		15mins	15	60	7.75	2.132	0.178	22.61	15.65	45.2	1.28	1.345	33.62
		15mins	15	75	8.66	2.136	0.174	24.35	3.48	48.7	1.251	1.266	38.47
		15mins	15	90	9.49	2.14	0.17	26.09	3.48	52.2	1.223	1.237	42.18
		30mins	30	120	10.95	2.149	0.161	30	7.83	60	1.158	1.19	50.41
		30mins	30	150	12.25	2.161	0.149	35.22	10.43	70.4	1.072	1.115	63.19
		30mins	30	180	13.42	2.175	0.135	41.3	12.17	82.6	0.971	1.021	80.9
		8:52am next day	848	1028	32.06	2.31 dry	0	100	117.39	200	0	0.485	412.02

Percolation Test Results, Feb 1 2007: PIT #7 - Influent Rise

		Time	Depth to water	elapsed time min	
Start depth to base:	3.60 m approx				
Depth before water:	water seeps in at 2.65m, 2.75m and 3.00m	16.01	2650	0	first encountered
Base of pit (LxW):	1.4 x 0.6 estimate	16.15 approx	3600 approx	14	pit deepened
Initial Water Volume:	influent	16:33	3135 mm	32	
		next day 08:49	2560 mm	976	