Comhairle Contae Thiobraid Árann
Tipperary County Council

Tier 2 Hydrogeological Assessment

of the

Proposed Fethard Burial Ground Extension

Fethard, Co. Tipperary

August 2018

Note: refer to Appendix 4 to read the initial (May 2017) Tier 1 investigation

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On behalf of

Tipperary County Council

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EXECUTIVE SUMMARY

Tipperary County Council (TCC) has retained Hidrigeolaíocht Uí Chonaire Teoranta to carry out a Tier 2 hydrogeological assessment of the proposed Fethard burial ground extension area. The site is located on the northern edge of Fethard town on the east side of the R689 road to Killenaule, 1.1 km north of the town centre and adjacent to the existing Calvary Burial Ground.

Intrusive site investigations including the installation of four groundwater monitoring wells onsite, and 12 months of baseline groundwater level and quality monitoring were carried out for the Tier 2 assessment between March 2017 and June 2018.

The hydrogeological investigations showed that the site is underlain by unsaturated sandy, gravelly SILT subsoil over weathered to slightly weathered limestone bedrock over competent limestone bedrock which contains deep preferential groundwater flow paths at depths of 67 mbgl and 82 m to 98 mbgl. The limestone bedrock underlying the site is a Regionally Important Aquifer - Karst (Diffuse) (Rk_d).

A source-pathway-receptor site conceptual model identified the groundwater in the bedrock aquifer underlying the site, and the Rivers Clashawley and Killenaule 450 m to 1 km south and southeast of the site, as receptors that could potentially be impacted by contaminants mobilised from the proposed burials by groundwater recharge infiltrating through site. The proposed burials in the extension area were taken to be the contaminant source in the conceptual model. The contaminant migration pathway comprised the mobilisation of contaminants deriving from the decomposition of buried remains by dissolution in infiltrating groundwater recharge, vertical migration of the contaminants in the recharge down through the unsaturated subsoil to the bedrock watertable, followed by further vertical groundwater flow down through the saturated bedrock to discharge into the deep preferential groundwater flow paths. The vertical groundwater flow discharging into the preferential groundwater flow paths mixes with lateral groundwater flow from upgradient in the preferential flow path and then migrates laterally along the preferential pathway to discharge to the surface water receptors.

The predicted ammonia concentration at the base of the unsaturated subsoil and in the saturated bedrock prior to discharge into the preferential flow paths at 67 mbgl and 82 m to 98 mbgl is 0.94 mg/l as N. This exceeds the SI 366 of 2016 threshold value of 0.175 mg/l as N for ammonia in groundwater.

The groundwater resource in the saturated bedrock beneath the site and above the deep preferential groundwater flow paths is considered to be negligible and there are no other receptors except the groundwater itself between the base of the site and the deep preferential flow paths, along the vertical pathway. As such, the risk associated with the ammonia concentration of 0.94 mg/l in the vertical groundwater flow beneath the site is considered to be low.

The quantitative risk assessment shows that the predicted concentrations of contaminants of concern are all attenuated to less than their respective SI 366 of 2016 threshold values by the time the infiltrating recharge mixes with the upgradient groundwater flow in the deep preferential groundwater flow paths.

The quantitative risk assessment also showed that the concentration of each of the contaminants of concern associated with the proposed burials would be attenuated to below their respective Surface Water Regulations (SI 272 of 2009) threshold by the time the groundwater flowing beneath the proposed site reached the zone of groundwater discharge to Rivers Clashawley and Killenaule downgradient of the site.

Given the outcome of the quantitative risk assessment, the potential risk associated with double burials at the proposed burial ground extension site is considered to be low. As such, in line with a Tier 2 assessment under the UK guidance (EA, 2004); it is considered that the proposed development should be acceptable from a hydrogeological perspective.

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1 Introduction

Tipperary County Council (TCC) has retained Hidrigeolaíocht Uí Chonaire Teoranta to carry out a Tier 2 hydrogeological assessment of the proposed Fethard burial ground extension area. The location of the site is shown in Figure 1.

2 Methodology

The Tier 2 hydrogeological assessment has been prepared in line with the requirements of a Tier 2 assessment under the UK Environment Agency Guidance Document "*Assessing the Groundwater Pollution Potential of Cemetery Developments*" (EA, 2004). The approach to the Tier 2 assessment is detailed in Table 1.

Table 1. Tier 2 Hydrogeological Assessment

Note: 1st Investigation was a Tier1 study (refer Appndx 4)

Desk Study	Confirm scope and extent of Tier 2 intrusive investigations
Site Investigation	Carry out walkover survey of site drainage: • Identify any indicators of poor drainage as part of assessment of subsoil permeability, groundwater discharge zones, and potential flooding areas • Identify any karst features present in limestone study areas
	Carry out well survey within 500 m of site • Take account of known wells from OSi maps, GSI databases, local knowledge from TCC and other stakeholders
	Supervise Drilling of boreholes and monitoring well installation • Direct Drilling contractor • Log borehole geology in line with BS5930 • Log groundwater behaviour during drilling • Adapt borehole design to site specific setting and geology &/or groundwater conditions encountered during drilling. • Direct installation of the monitoring well.
	Direct topographic survey of Site investigation locations: • New monitoring wells & surface water monitoring locations • Wells, springs, etc. identified during well survey • Any other relevant features from drainage survey
	Carry out quarterly water quality sampling at groundwater and surface water locations over a 12 month period
	Carry out falling head slug test to determine the aquifer hydraulic properties (i.e. hydraulic conductivity) at each monitoring well
	Carry out monthly groundwater level monitoring over a 12 month period with at least one occasion after heavy rainfall
Reporting	Prepare preliminary report in line with the following: • Process and analyse all data from Tier 2 site investigation and integrate with the data from Phase 1 investigations • Prepare Tier 2 report in line with Guidance Documents ○ Including recommendations on suitability of site

The desk study to confirm the scope and extent of the Tier 2 site investigation was carried out in February 2017.

The well survey of the area of the area within 500m of the proposed extension area was carried out on 21 March 2017. One borehole was identified within the well survey area. The well identified was a disused private industrial water supply borehole on the grounds of the Ribworld food processing plant, located approximately 125 m south of the site. The borehole was drilled in 2012 and the driller's log for the borehole is shown in Appendix 1.

Four groundwater monitoring boreholes named BH01, BH02 Shallow, BH02 Deep and BH03 were drilled on the proposed extension area between 15 March and 21 March 2017. BH02 Shallow and BH02 Deep are a nested pair of piezometers with the BH02 Shallow targeting groundwater (if any) in the shallow weathered bedrock, and BH02 Deep targeting groundwater in the deeper competent bedrock. The drilling works were carried out by the drilling contractor JS Drilling, The Quay, Thomastown, Co. Kilkenny, R95Y3F1. The drilling works were carried out under the supervision of a chartered hydrogeologist from Hidrigeolaíocht Uí Chonaire Teoranta (HUCT). The monitoring well design at each location was carried out by the hydrogeologist. The geology and well construction at each location were logged by the hydrogeologist.

The locations of monitoring wells BH01, BH02 and BH03, and of the Ribworld Borehole are shown on Figure 2. The borehole log for each monitoring well is shown in Appendix 1.

The topographical survey of the elevation in metres above Ordnance Datum (mAOD) and Irish National Grid (ING) Coordinates of the reference datum at each monitoring location was carried out on 25 May 2018 by Control Surveys Ltd., Innovation Works, National Technology Park, Plassey, Castletroy, Limerick, V94 V4KK. The survey results are shown in Table 2.

Monthly groundwater level monitoring was carried out at monitoring wells BH01, BH02 Shallow, BH02 Deep and BH03, and at the Ribworld Borehole between July 2017 and June 2018. The groundwater level monitoring data are shown in Table 3.

Falling and rising head slug tests to determine aquifer hydraulic conductivity were carried out at monitoring wells BH01, BH02 Deep and BH03 on 18 July 2017. There was insufficient groundwater present in BH02 Shallow to carry out slug tests on the borehole. The results of the tests are shown in Table 3. Details of the testing are shown in Appendix 2.

Quarterly groundwater quality monitoring was carried out at monitoring wells BH01, BH02 Shallow, BH02 Deep and BH03 between September 2017 and June 2018. The groundwater quality samples were analysed by the INAB accredited laboratory Southern Scientific Services Ltd., Unit B5, 4 Park Business Centre, Farranfore, Co. Kerry, Ireland, V93 E220. The field water quality parameters pH, electrical conductivity (EC) and temperature were measured onsite. EC and pH probes were calibrated on site using approved calibration standard solutions, and field measurements were taken from sample groundwater collected using a bailer. The groundwater quality monitoring data are shown in Table 4. The Certificates of Analysis for analyses by Southern Scientific Services Ltd. are provided in Appendix 3.

The desk study carried out prior to the Tier 2 site investigation determined that there are no surface water courses in the immediate vicinity of the proposed extension area. Following discussions with Tipperary County Council it was decided that no surface water quality monitoring would be carried out during the Tier 2 site investigation.

The Tier 2 hydrogeological assessment builds upon the Tier 1 site investigation carried out in December 2016, which included the excavation of five trial pits, TP01 to TP05, across the site area. Details of the Tier 1 site investigation are provided in the Tier 1 report (HUCT 2017), which is shown in Appendix 4. The locations of trial pits TP01 to TP05 are shown on Figure 2. The trial pit logs are shown in Appendix 4.

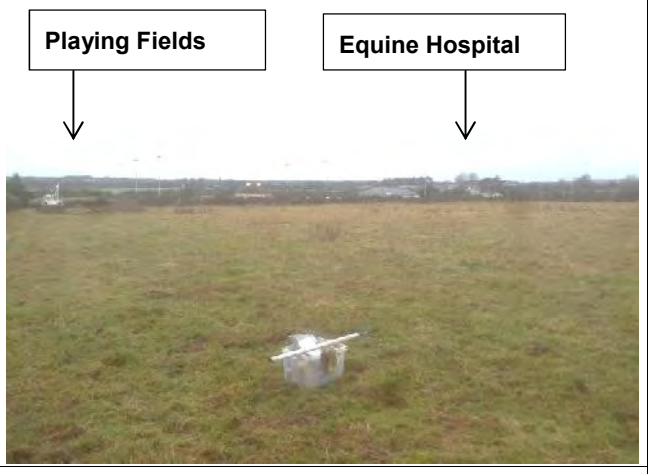
3 Location, site description and planned cemetery

The site is located on the northern edge of Fethard town on the east side of the R689 road to Killenaule, 1.1 km north of the town centre (Figure 1). The proposed extension area occupies part of an agricultural field adjacent to the north side of the existing cemetery. The proposed area is approximately 105 m long east to west and 40 m wide north to south, aligned with the existing cemetery boundary. The proposed area is set back 20 m from the adjacent R689 road and will be accessed from the existing cemetery. Photos of the proposed extension area are shown below.

The site is designed to accommodate approximately 616 double burial plots, as shown in Figure 2. At a burial rate of 16 per annum the life of the site will be 77 years. Maximum burial depth is expected to be 2.4 mbgl to the base of the burial.

Photo 1. Panoramic view northeast across site (boundary with existing cemetery on RHS of photo; boundary with R689 on LHS of photo)

Photo 2. View west across site along existing cemetery boundary, showing TP02 with TP01 and playing fields



3. View northwest across site, showing TP01 with playing fields and equine hospital in the distance

Photo 5. View southeast across TP04 with TP03 and northeast corner of existing cemetery beyond.

Photo 6. Typical subsoil profile, as represented by TP04

4 Environmental Setting

4.1 Hydrometeorology

Hydrometeorological data were obtained from Met Eireann. Met Éireann currently reference 1981 to 2010 as the baseline period for day-to-day weather and climate comparisons.

Annual rainfall: 884 mm. This is the average annual rainfall (1981-2010) for the 1 km grid square node immediately adjacent to the proposed extension area. The rainfall data have been obtained from the Met Eireann 1981 to 2010 Rainfall 1 km grid data (Walsh, 2012).

This compares to 950 mm average annual rainfall for the Cashel (Ballinamona) weather station for the period 1961 to 1990, and located 9 km west of Fethard (Fitzgerald and Forrestal, 1996).

Annual evapotranspiration losses: *516* mm. The nearest synoptic weather stations to the site that have annual average potential evapotranspiration data available for the period 1981 to 2010 are Kilkenny (35 km northeast), Cork Airport (89 km southwest), and Shannon Airport (87 km northwest). Average potential evapotranspiration (P.E.) at the three stations between 1981 and 2010 was 533 mm, 523 mm and 573 mm respectively (Personal Communication A. Murphy, 07 January 2013). Taking the average of the three stations suggests an annual average PE for the Fethard area of approximately 543 mm. Actual evapotranspiration (A.E.) is then estimated as 95% of P.E., to allow for seasonal soil moisture deficits giving an Actual Evapotranspiration of 516 mm.

Annual Effective Rainfall: *388* mm. The annual effective rainfall is calculated by subtracting actual evapotranspiration from rainfall.

4.2 Topography, surface hydrology, land use

The site is at an elevation of about 80 mOD (Figure 1). Kilknockan Hill rises to 130 mOD, 800 m north of the site. A ridge extends south-southwest from the hill towards Fethard, with the ridgeline sloping gently to about 60 mOD at the Clashawley River in the town centre. The site lies on the western side of the ridge, close to the ridgeline. In the vicinity of the site the ridgetop and flank is broad with a gentle west-southwest slope.

The land in the vicinity of the site is well drained, with no agricultural land drains or vegetative indicators of poor drainage. There are no streams in the vicinity of the site. A storm water drain runs along the western side of the R689 road adjacent to the site. The Clashawley River flows south towards Fethard approximately 1 km west of the site. The river turns east in the town centre. The Killenaule Stream flows south 350 m east of the site on the opposite side of the Kilknockan ridge and joins the Clashawley River on the eastern side of Fethard.

Landuse to the north and east of the site is agricultural, with a mix of pasture for silage and grazing. The existing cemetery forms the southern site boundary. A Tipperary Co. Co. depot and the Ribworld food processing industry are present south of the burial ground in turn. On the west side of the R689 there are various playing pitches. To the north of the playing pitches there is an equine hospital. Domestic residences also occur along the road.

4.3 Bedrock geology

The site and surrounding area are underlain by Dinantian Pure Bedded Limestone (DPBL) rock types.

The GSI Bedrock Seamless Bedrock 1:100k Mapping - Bedrock Rock Units map indicates that the site is underlain by bedrock from the Ballyadams Formation (Figure 3). This bedrock type comprises crinoidal wackestone/packstone limestone. The Ballyadams Formation limestones are overlain by limestones of the Clogrenan Formation, which form rockhead in the areas of high ground to the north and south of Fethard and the Clashawley River. The Clogrenan Formation limestones comprise cherty, muddy, calcarenitic limestone.

The bedrock strata are folded in the area. GSI mapping indicates the presence of a syncline axis (trough of a bedrock fold) running west-east to the south of Fethard. Bedrock strata to the north of the axis are expected to dip south towards the axis, such that the top surface of older strata get deeper moving south along the line of dip. That the older strata of the Ballyadams formation come to the rock surface on the north side of the axis, through the overlying Clogrenan Formation, indicates additional sub-folding within the overall southern dip towards the axis. This complex folding increases the likelihood of fractured rock occurring in the area. . The Mapped bedrock dip and strike data show strata dipping south at between 20^{O} to 30^{O} in the Ballyadams and Clogrenan limestones to north and south of the site. To the east of the site there is a record showing a northerly dip at 35^{O}.

Dark-grey, weathered and fractured, micrite, limestone bedrock over competent limestone bedrock was encountered below the site at monitoring wells BH01, BH02 Shallow, BH02 Deep and BH03.

4.4 Subsoils and soil geology

The subsoils at the site and across the surrounding area are predominantly mapped as glacial till (boulder clay) derived mainly from limestone bedrock. The subsoils beneath the Fethard urban area are mapped as Made Ground. The subsoils flanking the course of the Clashawley and Killenaule Rivers are mapped as alluvium. Bedrock outcrop occurs in places at the peak of areas of higher ground, such as at the top of Kilknockaun Hill to the north-northeast of the site. GSI subsoil permeability mapping indicates that the limestone till subsoils are classified as having moderate permeability.

Trial pits TP01 to TP05 encountered subsoil deposits of sandy gravelly SILT to depths of up to 4.0 mbgl. Boulders up 0.5 m in diameter were excavated from the trial pits. All of the trial pits were stable during excavation. All of the trial pits were dry during excavation and no mottling of the subsoil was observed.

In boreholes BH01, BH02 Shallow, BH02 Deep and BH03 the subsoils comprised sandy gravelly SILT to between 4.55 to 5.6 mbgl.

The ground conditions encountered in the intrusive investigations are summarised in Table 2. Borehole logs are provided in Appendix 1. Trial pit logs and photos of the trial pits are provided in Appendix 4.

The soils at the site and across the surrounding areas outside the Fethard urban area are mapped as deep well-drained soils. The soils across the Fethard urban area town centre are mapped as Made Ground.

4.5 Groundwater vulnerability

The GSI groundwater vulnerability map of the area shows that the groundwater vulnerability at the site is classified as High (Figure 5).

The depth to bedrock (DTB) of 4.55 to 5.6 m across the site at boreholes BH01, BH02 Shallow, BH02 Deep and BH03, together with the moderate to high permeability of the SILT subsoils encountered in the boreholes and trial pits suggests that the site specific vulnerability across the site is High.

Table 2. Summary of Findings of the Intrusive Investigations

Location	ING Coords	Ref. Datum (& Datum Elev. mAOD)	Summary Geology	Depth to Bedrock (mbgl)	Water Strike (mbgl)	Monitoring well (MW) response zone
TP01	X: 221022 Y: 135953	Ground Level (77.25)	0 to 0.25 m: Topsoil 0.25 to 1.2 m: Slightly gravelly SILT 1.2 to 4.0 m: Slightly sandy gravelly SILT	> 4.0 m	Dry, no mottling	
TP02	X: 221067 Y: 135961	Ground Level (79.06)	0 to 0.25 m: Topsoil 0.25 to 1.1 m: Slightly gravelly SILT 1.1 to 4.0 m: Slightly sandy gravelly SILT	> 4.0 m	Dry, no mottling	
TP03	X: 221121 Y: 135970	Ground Level (80.30)	0 to 0.25 m: Topsoil 0.25 to 0.9 m: Slightly gravelly SILT 0.9 to 3.8 m: Slightly sandy gravelly SILT	> 3.8 m	Dry, no mottling	
TP04	X: 221092 Y: 135998	Ground Level (79.79)	0 to 0.25 m: Topsoil 0.25 to 0.9 m: Slightly gravelly SILT 0.9 to 4.0 m: Slightly sandy gravelly SILT	> 4.0 m	Dry, no mottling	
TP05	X: 221045 Y: 135988	Ground Level (78.54)	0 to 0.25 m: Topsoil 0.25 to 1.4 m: Slightly gravelly SILT 1.4 to 4.0 m: Slightly sandy gravelly SILT	> 4.0 m	Dry, no mottling	
BH01	X: 221122.8 Y: 136002.0	Top of 2-inch Pipe (80.85) (Datum is 0.46 m above ground level)	0-0.3 m: TOPSOIL 0.3-1 m: gravelly SILT 1-2.8 m: slightly sandy gravelly SILT 2-4.55 m: slightly sandy gravelly SILT 4.55-6.9 m: weathered LIMESTONE 6.9-8.8 m: slightly weathered LIMESTONE 8.8-20.5 m: LIMESTONE	4.55	Dry, no water strike observed (Seepage rise to steady level at 15.5 mbgl overnight)	MW screen: 15.5 to 20.5 mbgl (Top of Sand/ Gravel pack at 13.3 mbgl)
BH02 Shallow	X: 221087.3 Y: 135957.2	Top of 2-inch Pipe (80.08) (Datum is 0.57 m above ground level)	0-0.2 m: TOPSOIL 0.2-2.8 m: slightly sandy slightly gravelly SILT 2.8-4.7 m: gravelly SILT 4.7-7.1 m: weathered LIMESTONE	4.7	Dry, no water strike observed (Eventual rise to steady level at 7.53 mbgl by 18 July 2017)	19.0 to 25.0 mbgl (Top of Sand/ Gravel pack at 17.2 mbgl)
BH02 Deep	X: 221089.2 Y: 135957.5	Top of 2-inch Pipe (80.08) (Datum is 0.58 m above ground level)	0-0.2 m: TOPSOIL 0.2-0.8 m: slightly gravelly SILT 0.8-2 m: slightly gravelly SILT 2-2.8 m: slightly gravelly SILT 2.8-4.05 m: very gravelly SILT 4.05-5.4 m: very silty GRAVEL 5.4-7.1 m: weathered LIMESTONE 7.1-10.05 m: slightly weath. LIMESTONE 10.05-18.9 m: LIMESTONE 18.9-19.1 m: weathered LIMESTONE 19.1-25.05 m: LIMESTONE	5.4	Dry, no water strike observed (Seepage rise to steady level at 19.9 mbgl over weekend)	5.1 to 7.1 mbgl (Top of Gravel pack at 4.8 mbgl)
BH03	X: 221042.1 Y: 135949.9	Top of 2-inch Pipe (78.45) (Datum is 0.6 m above ground level)	0-25.05 m: TOPSOIL 0.3-2.15 m: slightly sandy slightly gravelly SILT 2.15-2.9 m: slightly sandy gravelly SILT 2.9-5.6 m: slightly sandy very gravelly SILT 5.6-8.6 m: weathered LIMESTONE 8.6-13.7 m: weathered LIMESTONE 13.7-17.6 m: weathered LIMESTONE 17.6-25.1 m: LIMESTONE	5.6	Dry, no water strike observed (Eventual rise to steady level at 20.08 mbgl by 18 July 2017)	19.1 to 25.1 mbgl (Top of Sand/ Gravel pack at 17.0 mbgl)

4.6 Hydrogeology

4.6.1 Groundwater level

No groundwater was encountered in the trial pits TP01 to TP05 excavated across the site.

No water strikes were observed during the drilling of boreholes BH01, BH02 Shallow, BH02 Deep or BH03. In boreholes BH01 and BH02 Deep groundwater was observed in the boreholes shortly after completing the drilling of the borehole, with groundwater rising to its rest level in BH01 overnight and BH02 Deep over a weekend period. In boreholes BH02 Shallow and BH03 no groundwater was observed in the days immediately after drilling in March 2017, however groundwater was observed in both boreholes when monthly groundwater level monitoring commenced in July 2017. In each borehole it is assumed that small seepages within the borehole response zones account for the groundwater inflow to the borehole.

The boreholes occupy an elevated topographic position in the upper reaches of the catchment of the Clashawley and Killenaule Rivers in the Fethard area. The bedrock watertable observed in the deep bedrock boreholes BH01, BH02 Deep, BH03 and the Ribworld borehole varied between 13.45 mbgl at BH03 and 22.10 mbgl at BH02 Deep (65.0 mAOD to 56.17 mAOD). Depths to groundwater in the shallow weathered bedrock intersected by the borehole BH02 Shallow response zone varied between 7.42 mbgl and 7.53 mbgl (72.66 mAOD to 72.55 mAOD). These data show that water in the shallow weathered bedrock is at a much higher elevation than the groundwater in the deep bedrock and suggest that site is in a recharge zone where any shallow groundwater occurrence is likely to infiltrate vertically to the saturated deep bedrock.

Aquifer properties testing of boreholes BH01, BH02 Deep and BH03 indicated that the limestone bedrock has low hydraulic conductivity between 15 mbgl and 25 mbgl in the vicinity of the site (Section 4.6.3). The low hydraulic conductivity and small seepage inflows in boreholes BH01, BH02 Shallow, BH02 Deep and BH03 suggest that the volume of groundwater flow moving through the bedrock at these depths is small and is likely to be little more than the volume of vertically infiltrating recharge. This would imply that at depths down to 25 mbgl there is little additional input to groundwater flow through the bedrock beneath site from lateral/horizontal groundwater inflow from upgradient of the site.

The borehole log for the Ribworld borehole indicates that the first significant water strike occurred at 67 mbgl and had an associated inflow of approximately 2 to 3 m^3/hr in bedrock logged as strong, dark grey limestone. The main water strike encountered occurred at 82 mbgl to 98 mbgl in a zone of fractured limestone bedrock with sandy clay infill and a groundwater inflow of 40 to 45 m^3/hr. This very large inflow is indicative of lateral groundwater flow in a deep preferential flow path through the limestone bedrock, which would require to be fed by a large upgradient catchment to sustain the observed flow rates.

The Ribworld borehole is located 125 m south of the site and rest groundwater levels at the borehole range from 56.17 mAOD to 61.57 mAOD. The Ribworld borehole groundwater elevation ranged from 1.2 m to 4.1 m lower than the groundwater elevation at BH03. Figure 6 shows that the groundwater elevations at borehole BH03 and the Ribworld borehole follow the same trend. This suggests that groundwater in the vicinity of the response zone of BH03 (i.e. at 19 to 25 mbgl) is in hydraulic continuity with the very deep groundwater encountered in the Ribworld borehole water strikes. The higher elevation head of the groundwater intersected by BH03 compared to the Ribworld borehole suggests that the groundwater observed in the deep boreholes at the site is likely to be predominantly flowing vertically downwards to drain into the high transmissivity fractured rock at depths of 67 mbgl to 98 mbgl.

The groundwater elevation trend observed in borehole BH02 Deep matches the trends in BH03 and the Ribworld borehole in July to September 2017 and January to April 2018. In the periods October to December 2017 and May to June 2018 the water level response in BH02 Deep lags behind the response in BH03 and the Ribworld borehole. This suggests that borehole BH02 Deep has a less transmissive

connection to the bedrock aquifer than borehole BH03, such that the borehole reflects a subdued version of the degree of water level variation that occurs in the aquifer.

The groundwater level response in BH01 showed no variation during the monitoring period, with a constant groundwater elevation in the borehole of 64.79 mAOD. The borehole was purged during each of the groundwater sampling events in September and December 2017 and April and June 2018. After each sampling event, the borehole was found to have recovered to the same water level of 64.79 mAOD by the time of the subsequent water level monitoring event the following month. A possible explanation for this behaviour is that the response zone of BH01 intersects a seepage zone at or above 64.79 mAOD and that the borehole void below this level is effectively a sump in a block of impermeable limestone. As such, when the water level in the seepage zone is at or above 64.79 mAOD, the seepage drains into the sump and fills the borehole to the level of the prevailing water level. Once the water level in the seepage zone drops down below 64.79 mOD the borehole is cut off from the seepage and the borehole water level stays steady reflecting the stagnant water in the sump part of the borehole.

Borehole BH02 is screened in the shallow weathered bedrock at 5.1 m to 7.1 mbgl. It was installed to investigate if shallow weathered bedrock became saturated at any point during the annual hydrological cycle. The groundwater level response in BH02 Shallow shows very little seasonal variation. The observed depth of water at the bottom of the borehole varied between 0.09 m and 0.20 m. The water depth was 0.1 m or less in July and August 2017, and in May and June 2018. There is a 0.1 m length of blank pipe at the base of each 1 m length of monitoring well borehole screen. As such, observations where the water depth was 0.1 m or less reflect stagnant water in the 0.1 m sump at the base of the well and on these occasions the weathered bedrock around the borehole response zone is considered to be dry. When the depth of water in the well is greater than 0.1 m it is likely that the bedrock in the vicinity of well is saturated up to the observed level. This suggests that for the period September 2017 to April 2018 there was a small thickness saturated material in the shallow weathered bedrock underlying the site. It is likely that these saturated conditions reflect ponding of infiltration at the base the weathered bedrock during times when the infiltration rate slightly exceeds the ability of the deeper bedrock to accept it. Based on the indicators for vertical infiltration in the deeper boreholes, it is likely that the slight increase in vertical gradient created by the ponding is enough to driver the infiltration down to the deeper flowpaths, rather than generating significant lateral flow in the shallow weathered bedrock.

The groundwater level trends at the site monitoring wells and at the Ribworld borehole are shown on the graph in Figure 6. The detailed groundwater elevation data are shown in Table 3.

Table 3. Groundwater Level Data

Location	BH01	BH02 Shallow	BH02 Deep	BH03	Ribworld Borehole	Comment
X	221122.8	221087.3	221089.2	221042.1	221045.6	
Y	136002.0	135957.2	135957.5	135949.9	135822.8	
Ground Level (mAOD)	80.39	79.56	79.61	77.89	77.71 (Concrete Floor)/ 77.53 (GL)	
Ref Datum Point	Top of 2" Pipe				Top of 8" Steel Casing	
Ref Datum (mAOD)	80.85	80.08	80.08	78.45	77.93	
Ref Datum (magl)	0.46	0.57	0.58	0.60	0.22	
Year Drilled	2017	2017	2017	2017	2012	
DTB (mbDatum)	5.01	5.27	6.0	6.20	2.5	
Total Depth (mbgl)	20.50	7.10	25.05	25.10	98	
Weath Rock Thick (m)	3.45	2.40	4.60	11.00	2	
Response Zone (mbgl)	15.5 to 20.5	5.1 to 7.1	19 to 25	19.1 to 25.1	Open Hole	
Hydraulic Conductivity (m/d)	0.29	na	0.2	0.05		
Date	Rest GWL (mbDatum)					
18/07/2017	16.05	7.53	22.10	20.64	21.76	
30/08/2017	16.06	7.53	21.22	20.12	21.54	
25/09/2017	16.06	7.43	19.36	17.93	20.17	
23/10/2017	16.06	7.42	18.06	13.51	16.83	1 day after storm Brian
21/11/2017	16.06	7.51	17.78	17.94	20.00	
12/12/2017	16.06	7.45	17.52	14.46	18.07	
26/01/2018	16.06	7.43	16.13	13.67	16.93	
16/03/2018	16.06	7.42	15.87	13.45	16.36	
11/04/2018	16.06	7.45	16.51	15.14	18.51	
30/04/2018	16.06	7.44	20.05	17.98	20.03	
25/05/2018	16.06	7.52	17.61	19.96	21.03	
19/06/2018	16.06	7.53	18.17	20.81	21.47	
	Rest GWL (mAOD)					
18/07/2017	64.80	72.55	57.98	57.81	56.17	
30/08/2017	64.79	72.55	58.86	58.33	56.39	
25/09/2017	64.79	72.65	60.72	60.52	57.76	
23/10/2017	64.79	72.66	62.02	64.94	61.10	
21/11/2017	64.79	72.57	62.30	60.51	57.93	
13/12/2017	64.79	72.63	62.56	63.99	59.86	
26/01/2018	64.79	72.65	63.95	64.78	61.01	
16/03/2018	64.79	72.66	64.21	65.00	61.57	
11/04/2018	64.79	72.63	63.57	63.31	59.42	
30/04/2018	64.79	72.64	60.03	60.47	57.90	
25/05/2018	64.79	72.56	62.47	58.49	56.90	
19/06/2018	64.79	72.55	61.91	57.64	56.46	

4.6.2 Groundwater flow directions and gradients

The groundwater level data for monitoring wells BH02 deep and BH03, and the Ribworld borehole were analysed to estimate the groundwater flow direction and hydraulic gradient in the deep limestone bedrock below the site. Representative groundwater elevation data for the deep bedrock was available for each of the three wells for the periods July to September 2017 and January to April 208. The observed groundwater flow directions during these two periods range from 209^{O} east of north on 30 August 2017 to 141^{O} east of north on 16 March 2018 (i.e. south-southwest to southeast). The range of flow directions and the interpreted groundwater elevation contours for 30 August 2017 and 16 March 2018 is shown on Figure 7.

The lateral hydraulic gradient in the deep bedrock aquifer was estimated for each month with representative the groundwater elevation data. The estimated gradients varied from 0.013 on 18 July 2017 to 0.037 on 26 January 2018, with an average value of 0.025.

The calculated hydraulic gradient estimates are likely to be over-estimates. The groundwater elevation data for boreholes BH02 Deep and BH03 relate to the groundwater head at approximately 25 mbgl. The full suite of groundwater level data suggest that there is little lateral groundwater flow at this depth and that flow is directed vertically downwards towards the preferential flow paths at 67 mbgl and at 82 mbgl to 98 mbgl, which is where the bulk of the lateral groundwater flow is occurring. The vertical hydraulic gradient required to drive the groundwater from 25 mbgl to 67 mbgl and deeper leads means that the actual head at 67 mbgl and 82 mbgl below the site will be less than that observed at 25 mbgl. This in turn means that the lateral head difference between the site and the Ribworld borehole along the deep preferential flow paths is less than that estimated using the data from BH02 deep and BH03.

4.6.3 Aquifer characteristics

The GSI aquifer map of the area shows that the DPBL bedrock unit underlying the site comprises a Regionally Important Aquifer - Karst (Diffuse) (Rk_d) (Figure 7). The site is located in the Clonmel groundwater body (GWB).

Groundwater flow in the limestone bedrock occurs in faults and fissures in the rock. The groundwater flow is predominantly diffuse flow through the network of faults, fractures and fissures as indicated by the aquifer classification, and the GWB initial characterisation summary (GSI 2004) indicates that most of the groundwater moves rapidly along short flow paths and discharges into streams crossing the aquifers of the GWB.

Falling and rising head tests were carried out on monitoring wells BH01, BH02 and BH03 in July 2017, which are screened in the deep, limestone bedrock from greater than or equal to 15.5 mbgl to up to 25.1 mbgl. Analysis of the test data determined hydraulic conductivities of 0.3 m/d, 0.2 m/d and 0.05 m/d for monitoring wells BH01, BH02 and BH03 respectively, with a geometric mean of 0.14 m/d. Details of the slug test analysis are shown in Appendix 2.

The available data from the borehole log of the Ribworld borehole suggest that lateral groundwater flow beneath the site predominantly occurs in preferential pathways in the deep limestone bedrock at depths in the region of 67 mbgl and 82 mbgl to 98 mbgl, with groundwater flow rates in the region of 2 to 3 m^3/hr at 67 mbgl and 40 to 45 m^3/hr at 82 mbgl to 98 mbgl. Groundwater flow velocities in preferential flow paths in karstified bedrock aquifers are typically high and can be of the order of tens of metres per day.

4.6.4 Hydrochemistry

Groundwater quality samples were collected from monitoring wells BH01, BH02 Shallow, BH02 Deep and BH03 on 25 September and 12 December 2017, and 11 April and 19 June 2018. The sample on 12 December 2018 was collected during a period of heavy rain, with 25.8 mm of rainfall recorded at Moore Park rainfall station on 10 December 2017. The samples were analysed for the parameters listed in the guidance for a Tier 2 Assessment (EA, 2004). The water quality data are shown in Table 4.

The groundwater level data suggest that monitoring well BH02 Shallow captured ponded infiltrating recharge in the shallow weathered bedrock in September and December 2017, and in April 2018; however the sample from June 2018 is likely to have been stagnant water in the small sump at the base of the borehole. The water quality samples for monitoring well BH02 Shallow had high counts of total and fecal coliforms in December 2017, and elevated concentrations of chloride and sulphate. Concentrations of the major cations calcium, magnesium, potassium and sodium were above background levels. The monitoring well is located adjacent to the boundary of the existing cemetery and it is possible that the above background and elevated parameter concentrations derive from infiltration mobilising contaminants from the adjacent burials. The field containing the proposed extension area was regularly used for grazing livestock with the result that the areas around the monitoring wells were heavily poached and soiled with

animal waste. The concentration of animal waste around the well heads is another potential source of contaminants.

Monitoring Well BH01 predominantly behaved like a sump which filled to the brim on high groundwater level occasions and subsequently retained the water in the standpipe. Purging of the well generated negligible fresh groundwater inflow during sampling events such that the samples collected predominantly comprised residual water remaining in the sump-like standpipe after the attempted purging. The water quality samples for monitoring well BH01 also had had high counts of total and fecal coliforms in December 2017 and elevated concentrations of chloride in April 2018. BH01 is located approximately 40 m upgradient of the existing burial ground and is less likely to be impacted by contaminated infiltration from the burial ground than the other boreholes. It is possible that the observed elevated contaminant concentrations relate to the agricultural land use at the site.

The water quality data for monitoring well BH02 Deep show pH greater than 10, and elevated electrical conductivity, phosphate, chloride and ammonia in all samples. In addition sodium was elevated in the samples from December 2017 and April and June 2018 and the lead concentration was elevated in April 2018. Above background concentrations of iron occurred in all four samples which suggest anaerobic reducing conditions in the groundwater. No bacteria were detected in the sample from December 2017. The monitoring well is located adjacent to the boundary of the existing cemetery and it is possible that the above background and elevated parameter concentrations derive from infiltration mobilising contaminants from the adjacent burials. The current agricultural land use of the proposed site may also be contributing to the contamination.

The water quality data for monitoring well BH03 show pH in the range 7.7 to 8.6, and elevated electrical conductivity in September and December 2018, slightly elevated phosphate in September 2017 and April 2018, and elevated chloride in all samples. In addition high counts of total and fecal coliforms were detected in the sample from December 2017. The monitoring well is located adjacent to the boundary of the existing cemetery and it is possible that the above background and elevated parameter concentrations derive from infiltration mobilising contaminants from the adjacent burials. The current agricultural land use of the proposed site may also be contributing to the contamination.

The data suggest that the existing burial ground and the current agricultural land use may be resulting in elevated contaminant concentrations in the infiltrating recharge in the shallow weathered bedrock and in the fractured limestone bedrock down to depths of 25 mbgl.

4.6.5 Recharge

Recharge is the proportion of the effective rainfall (ER) (388 mm/yr, see Section 4.1) that infiltrates through to groundwater. Based on the high vulnerability, the low slope, and the well-drained soil of the area a recharge coefficient (i.e. the proportion of ER that goes to recharge) of 0.9 has been selected for the site (IWWG, 2005). Available recharge is therefore estimated to be 349 mm/yr.

Table 4 Baseline Water Quality Data

Sample Location			BH01	BH01	BH01	BH01	BH02 Shallow	BH02 Shallow	BH02 Shallow	BH02 Shallow	BH02 Deep
Sample Date			25/09/2017	12/12/2017	11/04/2018	19/06/2018	25/09/2017	12/12/2017	11/04/2018	19/06/2018	25/09/2017
Sampled By			P Conroy	P Conroy	P Conroy	P Conroy	P Conroy	P Conroy	P Conroy	P Conroy	P Conroy
Lab Report			38884 C	39508 C	40356 C	40967 C	38884 C	39508 C	40356 C	40967 C	38884 C
Lab Ref			C17Sep615	C17Dec336	C18 Apr 300	C18 Jun 554	C17Sep616	C17Dec337	C18 Apr 301	C18 Jun 555	C17Sep617
Sample Type			Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater
Parameter	Units	Groundwater Threshold Value (Tests 1-4) (SI 366 of 2016)	Grey turbid sample	Grey turbid sample	Grey turbid sample	Grey-brown turbid sample	Brown turbid sample	Brown turbid sample	Brown turbid sample	Brown turbid sample	Purge water orange-red initially; Brown turbid sample
PHYSICO-CHEMICAL PARAMETERS											
pH	pH Units		7.1	7.4	7.2	6.7	7.5	8	7.5	insuffic. Sample	10.3
Field pH	pH Units		7.04	7.02	7.07	7.17	7.25	insuffic. Sample	insuffic. Sample	insuffic. Sample	10.50
Field Conductivity @25 DegC	uS/cm @25	800 - 1875	708	704	700	712	**867**	insuffic. Sample	insuffic. Sample	insuffic. Sample	**920**
Field Dissolved Oxygen	mg/L		3	3.2	3.7	3.6	8.9	insuffic. Sample	insuffic. Sample	insuffic. Sample	3.2
Chemical Oxygen Demand (COD)	mg/L		<10	44	10	<10	41	85	194	44	93
Biological Oxygen Demand (BOD)	mg/L		2.4	1.62	1.9	<1	4.4	2.4	2.4	insuffic. Sample	2.6
Hardness	mg/l CaCO3										
Phosphate-Ortho(as P)	mg/l P	0.035	0.01	0.002	0.02	<0.01	0.01	0.003	**0.05**	<0.01	**7.69**
Total Phosphorous (as P)	mg/L P										
Potassium:Sodium Ratio (K:Na) (meq/l)	[-]										
Total Organic Carbon (TOC)	mg/L		2.01	1.64	4.19	9.51	3.31	9.42	40.53	15.4	52
MICROBIOLOGICAL											
Total Coliforms	mpn/100ml			4884				9208			
Pseudomonas Auriginosa	cfu/100ml			20.00				Insuffic Sample			
Faecal Coliforms	mpn/100ml			31				173			
Clostridium Perfringens	cfu/100ml			200				Insuffic Sample			
Faecal Streptococci	mpn/100ml			41				177			
MAJOR ANIONS											
Alkalinity Total	mg/L CaCO3		374	386	388	395	1623	428	459	579	547
Chloride	mg/L	24.0	13.6	10.8	**109.0**	4.6	**54.1**	**214.0**	**184.0**	**187.0**	**42.4**
Nitrate (as N)	mg/l N	8.50	5.01	2.61	2.78	3.12	1.03	4.76	3.96	3.45	<0.25
Nitrite (as N)	mg/l N	0.085	0.029	0.006	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sulphate	mg/L	187.5	12.5	11.4	116.0	2.3	<0.5	132.0	**209.0**	**196.0**	15.1
MAJOR CATIONS											
Ammonia (as N)	mg/l N	0.065 - 0.175	0.04	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	**0.18**
Calcium-Dissolved	mg/L		122	168	524	437	1214	342	11	1165	78
Magnesium-Dissolved	mg/L		10.6	10.5	10.6	9.0	39.5	34.7	0.4	31.5	18.3
Potassium-Dissolved	mg/L		3.6	3.5	6.2	2.6	6.4	7.6	0.1	8.1	4.9
Sodium-Dissolved	mg/L	150.0	15.7	16.2	16.0	9.8	38.0	125.0	1.6	**204.0**	15.8
DISSOLVED METALS											
Cadmium-Dissolved	ug/L		<1	<0.45	<0.45	<0.45	<1	<0.45	<0.45	<0.45	<1
Chromium-Dissolved	ug/L	37.5	<1	<1	<1	<1	<1	<1	<1	<1	19
Copper-Dissolved	mg/L	1.5	0.001	<0.001	0.001	<0.001	0.004	0.002	0.001	0.002	0.031
Iron-Dissolved	ug/L		<10	12	20	14	<10	9	30	9	1790
Lead-Dissolved	ug/L	7.5	<1	<1	<1	<1	<1	<1	<1	<1	3
Manganese-Dissolved	ug/L		4	7.8	6.1	2	4	16.7	55.5	13	21
Nickel-Dissolved	ug/L		<1	<1	1	<1	<1	<1	3.2	1	26
Zinc-Dissolved	ug/l	75	<8	<8	<8	9	<8	11	28.7	14	<8

Bold Red Text indicates exceeedance of EPA Threshold (ammonium threshold = 0.175 mg/l as N)

Table 4 Baseline Water Quality Data

Sample Location	BH02 Deep	BH02 Deep	BH02 Deep	BH03	BH03	BH03	BH03
Sample Date	12/12/2017	11/04/2018	19/06/2018	25/09/2017	12/12/2017	11/04/2018	19/06/2018
Sampled By	P Conroy	P Conroy	P Conroy	P Conroy	P Conroy	P Conroy	P Conroy
Lab Report	39508 C	40356 C	40967 C	38884 C	39508 C	40356 C	40967 C
Lab Ref	C17Dec338	C18 Apr 302	C18 Jun 556	C17Sep618	C17Dec339	C18 Apr 303	C18 Jun 557
Sample Type	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater
Parameter	Brown turbid sample	Purge water orange-red initially; white-grey turbid sample	Grey turbid sample	Milky brown turbid sample	Milky brown turbid sample	White brown turbid sample	Pale brown turbid sample
PHYSICO-CHEMICAL PARAMETERS							
pH	11.2	11	11.8	8.6	8.5	8	7.7
Field pH	11.40	11.18	11.10	8.70	8.51	7.80	7.83
Field Conductivity @25 DegC	**1372**	**1214**	**2182**	**1085**	**854**	735	795
Field Dissolved Oxygen	3.1	2.4	3.9	2.8	3.6	4.5	2.5
Chemical Oxygen Demand (COD)	245	340	35	13	42	25	<10
Biological Oxygen Demand (BOD)	2.29	4.2	<1	3.6	3.76	2.9	<1
Hardness							
Phosphate-Ortho(as P)	**7.5**	**13.8**	**2.61**	**0.13**	0.01	**0.09**	<0.01
Total Phosphorous (as P)							
Potassium:Sodium Ratio (K:Na) (meq/l)							
Total Organic Carbon (TOC)	76.6	243.7	16	5.05	5.61	25.4	17.6
MICROBIOLOGICAL							
Total Coliforms	<10				8864		
Pseudomonas Auriginosa	<10				<10		
Faecal Coliforms	20				213		
Clostridium Perfringens	<100				<100		
Faecal Streptococci	10				10		
MAJOR ANIONS							
Alkalinity Total	931	530	686	128	243	366	495
Chloride	**53.7**	**163.0**	**36.2**	**196.0**	**127.0**	**125.0**	**58.9**
Nitrate (as N)	0.36	0.41	<0.25	0.49	0.69	1.63	<0.25
Nitrite (as N)	<0.005	<0.005	**0.34**	0.036	<0.005	<0.005	<0.005
Sulphate	<0.5	<0.5	3.3	84.1	104.0	80.1	53.9
MAJOR CATIONS							
Ammonia (as N)	**0.87**	**1.41**	**0.62**	0.12	0.06	<0.02	<0.02
Calcium-Dissolved	695	504	5	54	304	438	852
Magnesium-Dissolved	4.2	6.4	0.5	8.2	9.8	13.3	18.1
Potassium-Dissolved	3.2	9.5	31.8	15.6	14.2	16.9	16.4
Sodium-Dissolved	**237.0**	**288.0**	**252.0**	115.2	109.0	78.3	69.2
DISSOLVED METALS							
Cadmium-Dissolved	<0.45	1.1	<0.45	<1	<0.45	<0.45	<0.45
Chromium-Dissolved	22.3	17.9	14	<1	<1	<1	<1
Copper-Dissolved	0.071	0.018	0.019	0.018	0.002	0.001	<0.001
Iron-Dissolved	730	1450	265	11	40	20	20
Lead-Dissolved	4.1	**11.5**	<1	<1	<1	<1	<1
Manganese-Dissolved	33.8	45.1	11	9	9.6	<1	51
Nickel-Dissolved	25.9	34.8	4	<1	<1	2.2	<1
Zinc-Dissolved	<8	33	8	<8	<8	<8	<5

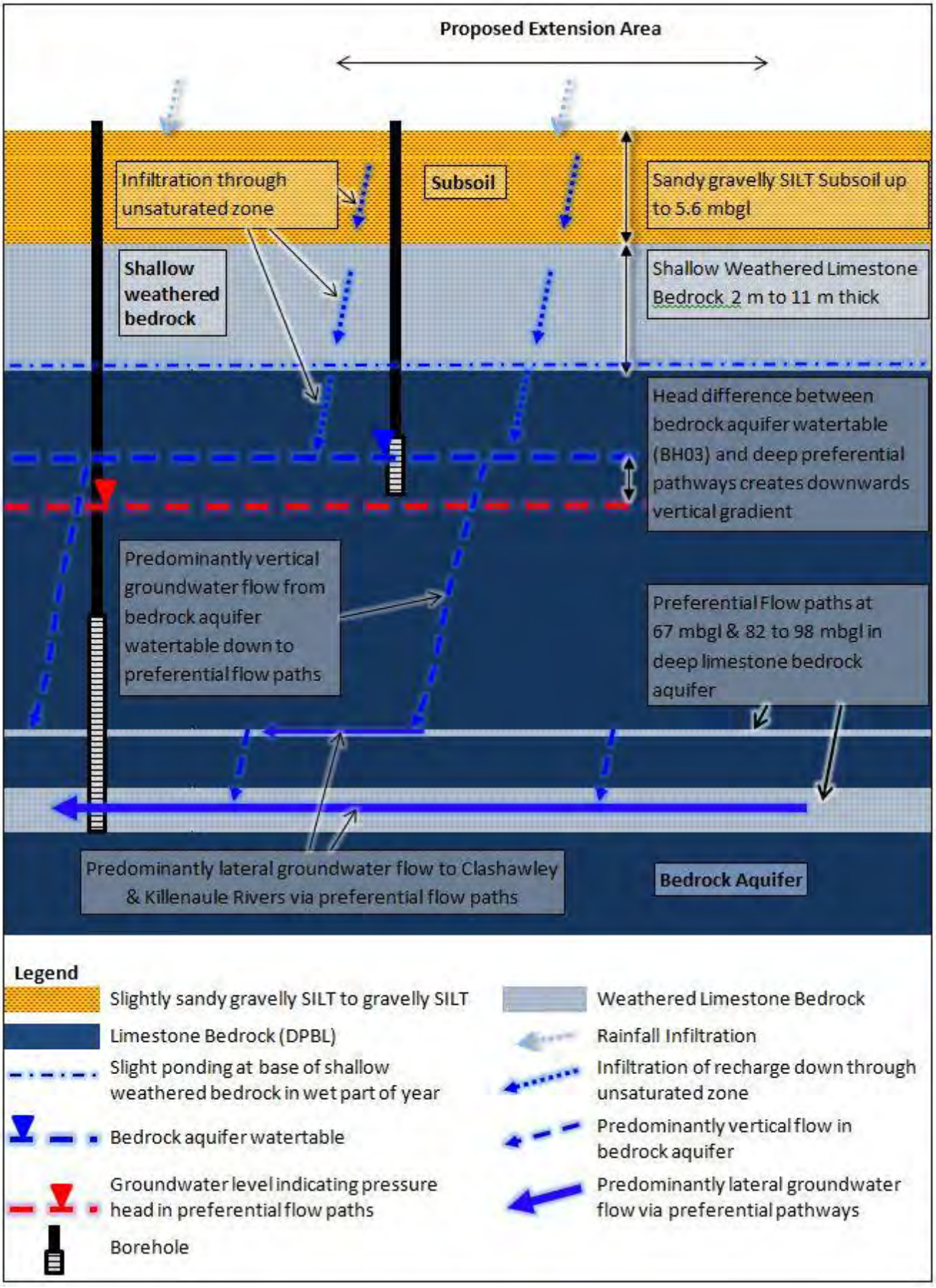
Bold Red Text indicates exceeedance of EPA Thresh

4.6.6 Hydrogeological conceptual model

Recharge to the site infiltrates vertically through the unsaturated sandy gravelly SILT subsoil down to the unsaturated shallow weathered limestone bedrock. During the wetter period of the year, approximately September to April small volumes of recharge may pond at the base of the unsaturated zone; however the ponded water is expected to infiltrate vertically down to the deeper limestone bedrock rather than to generate horizontal flow in the shallow weathered bedrock. The infiltrating recharge continues to move down through the rock into the saturated bedrock. The bedrock appears to be saturated from below approximately 13.5 mbgl to 21 mbgl depending on the season, with the watertable at its deepest between May and August. The groundwater in the saturated bedrock aquifer down to approximately 67 mbgl is considered to continue to flow predominantly vertically downwards towards deep preferential horizontal flow paths in limestone bedrock at 67 mbgl and between 82 m and 98 mbgl. The infiltrating groundwater discharges into these preferential horizontal groundwater flow paths where it mixes with the groundwater flow from upgradient along the pathways. Groundwater flows of 2 m^3 to 3 m^3/hr at 67 mbgl and 40 m^3 to 45 m^3/hr were observed at 82 m to 98 mbgl in the preferential pathways intersected by the Ribworld Borehole in the deep limestone bedrock aquifer. Groundwater flow along the preferential pathways downgradient of the site is expected to discharge to the Clashawley and Killenaule Rivers between 450 m southeast and 1 km south of the site.

The site conceptual model is illustrated in the schematic cross-section in Figure 8.

Figure 8 Basic 2D Schematic Hydrogeological Conceptual Model Diagram



5 Source-Pathway-Receptor Framework

The current standard approach to assessing the potential environmental risk associated with a source of contaminants is through the source – pathway – receptor (SPR) framework. This approach identifies the potential *sources* of contamination which might be present in or impact on a study area. *Pathways* by which the contaminants could migrate from the source into the greater environment are subsequently identified. Finally environmental *receptors* in the study area, which could suffer negative impacts as a result of exposure to the contaminants are identified.

5.1 Potential sources of contamination

The contaminant source of interest in this study is the proposed burial ground site. The proposed site is expected to have a low burial rate (estimated at 16 burials/year based on data for Calvary Cemetery, Fethard for the period 2001 to 2015). The UK guidance (EA, 2004) indicates that a human corpse typically decays within 10 to 12 years, losing over half the pollutant load in the first year. The loading continues to half year on year such that less than 0.1% of the original load is left after 10 years. A wide range of chemicals are released from the burials. A subset of these compounds has been selected to be contaminants of concern (COCs) based on their inclusion in the list of groundwater threshold values in Schedule 5 of SI 366 of 2016. The selected COCs are ammonia, phosphorous, sulphate, and chloride. The likely behaviour of each COC in the subsurface is described in Table 5.

Based on the UK guidance the contaminant loading from a burial becomes negligible after 10 years (EA, 2004). The maximum annual contaminant loading will therefore be reached after 10 years and will remain constant until closure, following which there will be a 10 year tail off period. The expected contaminant loadings of the COCs are shown in Table 6.

An embalmed body contains 180 g of formaldehyde in 9 litres of embalming fluid, of which about half is degraded rapidly in the decomposition process (EA 2004). The half-life of formaldehyde has been reported between 1-7 days in surface water and 2-14 days in groundwater, based on estimated aqueous aerobic biodegradation half lives (Pubchem, 2019). On the basis of studies in which humans and experimental animals were exposed to formaldehyde by inhalation, IARC has classified formaldehyde in Group 1 (carcinogenic to humans). The weight of evidence indicates that formaldehyde is not carcinogenic by the oral route. In assessing the need for a drinking water threshold for formaldehyde, the WHO concluded that it is not considered necessary to set a formal guideline value for formaldehyde in view of the significant difference between the expected concentrations of formaldehyde in drinking-water and the tolerable concentration (WHO 2005). Given this conclusion by the WHO Formaldehyde has not been selected as a contaminant of concern.

There are other potential sources of contaminants in the vicinity of the site, including agricultural land use upgradient of the site, and the existing adjacent burial ground on the downgradient side of the site.

Baseline groundwater quality monitoring between September 2017 and June 2018 encountered high counts of total and fecal coliforms, elevated electrical conductivity, and elevated concentrations of chloride, ammonia and phosphate in shallow and deep groundwater in the limestone bedrock aquifer adjacent to the upgradient boundary of the existing burial ground at BH02 Shallow, BH02 Deep and BH03. In addition, high counts of total and fecal coliforms, and elevated chloride concentrations were observed in deep groundwater away from the existing burial ground at the up gradient boundary of the proposed extension area at BH01. It is possible that existing burial ground and the agricultural land use at the site may be contributing to the observed contamination.

Table 5. Contaminants of Concern

Contaminant of Concern	Environmental Fate	Groundwater Threshold (SI 366 of 2016)
Ammonia & nitrate	Research on onsite wastewater treatment systems in Ireland indicates that ammonium and total nitrogen can be significantly reduced through denitrification beneath infiltration areas for conventional septic tank systems. The degree of attenuation that occurs is strongly linked to the formation of a biomat at the base and along infiltration (percolation) trenches. EPA guidance recommends 70% as a typical attenuation factor for nitrogen (EPA, 2011). It is assumed that biomats will occur at the base of burial plots and similar attenuation rates will apply to nitrogen released from burial grounds. It is assumed that the denitrification (biological conversion of ammonia to nitrate and nitrate to nitrogen gas) occurs in the 1 m of subsoil directly below the burial. At greater depth in the unsaturated zone it is assumed that aerobic conditions prevail and only nitrification occurs (biological conversion of ammonia to nitrate). UK guidance recommends a general nitrification half-life of 1 to 6 years for sand and gravel lithology (Buss et al, 2003). Half lives as short as 13 days have been observed in sandy, aerobic conditions (Buss et al, 2003). With an average of 5.1 m of unsaturated slightly sandy gravelly SILT subsoils at the site it is assumed that an ammonium nitrification half of life of 1 year is applicable between 1 m and 1.7 m below the burial depth (i.e. between 3.4 m and 5.1 mbgl). The unsaturated zone travel time for infiltration to travel from 3.4 m to 5.1 mbgl is estimated at 2.0 years (Appendix 6)	NH_3: 175 ug/l as N NO_3: 37.5 mg/l as NO_3
Phosphorous	Research on onsite wastewater treatment systems in Ireland indicates that phosphorous can be significantly attenuated by adsorption beneath infiltration areas for conventional septic tank systems. EPA guidance recommends 90% as a typical attenuation factor for phosphorous (EPA, 2011). The phosphorous threshold under SI 366 of 2016 relates to ortho-phosphate (PO_4).	35 ug/l as P
Sulphate	Sulphate is expected to be attenuated by dilution only in the burial ground setting under consideration; however where sufficiently anaerobic conditions exist (i.e. where all nitrate has been consumed) sulphate can be reduced to hydrogen sulphide gas.	187.5 mg/l as SO_4
Chloride	Chloride behaves conservatively in the subsoil and groundwater and is attenuated by dilution only.	24 mg/l

It is considered that the groundwater quality observed in the boreholes adjacent to the existing burial ground are likely to reflect the quality of the infiltration that might occur beneath the proposed extension area, rather than the water quality of background groundwater flow in the bedrock aquifer upgradient of the site. The water quality observed in borehole BH01 is considered to represent the water quality of background groundwater flow in the bedrock aquifer upgradient of the site

Table 6. Contaminant Loadings

	Grams (g) of contaminant released per annum per burial				
Year	**NH4 (as N)**	**NO3**	**P**	**SO4**	**Cl**
1	677	Assume Nitrate derives from nitrification of residual ammonia after infiltration passes through the 1 m thick denitrification zone directly beneath the burial depth	250	210	48
2	342		125	110	24
3	171		63	54	12
4	86		32	27	6
5	39		16	12	3
6	23		8	6	2
7	7.8		4	3	1
8	3.9		2	1.5	0.5
9	1.9		1	0.75	0.25
10	1.0		0.5	0.38	0.13
Total annual mass of contaminant released after >10 years of burials at a rate of 1 burial per year (g)	1352	0	502	425	97
Total annual mass of contaminant released after >10 years of burials at a rate of 13 burials per year (g)	21632	0	8032	6800	1552

5.2 Pathways

The pathway of interest with respect to migration of contaminants from the source (i.e. the proposed cemetery) is the groundwater pathway. This pathway comprises infiltration of rain water through the ground surface. The infiltrating water (recharge) encounters and dissolves the source contaminants within the burial plots. The recharge continues to infiltrate vertically through the unsaturated subsoil and unsaturated weathered and competent limestone bedrock below the plots until it reaches the groundwater table in the deep, limestone bedrock at between 13.5 mbgl and 21 mbgl. Groundwater in the saturated bedrock aquifer below the watertable flows predominantly vertically down through the competent low permeability limestone until it discharges in to deep preferential groundwater flow path at depths of approximately 67 mbgl and 82 m to 98 mbgl. Groundwater in the preferential flow paths flows predominantly horizontally to eventually discharge into the Clashawley and Killenaule Rivers.

The contaminant loading in the recharge from the burial ground is likely to be diluted by cleaner upgradient groundwater flowing beneath the site in the preferential pathways. Any contaminants eventually discharging to surface water via the groundwater pathway will be further diluted by the upstream flow in the surface water feature.

Attenuation of the initial contaminant loading along the migration pathway by processes such as sorbtion, biodegradation and dilution has been assessed quantitatively using basic mass balance calculations in line with Tier 2 assessment requirements under the UK Guidance (EA, 2004). The various components of the contaminant migration pathway are described in Table 7. Contaminant concentrations at each stage along the pathway are quantified in Table 10.

Table 7. Components of the Contaminant Migration Pathway

Pathway Component	Description
Infiltration	Infiltration into the subsurface (i.e. recharge) is estimated at 0.349 m/yr per m^2 of surface area. The proposed extension area surface area is measured at 4,920 m^2. The product of surface area and infiltration rate gives the annual infiltration volume, i.e. 1739 m^3/year. This assumes that any infiltration obstructed by impermeable paths, parking or plinths infiltrates via adjacent permeable surface cover. The travel time for infiltration to pass vertically down through the unsaturated zone is calculated based on a plug flow conceptual model, i.e. any infiltration input at the surface is matched by recharge output at the base of the unsaturated zone with no change of water volume in between. The travel time of relevance for the QRA is the travel time between a depth of 1 m below the burial depth (3.4 mbgl) and the base of the unsaturated zone (average of 5.1 mbgl), i.e. travel time across a 1.7 m vertical distance. This is the zone where ammonia nitrification is expected to occur with an ammonia half life of 1 yr. The estimated travel time is 2.0 years (Appendix 6). The infiltrating recharge dissolves the contaminants released by the burials to give an average contaminant concentration in the recharge/leachate (see Table 10).
Attenuation in Subsoil	Double burial scenarios are envisaged with the contaminant release point (i.e. base of the burials) at 2.4 mbgl. In the 1 m of unsaturated subsoil beneath the burials (i.e. 2.4 m to 3.4 mbgl) attenuation of 70% of the nitrogen load by denitrification and 90% of the phosphorous load by adsorption can be expected to occur, assuming equivalence with EPA Guidance on attenuation rates beneath septic tank system discharges to groundwater. In the remaining unsaturated subsoil below 3.4 mbgl, ammonia nitrification is expected to occur with an ammonia half life of 1 year, based on EPA guidance on ammonia attenuation in soil and groundwater. Denitrification converts the ammonia to nitrate, such that the reduction in ammonia concentration gives a corresponding increase in nitrate concentration. Phosphorous attenuation below 3.4 mbgl is assumed to continue by adsorption at a rate of 90% reduction in loading per metre of subsoil travelled by the infiltrating water. No subsoil attenuation has been considered for sulphate or chloride. The attenuated dissolved concentration of each contaminant at the base of the unsaturated zone is shown in Table 10.
Dilution at the watertable	Section 4.6.3 indicates that the groundwater flow of up to 48 m^3/hr (1,152 m^3/day) can be expected in the deep preferential groundwater flow paths beneath the site. The infiltrating recharge reaches the bedrock aquifer water table and flows predominantly vertically down to the deep preferential flow paths where it with the preferential groundwater flow from upgradient of the site. Mixing of the vertical groundwater flow from the site and the horizontal flow from upgradient in the preferential flow paths results in dilution of the concentration of the residual contaminants that remained in the infiltrating recharge at the base of the subsoil.
Lateral Groundwater Flow	The dissolved contaminants in the groundwater migrate laterally in the direction of groundwater flow. In this case groundwater flow is to the south. The closest groundwater discharge points to the site are the Rivers Clashawley and Killenaule at between 450 m and 1 km from the site to the south and southeast. Further attenuation of contaminants during intergranular groundwater flow through the subsoil is likely by dispersion and biodegradation; however quantification of this type of attenuation is more appropriate to a Tier 3 assessment and has not been included in this assessment.
Dilution at surface water discharge point	Groundwater flow beneath the site is considered to discharge to the Rivers Clashawley and Killenaule to the south and southeast of the site. Any residual contaminants in the groundwater at the discharge point to the rivers will be diluted by mixing with the river flow at the discharge point (Table 10).

5.3 Receptors

The receptors identified in the vicinity of the proposed burial ground site are shown in Table 8. The groundwater in the bedrock aquifer underlying the site is the first receptor encountered along the contaminant migration pathway. The groundwater quality in the bedrock aquifer is protected by SI 366 of 2016 and the concentrations of the contaminants of concern must be less than the thresholds set out in Schedule 5 of the Regulations. The next closest receptors to the site are the Rivers Clashawley and Killenaule where the groundwater flow beneath the site discharges into the rivers to the south and southeast of the site. No other receptors have been identified. The Ribworld borehole is not considered to be a receptor as it is not not in use.

Table 8. Identified Receptors

Location	Type	Distance from closest boundary of designated burial area (m)	Comment
Identified Receptors			
Groundwater in the bedrock aquifer beneath the site	Groundwater	Directly beneath site.	Average Unsaturated Zone subsoil thickness of 2.7 m between burial depth and base of subsoil.
River Clashawley and Killenaule	Surface Water	Minimum of 450 m	

6 Basic Quantitative Risk Assessment

Within the SPR framework, the likelihood of the identified receptors being exposed to an identified source-contaminant via a migration pathway and the potential severity of the impact of that exposure are assessed to give an indication of the risk associated with each of the SPR linkages. In line with Tier 2 requirements, a basic quantitative risk assessment of the proposed burial ground extension site has been carried out and is summarised in Table 9.

The quantitative assessment shows that the predicted concentrations of the contaminants of concern except ammonia are attenuated to less than their respective SI 366 of 2016 threshold values by the time the infiltrating recharge reaches the base of the unsaturated subsoil. The ammonia concentration in the infiltration at the base of the unsaturated subsoil is predicted to be 0.94 mg/l as N. Ignoring any further attenuation in the unsaturated bedrock, this is approximately the ammonia concentration expected in the recharge immediately prior to reaching the watertable. The concentration of 0.94 mg/l as N exceeds the SI 366 of 2016 threshold value of 0.175 mg/l for ammonia in groundwater. The hydrogeological conceptual model considers that there is negligible lateral groundwater flow in the saturated bedrock between the water table and the deep preferential groundwater flow paths at 67 mbgl and 82 m to 98 mbgl. As such, the ammonia contaminated groundwater is expected to flow vertically down to the preferential pathways. Ignoring any further attenuation in the saturated bedrock, the ammonia concentration expected in the groundwater immediately prior to reaching the preferential flow paths is 0.94 mg/l as N. The groundwater resource in the saturated bedrock beneath the site and above the deep preferential groundwater flow paths is considered to be negligible and there are no other receptors between the base of the site and the deep preferential flow paths, along the vertical pathway. As such, the risk associated with the ammonia concentration of 0.94 mg/l in the vertical groundwater flow beneath the site is considered to be low.

The contaminated vertical groundwater flow beneath the site is assumed to mix fully with the upgradient groundwater flow passing beneath the site in the preferential flow path, once it discharges into the preferential flow path. The concentration of ammonia in the groundwater in the preferential flow path after mixing is 0.103 mg/l as N. This takes account of any background upgradient contamination in the preferential flow path. The concentration of 0.103 mg/l as N is below the SI 366 of 2016 threshold value of 0.175 mg/l for ammonia in groundwater. As such, the quantitative assessment shows that the predicted concentrations of contaminants of concern are all attenuated to less than their respective SI 366 of 2016 threshold values by the time the infiltrating recharge mixes with the upgradient groundwater flow in the deep preferential groundwater flow paths beneath the site.

The quantitative assessment shows that the predicted concentrations of contaminants of concern are all attenuated to below their respective SI 272 of 2009 threshold values following dilution at the point of discharge to surface water.

As such, **the risk associated with the proposed burial ground extension is considered to be low**.

Table 9. Basic Quantitative Risk Assessment

S-P-R Step		Contaminant Concentrations				
		NH_4 (as N)	NO_3	P	SO_4	Cl
Source	Source Contaminant Mass [1] (Total annual mass of contaminant released after >10 years of burials at a rate of 12 burials per year) (g)	21632	0	8032	6800	1552
	Infiltration through proposed burial ground extension site (m3/yr)	1717				
	Dissolved annual average Contaminant Concentration in leachate (mg/l)	12.6	0.0	4.7	4.0	0.9
Pathway	N & P Attenuation Factors at 1 m below release point (EPA, 2011 App D, Table D5)	0.7		0.9		
	Attenuated Ammonia concentration (mg/l as N) at 1 m below release point. (Denitrification gives a reduction in Total N loading, i.e. no increase in nitrate concentration)	3.78				
	Ammonia (mg/l as N) & Nitrate (mg/l as NO3) concentrations at base of unsaturated zone after ammonia attenuation by nitrification: Travel time of 4.5 yr for infiltration through 5.2 m unsaturated zone between 1 m below release point and the water table. Nitrification half life of 1 year.	0.94	12.6			
	Phosphate concentration (mg/l as P) at base of saturated zone assuming 0.9 attenuation factor by soil adsorption for each metre of the 6.2 m of unsaturated subsoil beneath the burial depth			0.009		
	Contaminant concentration at base of unsaturated zone	**0.94**	**12.6**	**0.009**	**4.0**	**0.9**
	Background Contaminant Concentration in groundwater (mg/l) (Average of baseline concentrations at BH01, BH02 & BH03 with values below the detection limit (DL) evaluated as 0.5 x DL)	0.02	15	0.01	35.5	34.5
	Groundwater flow at upgradient site boundary (m3/yr)	17,520				
	Diluted contaminant concentration in groundwater (mg/l)	**0.103**	**14.8**	**0.01**	**33**	**32**
	Volume of discharge to River Suir deriving from infiltration plus groundwater flow beneath site (m3/yr)	19,237				
	Volume of Dry Weather Flow in River Suir 1.6 km south of site at Hydrometric Station 16009, Cahir Park (m3/yr)	31,536				
	Diluted Contaminant Concentration in River Suir opposite site (mg/l)	**0.04**	**5.6**	**0.004**	**12.4**	**11.9**
Receptor	*Groundwater Contaminant Threshold Concentration at Receptor (mg/l) (SI 366 of 2016)*	*0.175*	*37.5*	*0.035*	*187.5*	*24*
	Surface Water Contaminant Threshold Concentration at Receptor (mg/l) (SI 272 of 2009)	*0.065*		*0.035*		

[1] Source contaminant mass taken from Table 6

7 Conclusions

The hydrogeological setting of the Fethard burial ground extension site was characterised through desk study and site investigations and showed that the site is underlain by unsaturated sandy gravelly SILT subsoil over weathered to slightly weathered limestone bedrock, over competent limestone bedrock with preferential groundwater flow paths present in the deep limestone at depths of 67 mbgl and 82 m to 98 mbgl. The limestone bedrock underlying the site is a Regionally Important Aquifer - Karst (Diffuse) (Rk_d).

A source-pathway-receptor site conceptual model identified the groundwater in the bedrock aquifer underlying the site, and the Rivers Clashawley and Killenaule 450 m to 1 km southeast and south of the site, as receptors that could potentially be impacted by contaminants mobilised from the proposed burials by groundwater recharge infiltrating through site.

A Tier 2 basic quantitative hydrogeological risk assessment of the proposed development indicated that the concentration of each of the contaminants of concern associated with the proposed burials, except ammonia, would be attenuated to below their respective Groundwater Regulations (SI 366 of 2016) threshold by the time the infiltrating groundwater recharge reached the base of the unsaturated zone.

The predicted ammonia concentration at the base of the unsaturated subsoil and at depth in the saturated bedrock just prior to discharge into the deep preferential groundwater flow paths at 67 mbgl and 82 m to 98 mbgl is 0.94 mg/l as N, which exceeds the SI 366 of 2016 threshold value of 0.175 mg/l as N for ammonia in groundwater.

The groundwater resource in the saturated bedrock beneath the site and above the deep preferential groundwater flow paths is considered to be negligible and there are no other receptors except the groundwater itself between the base of the site and the deep preferential flow paths, along the vertical pathway. As such, the risk associated with the ammonia concentration of 0.94 mg/l in the vertical groundwater flow beneath the site is considered to be low.

The quantitative risk assessment shows that the predicted concentrations of contaminants of concern are all attenuated to less than their respective SI 366 of 2016 threshold values by the time the infiltrating recharge mixes with the upgradient groundwater flow in the deep preferential groundwater flow paths beneath the site.

The quantitative risk assessment also showed that the concentration of each of the contaminants of concern associated with the proposed burials would be attenuated to below their respective Surface Water Regulations (SI 272 of 2009) threshold by the time the groundwater flowing beneath the proposed site reached the zone of groundwater discharge to Rivers Clashawley and Killenaule downgradient of the site.

Given the outcome of the quantitative risk assessment, the potential risk associated with double burials at the proposed burial ground extension site is considered to be low. As such, in line with a Tier 2 assessment under the UK guidance (EA, 2004); it is considered that the proposed development should be acceptable from a hydrogeological perspective.

8 Recommendations

If the burial rate at the proposed site turns out to be greater than 16 burials per year on an ongoing basis, then the quantitative risk assessment should be revised to assess the risk to downgradient receptors associated with the increased burial rate.

9 References

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Figures

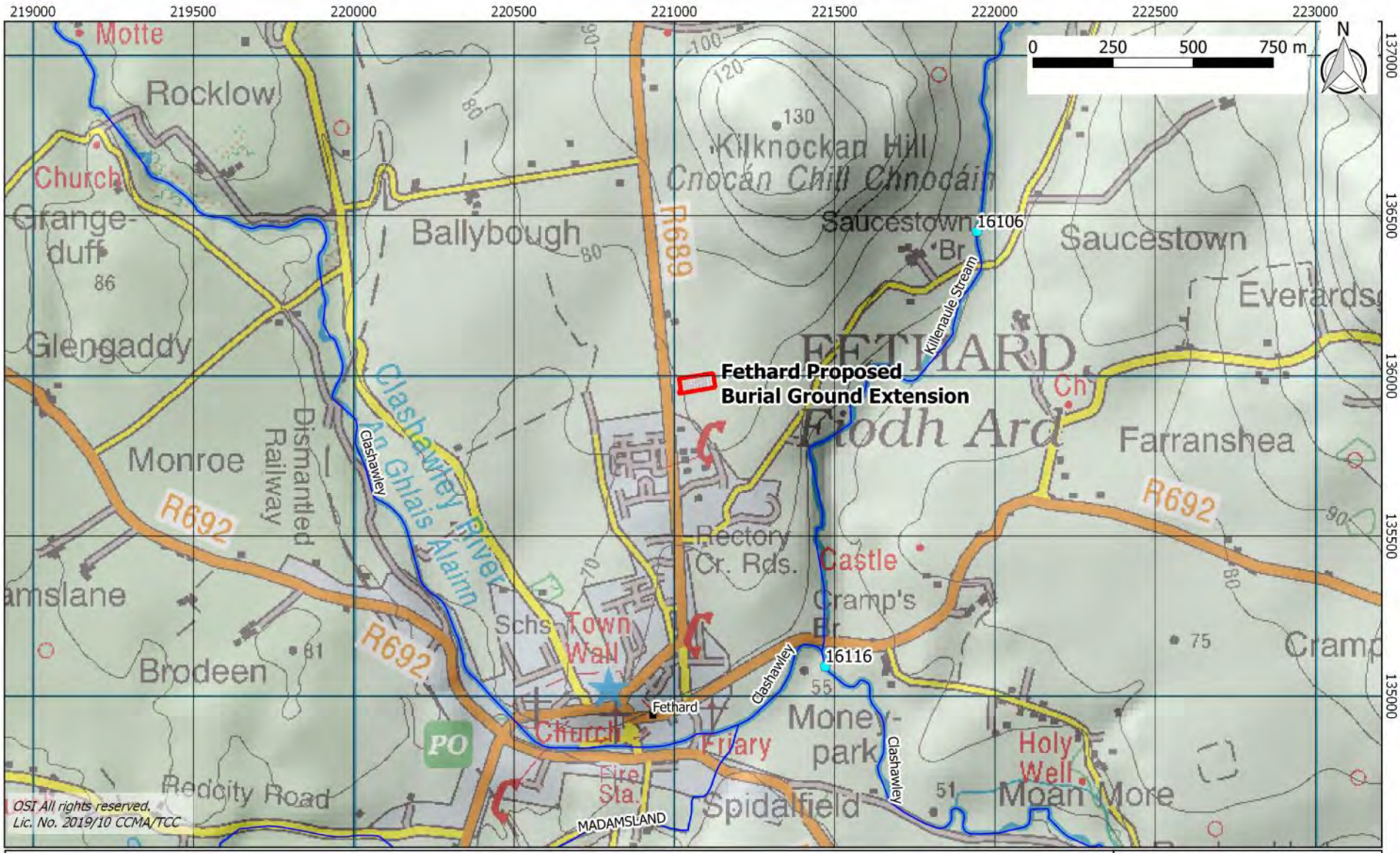


Figure 1. Site Location

- Burial Ground Extension Site Boundary
- River
- Hydrometric Gauging Station (showing station number label)

Hidrigeolaíocht Ui Chonaire Teoranta
Project No. & Name: 1092 Tipperary Burial Ground Extensions
Stage: Fethard Phase 2
Drawn By: Peter Conroy
Date: 20190829
Revision No: A

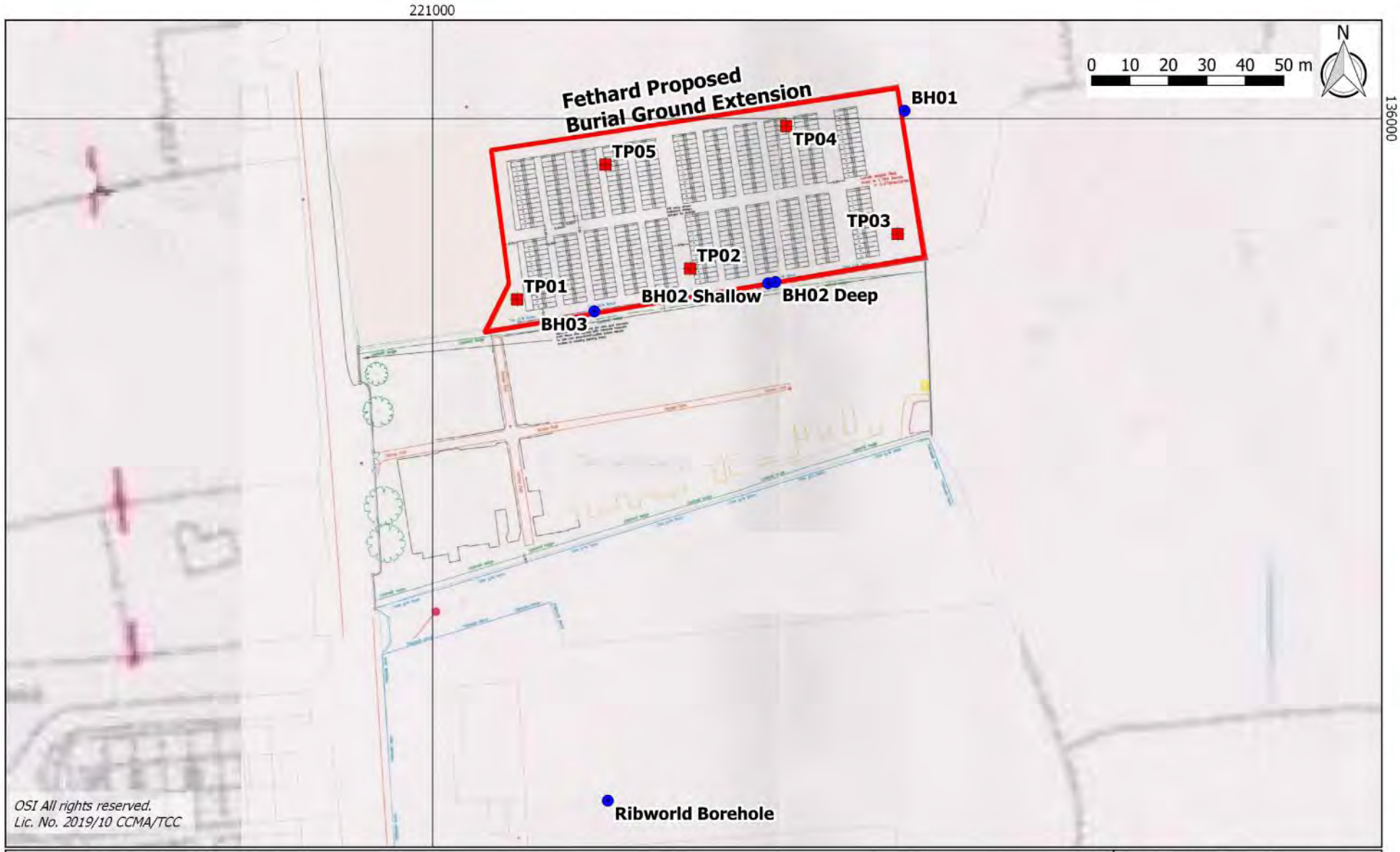


Figure 2. Site Layout

Burial Ground Extension Site Boundary

Borehole

Trial Pit

Proposed Burial Plots Layout

Hidrigeolaíocht Uí Chonaire Teoranta
Project No. & Name: 1092 Tipperary Burial Ground Extensions
Stage: Fethard Phase 2
Drawn By: Peter Conroy
Date: 20190830
Revision No: A

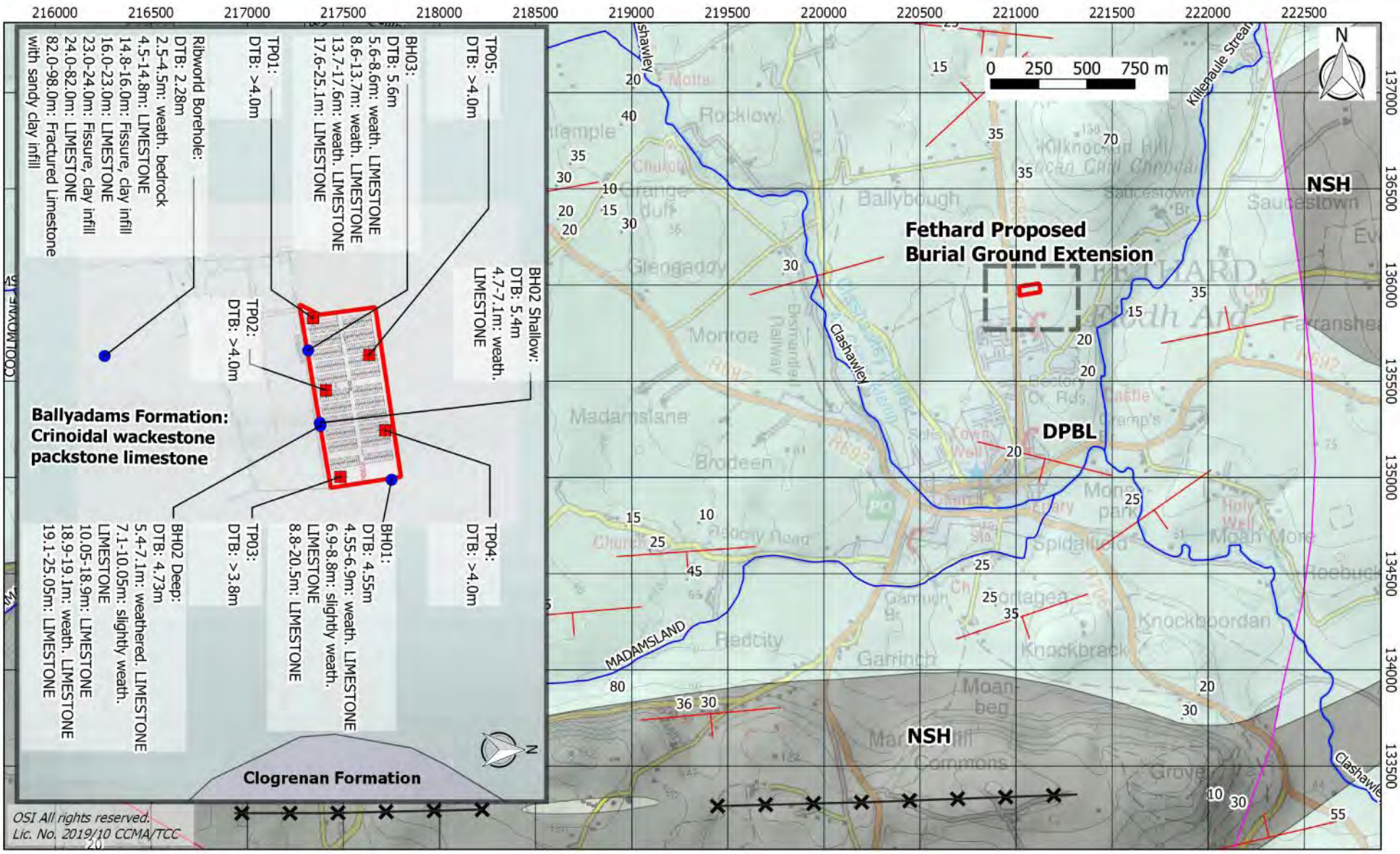


Figure 3. Bedrock Geology

Burial Ground Extension Boundary
River
Trial Pit
Borehole
Bedrock Dip
54
Bedrock Fault
Synclinal Axis
Namurian Shale (NSH)
Dinantian Pure Bedded Limestone (DPBL) (includes Ballyadams & Clogrenan Fmns)

Hidrigeolaíocht Uí Chonaire Teoranta
Project No. & Name: 1092 Tipperary Burial Ground Extensions
Stage: Fethard Phase 2
Drawn By: Peter Conroy
Date: 20190830
Revision No: A

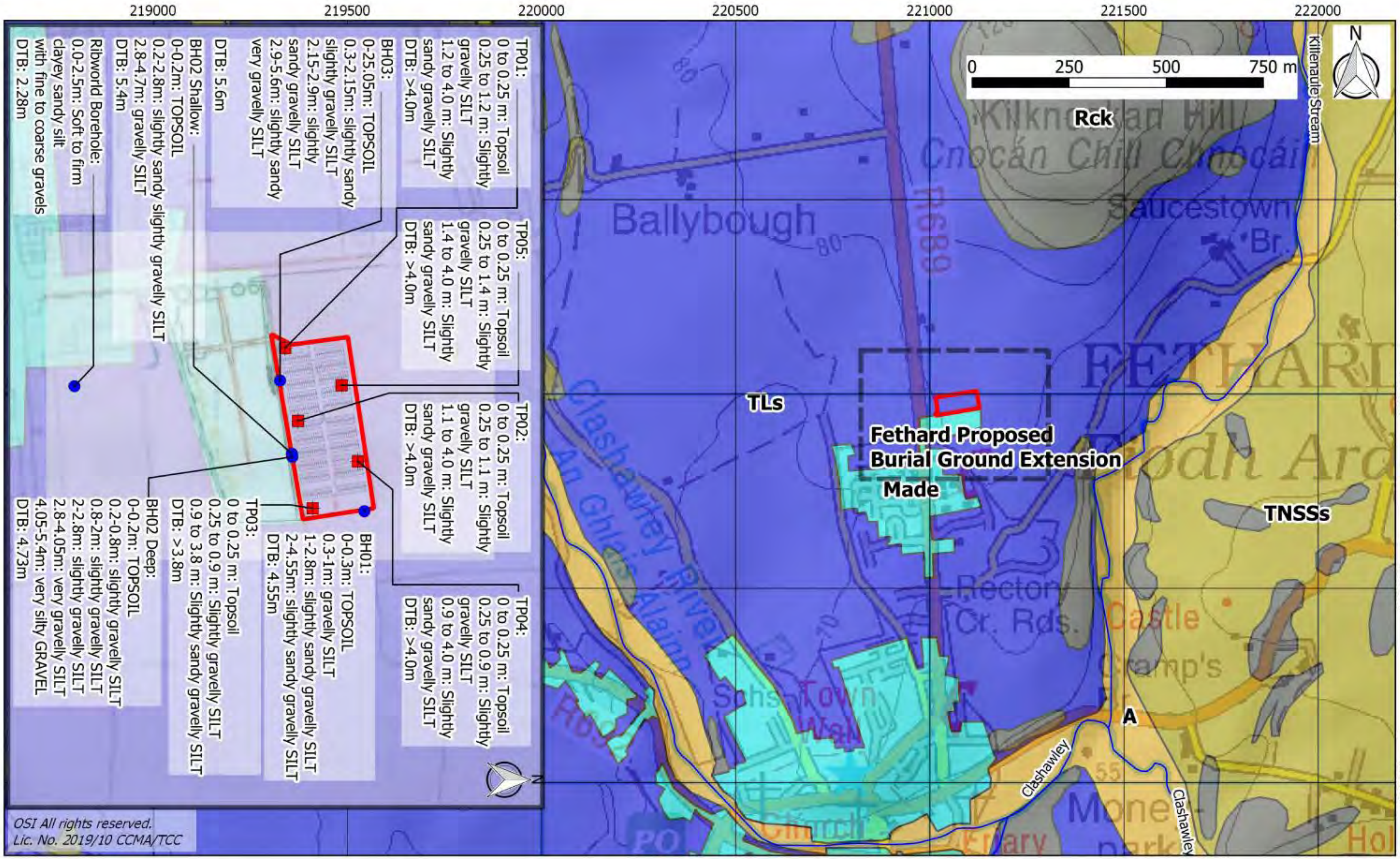


Figure 4. Subsoil

- Burial Ground Extension Boundary
- River
- Trial Pit
- Borehole
- Limetsone Till (TLs)
- Alluvium (A)
- Made Ground (Made)
- Bedrock Outcrop (Rck)
- Till derived from Namurian sandstones and shalesTNSSs

Hidrigeolaíocht Uí Chonaire Teoranta
Project No. & Name: 1092 Tipperary Burial Ground Extensions
Stage: Fethard Phase 2
Drawn By: Peter Conroy
Date: 20190830
Revision No: A

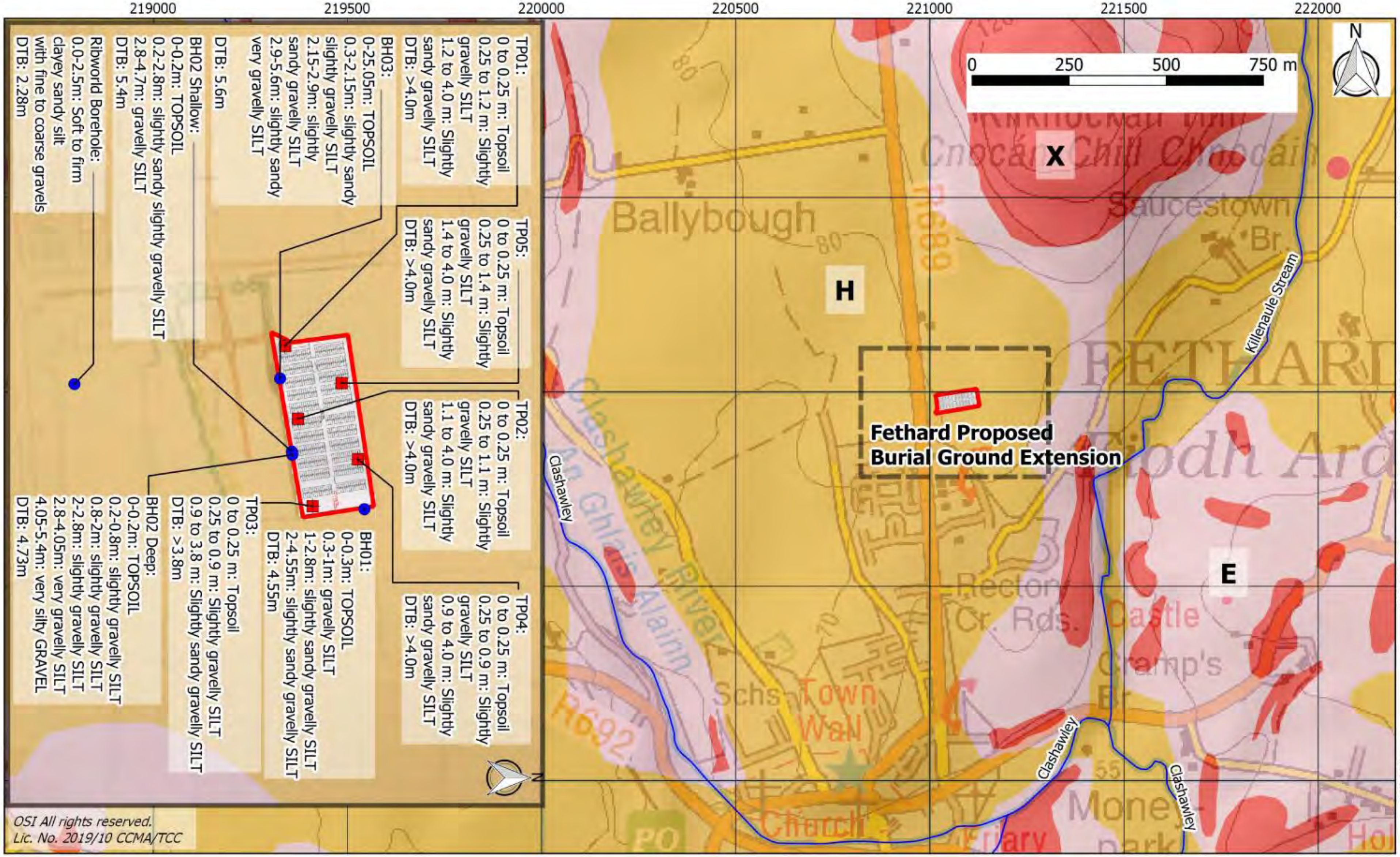


Figure 5. Groundwater Vulnerability

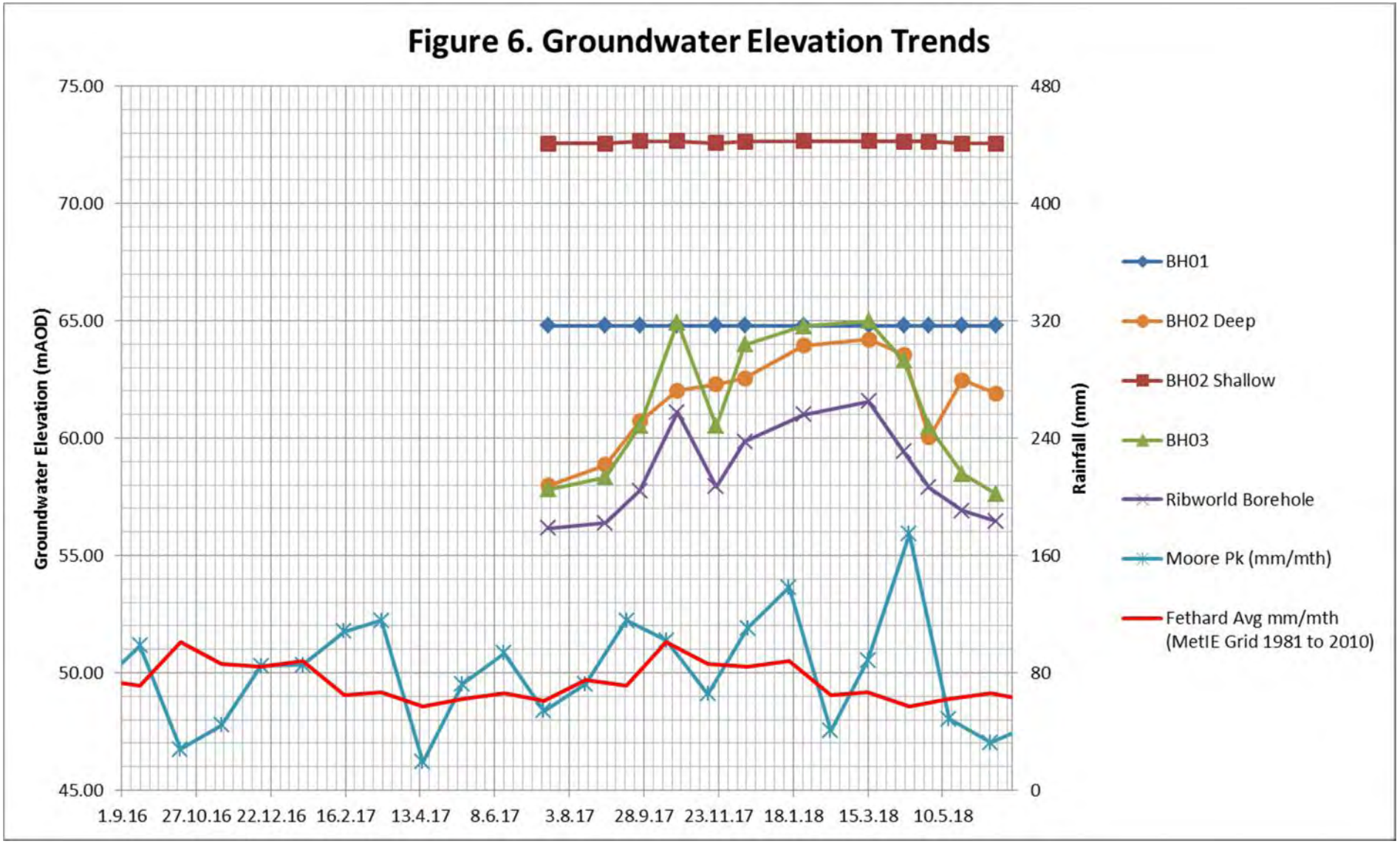
- Burial Ground Extension Boundary
- River
- Trial Pit
- Borehole

Groundwater Vulnerability

- Extreme (X)
- Extreme (E)
- High (H)

Hidrigeolaíocht Uí Chonaire Teoranta
Project No. & Name: 1092 Tipperary Burial Ground Extensions
Stage: Fethard Phase 2
Drawn By: Peter Conroy
Date: 20190830
Revision No: A

Figure 6. Groundwater Elevation Trends



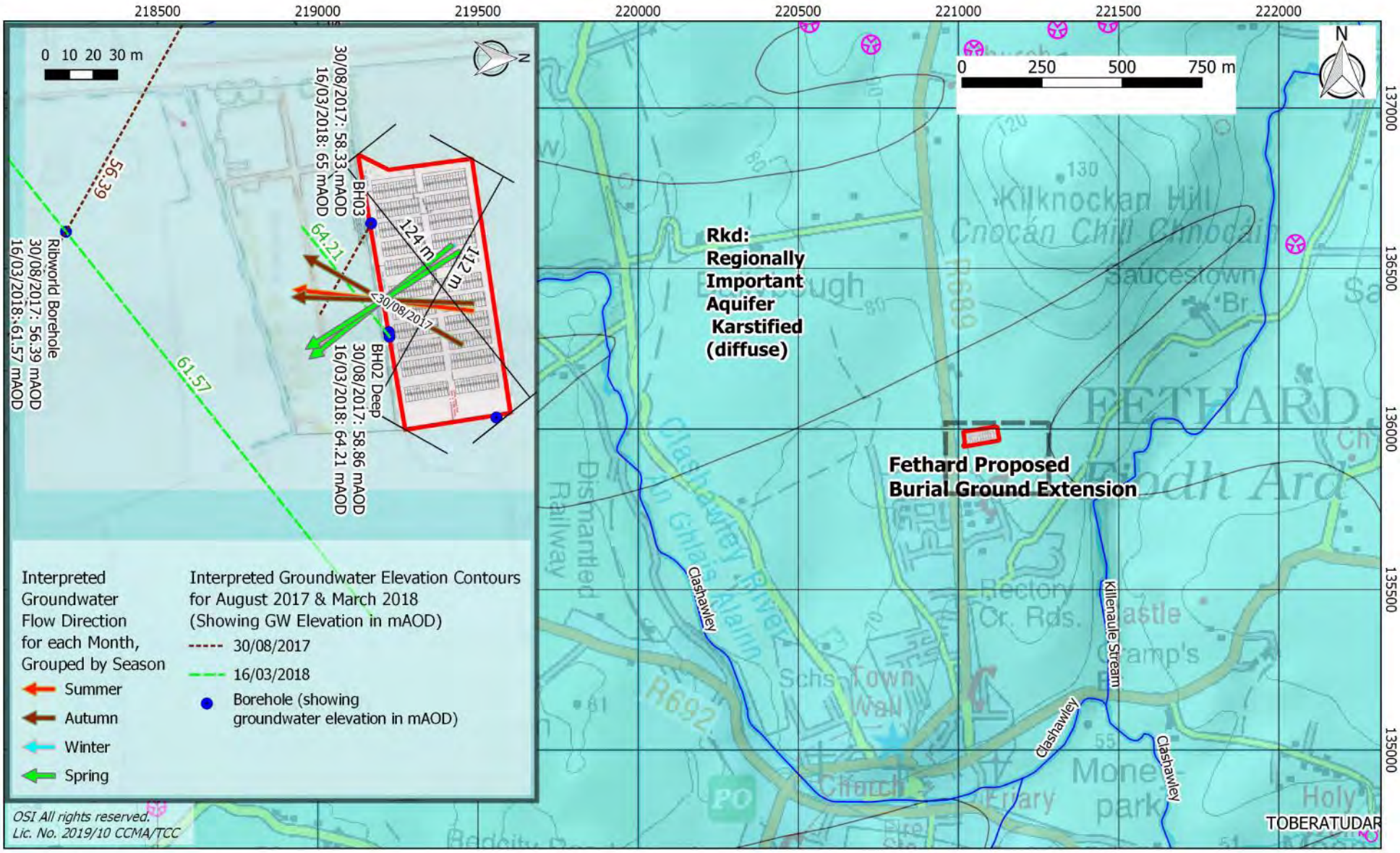


Figure 7. Bedrock Aquifer

Burial Ground Extension Boundary
River
Trial Pit
Borehole
Bedrock Aquifer
RKd
112 m
Width of Proposed Burial Layout Perpendicular to Limits of Range of Groundwater Flow Direction
Karst Features
Borehole
Enclosed Depression

Hidrigeolaíocht Uí Chonaire Teoranta
Project No. & Name: 1092 Tipperary Burial Ground Extensions
Stage: Fethard Phase 2
Drawn By: Peter Conroy
Date: 20190830
Revision No: A

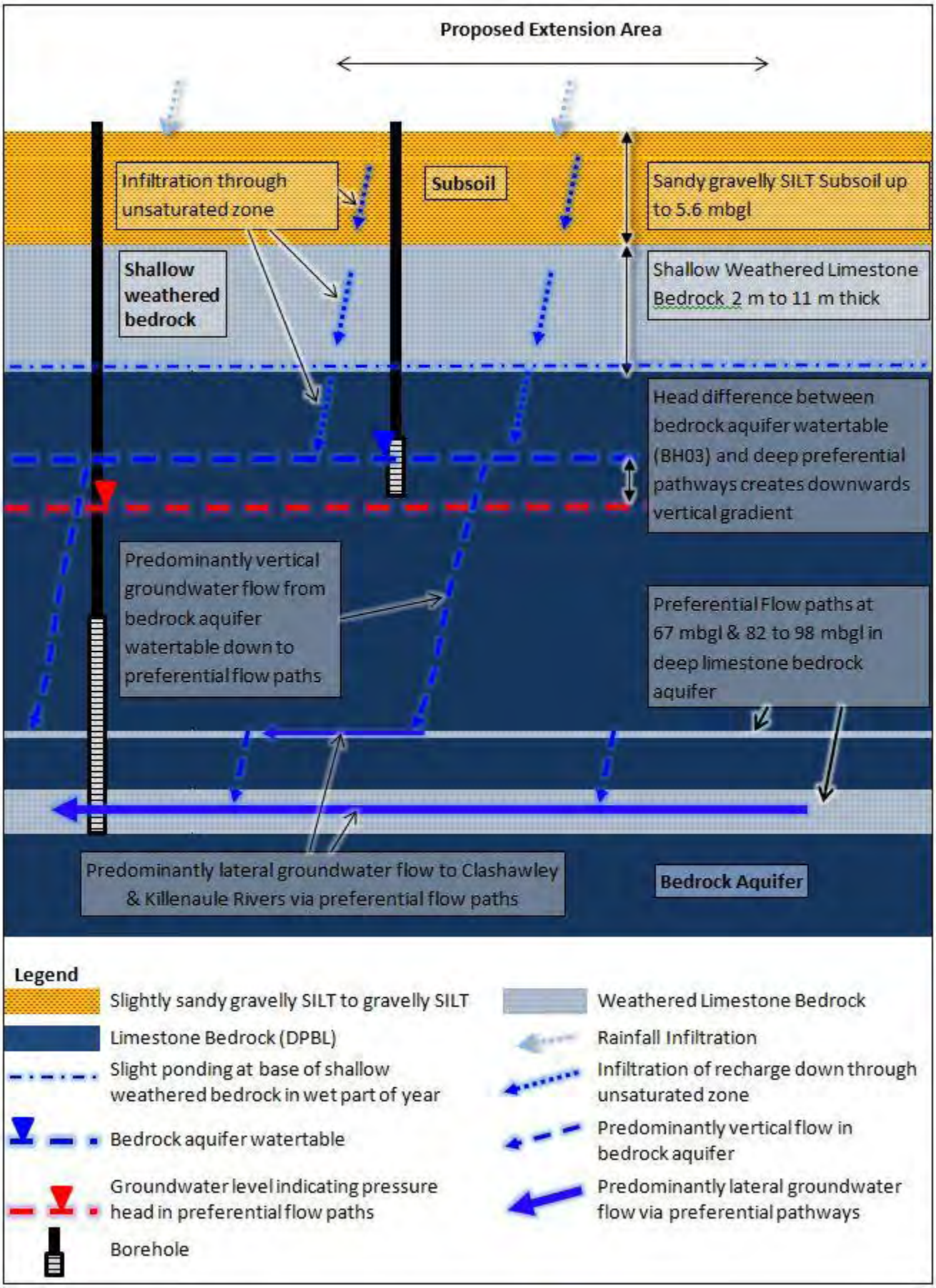


Figure 8. Basic 2D Schematic Hydrogeological Conceptual Model Diagram

APPENDIX 1

Borehole Logs

BOREHOLE LOG

		BOREHOLE ID: **BH01**	SHEET NUMBER: **1 of 1**
	CLIENT: **Tipperary County Council**	EASTING: **221122.76**	NORTHING: **136002.02**
	PROJECT: **Burial Ground Ext Hydrogeol Ass - Fethard**	DATE STARTED: **15/03/2017**	DATE COMPLETED: **16/03/2017**
	PROJECT NUMBER: **1092**	GROUND LEVEL (mOD): **80.39**	TOP OF STANDPIPE (mOD): **80.85**
	DRILL METHOD 1: **Robit DTH-RoX MU** DM1 DIA. & DEPTH: **168 mm to 4.55 mbgl**	DRILLED DEPTH (mbgl): **20.5**	DEPTH OF STANDPIPE FROM TOP OF PIPE (m): **20.96**
STATUS: **Final**	DRILL METHOD 2: **5" Open Hole** DM2 DIA. & DEPTH: **125 mm to 20.5 mbgl**	DRILL CONTRACTOR: **JSD**	LOGGED BY: **PC**

Depth (m)	Description (mbgl)
0	0-0.3m: TOPSOIL
0	0.3-1m: Soft to firm, damp, brown, gravelly SILT. Gravel clasts are angular to sub-angular, fine to medium size, limestone.
1	1-2.8m: Stiff becoming very stiff, damp, pale brown, slightly sandy gravelly SILT. Gravel clasts are angular to sub-angular, fine to medium size, limestone. Occasional brown/white mottling suggesting preferential vertical pathways.
3	2-4.55m: Very stiff, damp, brown, slightly sandy gravelly SILT. Gravel clasts are angular to sub-angular, fine to medium size, limestone with occasional boulders.
5	4.55-6.9m: Dry, dark-grey, weathered, mictrite LIMESTONE Bedrock with silt infill.
7	6.9-8.8m: Dry, dark-grey, slightly weathered, mictrite LIMESTONE Bedrock
9	8.8-20.5m: Dry, dark grey, competent micrite LIMESTONE Bedrock.

Water Strike / Water Rise: A

Well Construction

- Top of 50mm ID Standpipe at -0.46mbgl
- Top of Sand/Gravel at 13.3mbgl
- Rise to 15.5mbgl by overnight seepage, hole dry previous evening
- Top of Screen (1mm slot) at 15.5mbgl
- Oxide stained clasts 14.75 to 17.6 mbgl suggests seepage zone
- Base of Screen at 20.5mbgl

NOTES: RWL 18/07/2017 16.05mbgl

RWL = Rest Water Level; SC = Steel Casing; EC = Electrical Conductivity; mbgl = metres below ground level; ID = Inner Diameter; MW = Monitoring Well

Bentonite Pellets | Sand Plug | MW Blank Casing

Cement Grout | Gravel Pack | MW Screen

BOREHOLE LOG

		BOREHOLE ID: **BH02 Deep**	SHEET NUMBER: **1 of 1**
	CLIENT: **Tipperary County Council**	EASTING: **221089.2**	NORTHING: **135957.48**
	PROJECT: **Burial Ground Ext Hydrogeol Ass - Fethard**	DATE STARTED: **16/03/2017**	DATE COMPLETED: **20/03/2017**
	PROJECT NUMBER: **1092**	GROUND LEVEL (mOD): **79.61**	TOP OF STANDPIPE (mOD): **80.08**
	DRILL METHOD 1: **Robit DTH-RoX MU** DM1 DIA. & DEPTH: **168 mm to 2.85 mbgl**	DRILLED DEPTH (mbgl): **25.05**	DEPTH OF STANDPIPE FROM TOP OF PIPE (m): **25.52**
STATUS: **Final**	DRILL METHOD 2: **5" Open Hole** DM2 DIA. & DEPTH: **125 mm to 25.05**	DRILL CONTRACTOR: **JSD**	LOGGED BY: **PC**

Depth (m) | Soil Samples | Graphic Log | Description (mbgl) | Water Strike | Water Rise | Well Construction

0-0.2m: TOPSOIL

0.2-0.8m: Firm to stiff, damp, brown, slightly gravelly SILT. Gravel clasts are angular to sub-angular, fine to medium size, limestone.

0.8-2m: Very stiff, dry pale brown slightly gravelly SILT with occasional cobbles. Gravel clasts are angular to sub-angular, fine to medium size, limestone.

2-2.8m: Very stiff, dry pale brown slightly gravelly SILT with occasional cobbles. Gravel clasts are angular to sub-angular, fine to medium size, limestone. Occasional thin sand partings

2.8-4.05m: Damp, pale brown very gravelly SILT. Gravel clasts are angular to sub-angular, fine to medium size, limestone.

4.05-5.4m: Damp, pale brown, very silty, angular to subangular fine to medium GRAVEL. Gravel clasts are dark grey micrite limestone.

5.4-7.1m: Dry, dark grey, weathered micrite LIMESTONE bedrock with occasional silt infill

7.1-10.05m: Dry, dark grey, slightly weathered micrite LIMESTONE Bedrock. Occasional calcite clasts.

10.05-18.9m: Dry, dark grey, competent micrite LIMESTONE Bedrock.

18.9-19.1m: Dry, dark grey and pink-red, weathered LIMESTONE bedrock with silt infill

19.1-20.05m: Dry, dark grey, competent micrite LIMESTONE Bedrock.

A

Top of 50mm ID Standpipe at -0.58mbgl

Top of Sand/Gravel at 17.2mbgl

Top of Screen (1mm slot) at 19.0mbgl

Rise to 19.9mbgl by seepage over weekend, hole dry at start of weekend

Base of Screen at 25.05mbgl

NOTES: RWL 18/07/2017 22.10mbgl

RWL = Rest Water Level; SC = Steel Casing; EC = Electrical Conductivity; mbgl = metres below ground level; ID = Inner Diameter; MW = Monitoring Well

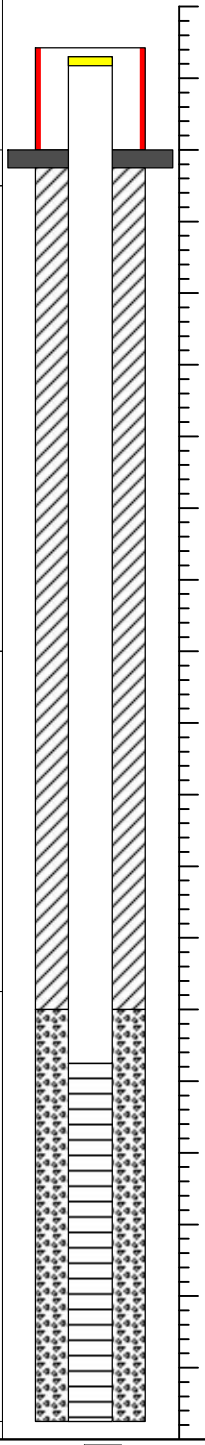
Bentonite Pellets | Sand Plug | MW Blank Casing

Cement Grout | Gravel Pack | MW Screen

BOREHOLE LOG

		BOREHOLE ID: **BH02 Shallow**	SHEET NUMBER: **1 of 1**
	CLIENT: **Tipperary County Council**	EASTING: **221087.33**	NORTHING: **135957.17**
	PROJECT: **Burial Ground Ext Hydrogeol Ass - Fethard**	DATE STARTED: **20/03/2017**	DATE COMPLETED: **20/03/2017**
	PROJECT NUMBER: **1092**	GROUND LEVEL (mOD): **79.56**	TOP OF STANDPIPE (mOD): **80.08**
	DRILL METHOD 1: **Robit DTH-RoX MU** DM1 DIA. & DEPTH: **168 mm to 2.8 mbgl**	DRILLED DEPTH (mbgl): **7.1**	DEPTH OF STANDPIPE FROM TOP OF PIPE (m): **7.62**
STATUS: **Final**	DRILL METHOD 2: **5" Open Hole** DM2 DIA. & DEPTH: **125 mm to 7.1**	DRILL CONTRACTOR: **JSD**	LOGGED BY: **PC**

Depth (m)	Soil Samples	Graphic Log	Description (mbgl)	Water Strike	Water Rise
0			0-0.2m: TOPSOIL		
			0.2-2.8m: Damp brown, slightly sandy slightly gravelly SILT. Gravel clasts are angular to sub-angular, fine to medium size, limestone.		
3			2.8-4.7m: Damp, brown, gravelly SILT. Gravel clasts are angular to sub-angular, fine to medium size, limestone.		
5			4.7-7.1m: Dry, dark-grey, weathered, mictrite LIMESTONE Bedrock. Occasional orange-brown staining on clast faces.		



Top of 50mm ID Standpipe at -0.57mbgl

Top of Gravel at 4.8mbgl

Top of Screen (1mm slot) at 5.1mbgl

Hole dry. Occasional orange brown staining on weathered limestone clasts 4.6 to 7.1 mbgl

Base of Screen at 7.1mbgl

NOTES: Borehole dry

RWL = Rest Water Level; SC = Steel Casing; EC = Electrical Conductivity; mbgl = metres below ground level; ID = Inner Diameter; MW = Monitoring Well

Bentonite Pellets | Sand Plug | MW Blank Casing

Cement Grout | Gravel Pack | MW Screen

HUCT SEIRBHÍSÍ HIDRIGEOLAÍOCHTA

BOREHOLE LOG

		BOREHOLE ID: **BH03**	SHEET NUMBER: **1 of 1**
	CLIENT: **Tipperary County Council**	EASTING: **221042.05**	NORTHING: **135949.91**
	PROJECT: **Burial Ground Ext Hydrogeol Ass - Fethard**	DATE STARTED: **20/03/2017**	DATE COMPLETED: **21/03/2017**
	PROJECT NUMBER: **1092**	GROUND LEVEL (mOD): **77.89**	TOP OF STANDPIPE (mOD): **78.45**
	DRILL METHOD 1: **Robit DTH-RoX MU** DM1 DIA. & DEPTH: **152 mm to 2.9 mbgl**	DRILLED DEPTH (mbgl): **25.1**	DEPTH OF STANDPIPE FROM TOP OF PIPE (m): **25.66**
STATUS: **Final**	DRILL METHOD 2: **5" Open Hole** DM2 DIA. & DEPTH: **125 mm to 25.1**	DRILL CONTRACTOR: **JSD**	LOGGED BY: **PC**

Depth (m)	Soil Samples	Graphic Log	Description (mbgl)	Water Strike	Water Rise	Well Construction
-1 to 26			0-0.3m: TOPSOIL 0.3-2.15m: Stiff, damp, pale brown, slightly sandy, slightly gravelly SILT with cobbles. Gravel clasts are sub-angular to sub-round, fine to medium size, limestone. 2.15-2.9m: Stiff, damp, pale brown, slightly sandy, gravelly SILT with cobbles. Gravel clasts are sub-angular to sub-round, fine to medium size, limestone. 2.9-5.6m: Damp, pale brown, slightly sandy, very gravelly SILT. Gravel clasts are sub-angular to sub-round, fine to medium size, limestone. 5.6-8.6m: Damp, dark grey, weathered micrite LIMESTONE Bedrock with occasional silt infill 8.6-13.7m: Damp, dark grey, weathered micrite LIMESTONE Bedrock with occasional spots of oxide staining on clast faces and occasional calcite clasts 13.7-17.6m: Dry, dark grey, weathered micrite LIMESTONE Bedrock with some oxide staining on clast faces and frequent orange silt infill and occasional calcite clasts 17.6-25.1m: Dry, dark grey competent micrite LIMESTONE Bedrock with occasional calcite veins up to 1 mm aperture	A		Top of 50mm ID Standpipe at -0.6mbgl Top of Sand/Gravel at 17.0mbgl Top of Screen (1mm slot) at 19.1mbgl Hole drilled dry. Eventual seepage rise to RWL of 20.8mbgl by 18/07/2017 Base of Screen at 25.1mbgl

NOTES: RWL 18/07/2017 20.64mbgl

RWL = Rest Water Level; SC = Steel Casing; EC = Electrical Conductivity; mbgl = metres below ground level; ID = Inner Diameter; MW = Monitoring Well

Bentonite Pellets | Sand Plug | MW Blank Casing

Cement Grout | Gravel Pack | MW Screen

JS Drilling Ltd., The Old Creamery, Ballyhale, Co. Kilkenny, Ireland.

Mobile: 0877433451 Tel: 0567768944 E-mail: jim@jsdrilling.ie Web: www.jsdrilling.ie Vat No: IE 6431197 F

JS DRILLING
Geological & Environmental Drilling Contractors

RIBWORLD BOREHOLE

18-12-2012

Dawn Fresh Foods,
Fethard,
Co. Tipperary.

Draft Borehole Log

Depth (mbgl)	Description	Comments
0.0m-2.5m	Soft to firm clayey sandy silt with fine to coarse gravels	
2.5m-4.5m	Light grey weathered bedrock	
4.5m-14.8m	Strong dark grey LIMESTONE	
14.8m-16.0m	Fissure containing soft light brown clay.	Slight seepage of water
16.0m-23.0m	Strong dark grey LIMESTONE	
23.0m-24.0m	Fissure containing soft grey clay.	
24.0m-40.0m	Strong dark grey LIMESTONE	Water at 34m left for 20mins – No change in level
40.0m-82.0m	Strong dark grey LIMESTONE	• Slight seepage at 57m • Water at 67m approx. 2-3m^3/hr
82.0m-98.0m	Fractured dark grey Limestone with light brown sandy clay.	Water at 82m approx. 40-45m^3/hr
Comments: Static Water level on 18th Dec 19.5mbgl Borehole open to 98.0mbgl		

APPENDIX 2

Slug Tests

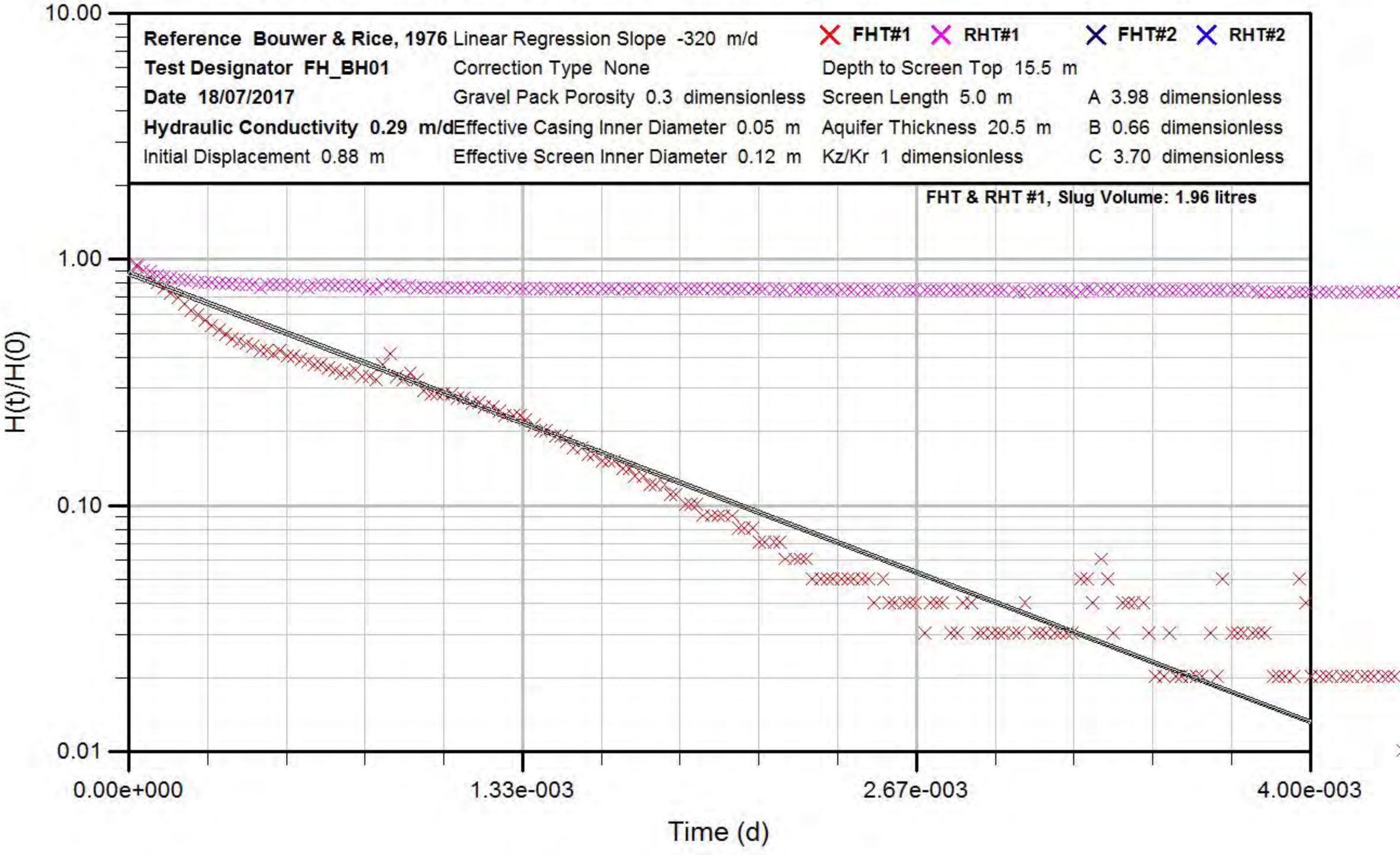
TableA2.1. Slug Test Analysis Details

Current Name	Borehole Diameter (m)	Liner Diameter (m)	Gravel Pack Radius (m) (= BH Dia/2)	Grout/ Bentonite Seal	Gravel Pack Top (mbD)	Gravel Pack Bottom (mbD)	Screen Top (mbD)	Screen Bottom (mbD)	Nominal Screen Length	Liner Rad or GP Radius?	Liner Dia/2 (GWL >Top Scrn/GP) OR modified GP Radius (GWL < TopScrn/GP)	Slug vol (m3)	Theoretical H0 (m)
			Eff. Screen Radius						*Eff. Well Scrn Lgth*	*Eff. Casing Radius*	*Eff. Casing Radius*		
FH_BH01	0.125	0.051	0.0625	Top of GP to 0 mbD	13.76	20.96	15.96	20.96	5	GP	0.030	0.00196	0.96
FH_BH02 Deep	0.125	0.051	0.0625	Top of GP to 0 mbD	17.78	25.52	19.58	25.52	6	GP	0.030	0.00196	0.96
FH_BH03	0.125	0.051	0.0625	Top of GP to 0 mbD	17.6	25.66	19.70	25.66	6	GP	0.030	0.00196	0.96

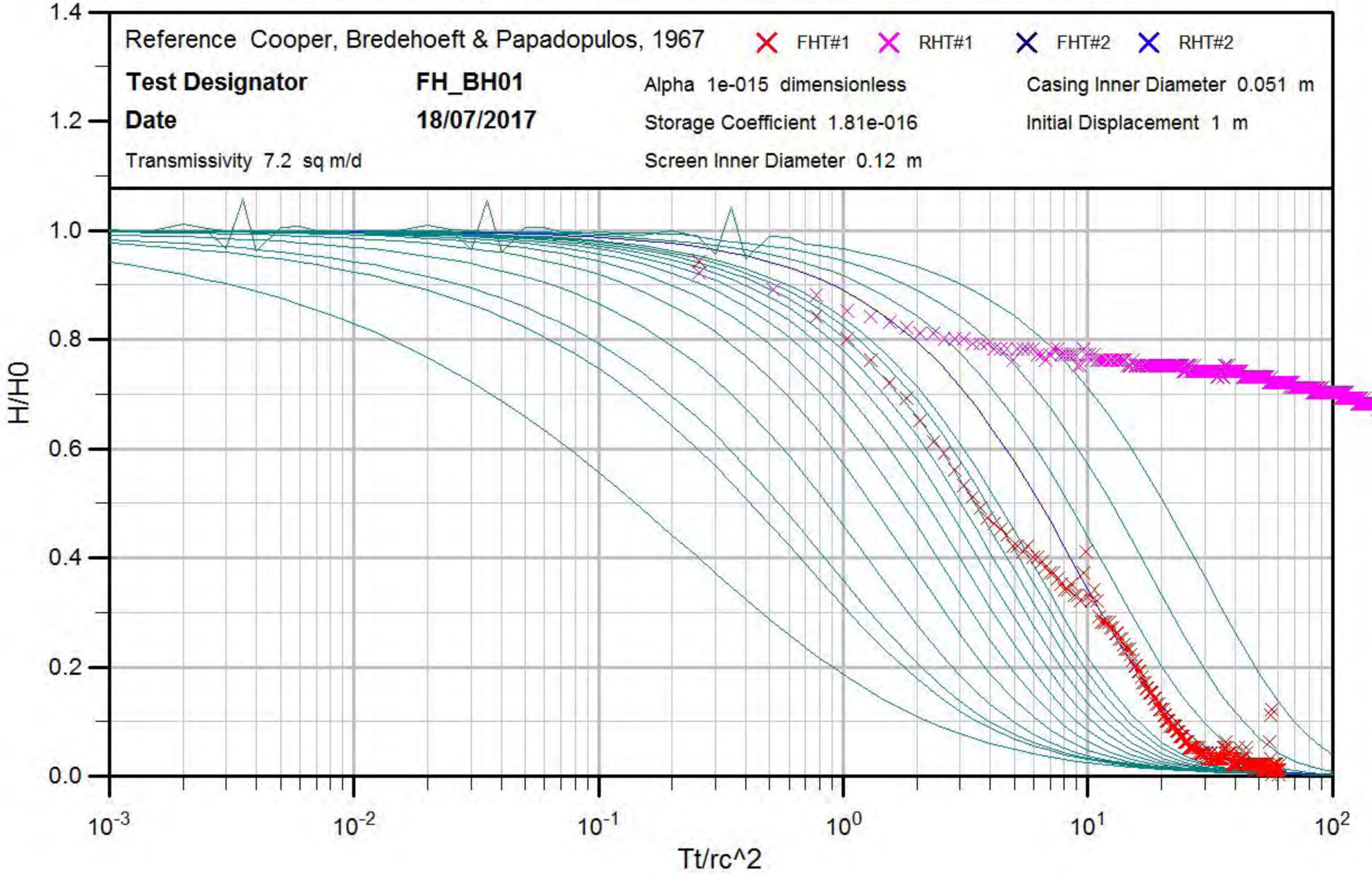
	Graph h(t) vs t RHT & FHT Done? Yes/No	RHT H0 (m)	FHT tA (sec)	RHT tA (sec)	Effective Casing Radius changes	Effective Casing Radius changes	Effective Casing Radius Changes TRUE ==> check GP Radius used	Calc Normalised Data RHT & FHT	Graph Normalised Data RHT & FHT	FHT T0 (sec)	RHT T0 (sec)	T0 RHT vs FHT Large Difference?	Analyse Cooper et al 1967. Alpha realistic?
	Trans Method	*Trans Method*	*Trans Method*	*Trans Method*	*H0 R&FHT < H0theor*	*T0 FHT lags after T0 RHT*	*yes/no*	*H(t)/H0*	*Log(H(t)/H0) vs t*	*H(t)/H0 = 0.378*	*H(t)/H0 = 0.378*	*Dynamic skin?*	*Low alpha = Low K skin?*
FH_BH01	Yes	0.47	6	6	Yes	No	Yes	Done	Done	56	Insuff Rec	Yes - Possible dynamic skin	Alpha un-realistically low
FH_BH02 Deep	Yes	0.07	22	12	Yes	Yes	Yes	Done	Done	Insuff Rec	32	Yes - Possible dynamic skin	Alpha High
FH_BH03	Yes	0.09	2	8	Yes	Yes	Yes	Done	Done	Insuff Rec	32	Yes - Possible dynamic skin	Alpha High

	RHT (down) & FHT (up) concave curv.	[RHT (down) & FHT (up)] Vs. [Meas. GWL & Top Scrn/GP]	Kest (m/d)	Comment
.	*GWL in Screen impact*		0.14	Geomean
FH_BH01	No	GWL in screen but impact seems small	0.29	Kest from Bouwer & Rice (1976) analysis. Data evaluation suggests low-k skin & possibly dunamic skin present. Kest may underestimate actual k of the aquifer
FH_BH02 Deep	No	GWL in screen but impact seems small	0.2	Kest from Bouwer & Rice (1976) analysis. Data evaluation possibly suggests dunamic skin present. Kest may underestimate actual k of the aquifer. Or because Well had not recovered from FHT, perhaps the effective slug volume was very small, i.e. (Vol of Physical Slug - Vol of Residual Unequalised water from FHT)
FH_BH03	No	GWL in screen but impact seems small	0.05	Kest from Bouwer & Rice (1976) analysis. Data evaluation possibly suggests dunamic skin present. Kest may underestimate actual k of the aquifer. Or because Well had not recovered from FHT, perhaps the effective slug volume was very small, i.e. (Vol of Physical Slug - Vol of Residual Unequalised water from FHT)

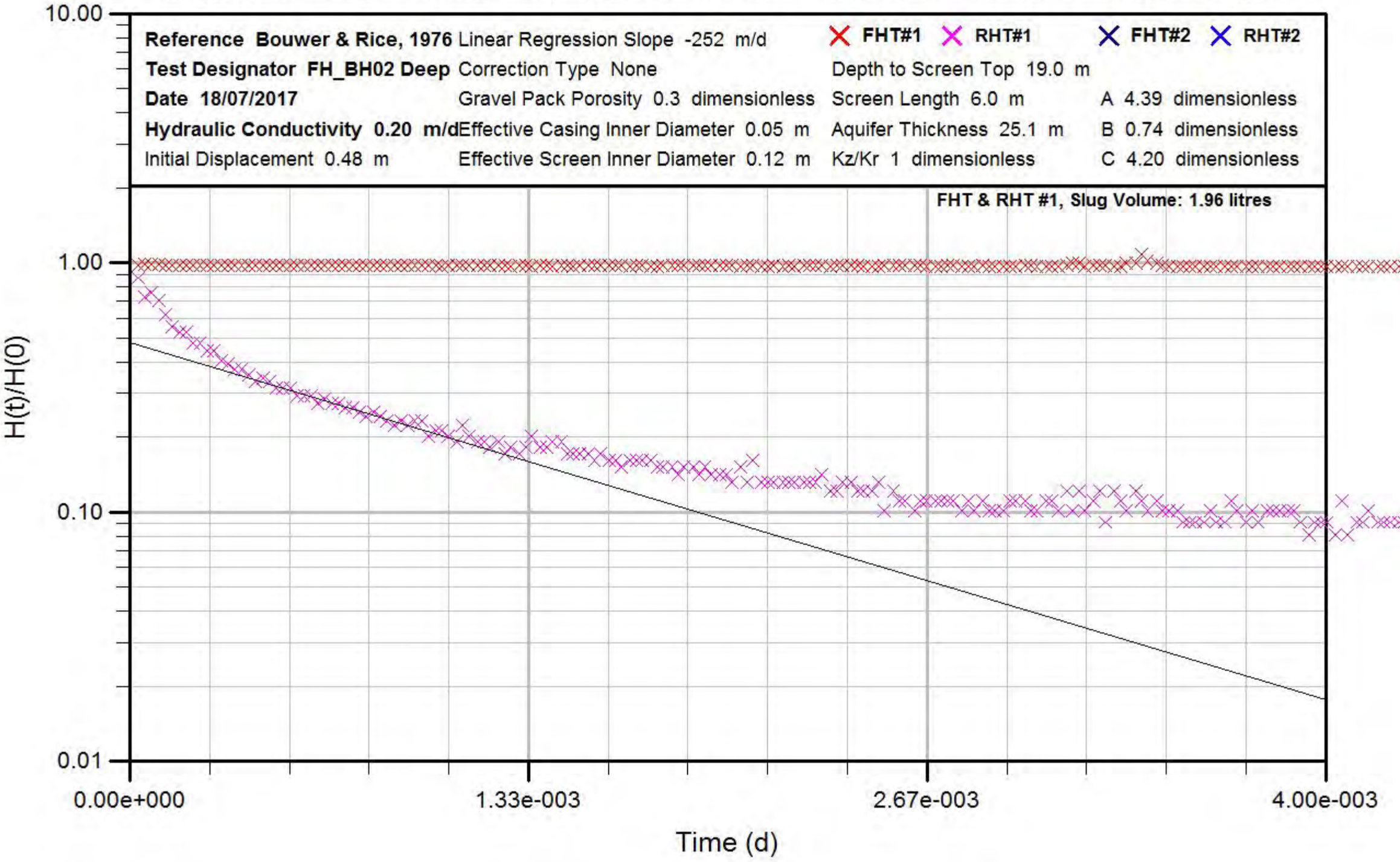
FH_BH01 Falling & Rising Head Tests - Hydraulic Conductivity Analysis



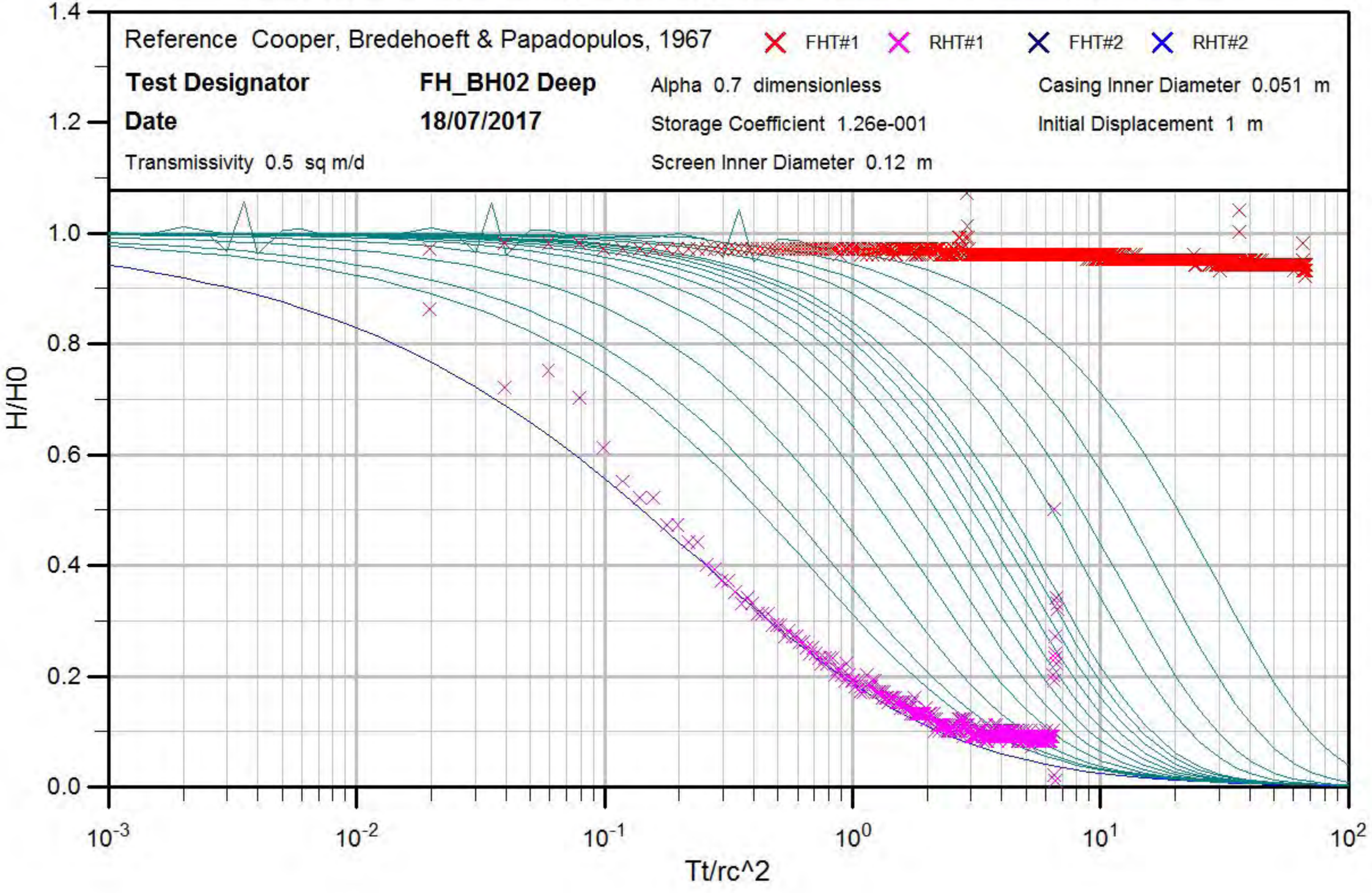
FH_BH01 Falling & Rising Head Tests - Low K Skin Check



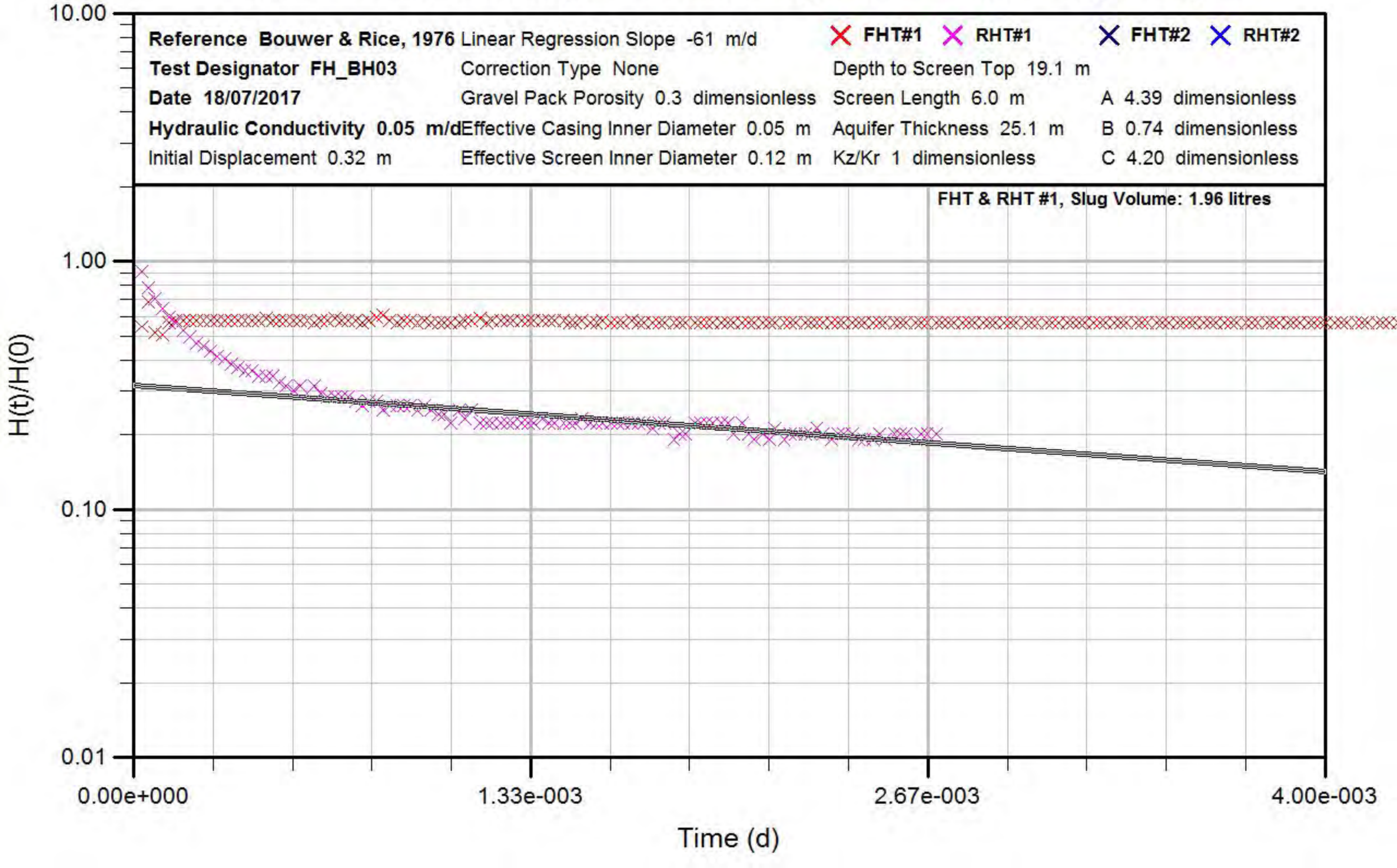
FH_BH02 Deep Falling & Rising Head Tests - Hydraulic Conductivity Analysis



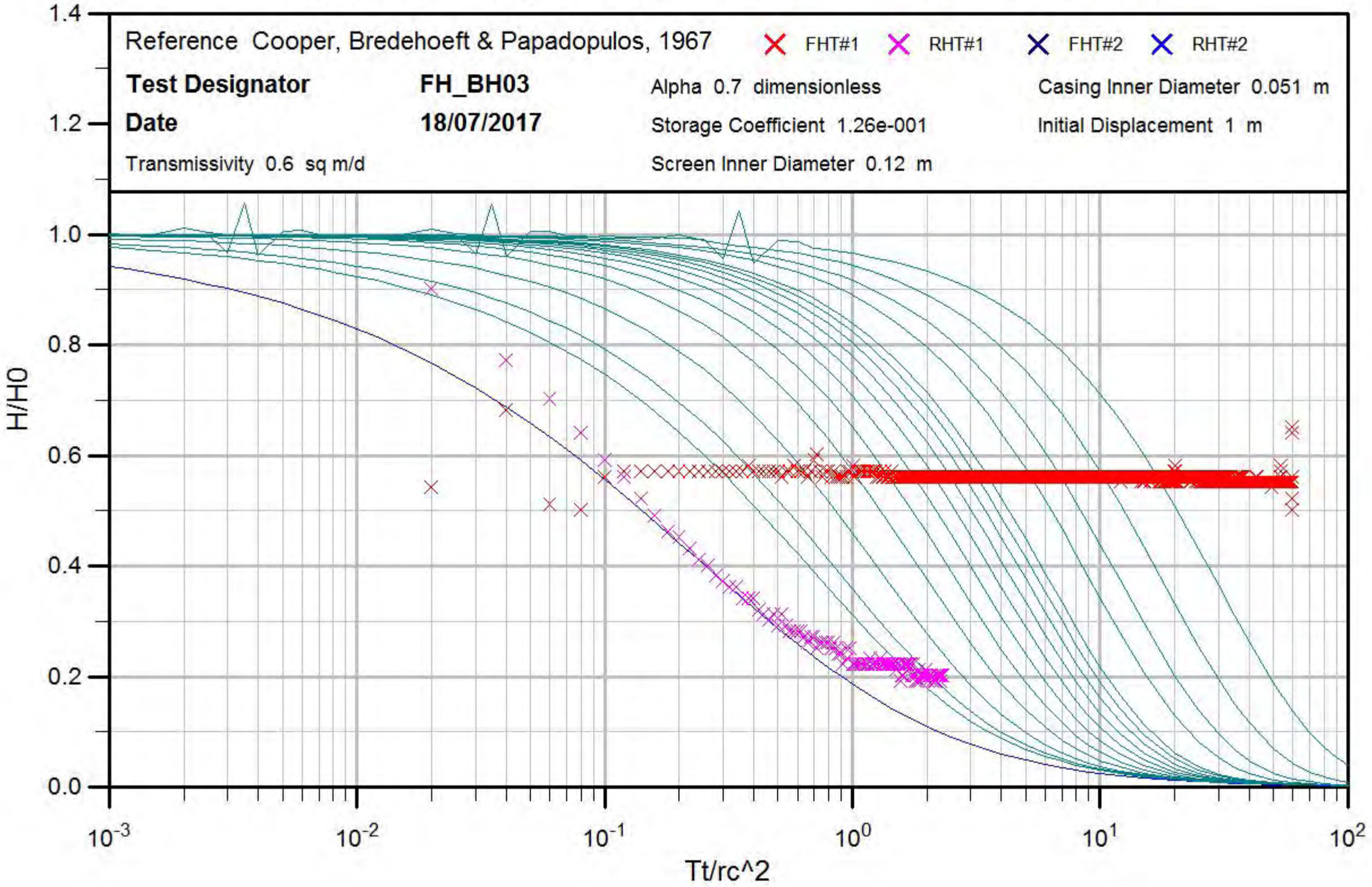
FH_BH02 Deep Falling & Rising Head Tests - Low K Skin Check



FH_BH03 Falling & Rising Head Tests - Hydraulic Conductivity Analysis



FH_BH03 Falling & Rising Head Tests - Low K Skin Check



APPENDIX 3

Water Quality Laboratory Certificates

ANALYSIS REPORT

CUSTOMER:	**TIPPERARY COUNTY COUNCIL**	**SAMPLE TYPE:**	**GROUND WATER**
ADDRESS:	Civic Offices, Limerick Road, Nenagh, County Tipperary	**CONDITION OF SAMPLE ON RECEIPT:**	Satisfactory
		DATE SAMPLED:	25 September 2017
REPORT TO:	**PETER CONROY**	**DATE RECEIVED:**	26 September 2017
SAMPLED BY:	**Peter Conroy**	**DATE ANALYSED:**	26 September 2017 – 27 October 2017
SAMPLING PT:	**1092 Burial Grounds Hydrogeological Assessments**	**DATE REPORTED:**	03 November 2017
ORDER NO:	-	**WORK NO.:**	**38884 C | 17P-067 |**

Ruth Murphy
Chemistry Laboratory Manager

Index to symbols used:

(F)	Analysis carried out at our Farranfore Laboratory.
Note 5a	Result outside scope of accreditation for Calcium (1-250 mg/L)
Note 5b	Result outside scope of accreditation for Alkalinity (5-800 mg/L $CaCO_3$)

- **The results relate only to the items tested.**
- **Opinions and interpretations expressed herein are outside the scope of INAB accreditation.**
- **The analysis report shall not be reproduced except in full without written approval of the laboratory.**

Table of Results

Method:	Parameter:	Unit	C17 Sep 615	C17 Sep 616	C17 Sep 617	C17 Sep 618	C17 Sep 619	C17 Sep 620	C17 Sep 621	C17 Sep 622
			Fethard BH01	**Fethard BH02 (Shallow)**	**Fethard BH02 (Deep)**	**Fethard BH03**	**Cahir BH01 Cahir**	**Cahir BH02**	**Cahir BH03**	**Cahir House Hotel**
	Chemical Analysis: (F)									
SCP 038	Cadmium dissolved	mg/l	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SCP 038	Chromium dissolved	mg/l	<0.001	<0.001	0.019	<0.001	<0.001	<0.001	<0.001	<0.001
SCP 038	Copper dissolved	mg/l	0.001	0.004	0.031	0.018	0.001	<0.001	0.002	0.003
SCP 038	Lead dissolved	mg/l	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001
SCP 038	Nickel dissolved	mg/l	<0.001	<0.001	0.026	<0.001	<0.001	<0.001	0.004	<0.001
SCP 038	Zinc dissolved	mg/l	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
SCP 038	Manganese dissolved	mg/l	0.004	0.004	0.021	0.009	0.006	0.002	0.038	<0.001
SCP 053a	**Calcium**	mg/l	121.73	**1213.60**[Note 5a]	78.08	54.26	101.30	108.70	49.98	94.49
SCP 053a	Magnesium	mg/l	10.609	39.467	18.259	8.163	11.91	12.33	15.735	9.550
SCP 053a	Sodium	mg/l	15.743	37.981	15.759	115.194	8.19	5.93	32.672	26.428
SCP 053a	Potassium	mg/l	3.577	6.363	4.941	15.584	10.48	8.88	27.354	17.792
SCP 052	pH	pH Unit	7.1	7.5	10.3	8.6	7.5	7.3	8.2	7.3
SCP 015	DO	mg/L	8.77	9.00	5.40	5.81	8.94	8.62	6.65	6.47
SCP 027a	Ammonium	mg/L N	0.04	<0.02	0.18	0.12	0.10	0.13	0.06	0.03
SCP 016	COD	mg/L	<10	41	93	13	<10	<10	<10	<10
SCP 015	BOD	mg/L	2.4	4.4	2.6	3.6	1.1	<1.0	9.7	<1.0
SCP 027c	Orthophosphate	mg/L P	0.01	0.01	7.69	0.13	0.03	0.03	<0.01	0.69
SCP 027g	Nitrate NO_3 as N	mg/L N	5.01	1.03	<0.25	0.49	2.24	2.77	1.23	7.96
SCP 027f	Nitrite NO_2 as N	mg/L N	0.029	<0.005	<0.005	0.036	0.006	0.005	0.017	<0.005

Table of Results

Method:		Parameter:	Unit	C17 Sep 615	C17 Sep 616	C17 Sep 617	C17 Sep 618	C17 Sep 619	C17 Sep 620	C17 Sep 621	C17 Sep 622
				Fethard BH01	**Fethard BH02 (Shallow)**	**Fethard BH02 (Deep)**	**Fethard BH03**	**Cahir BH01 Cahir**	**Cahir BH02**	**Cahir BH03**	**Cahir House Hotel**
		Chemical Analysis: (F)									
SCP 027d		Sulphate	mg/L	12.5	<0.5	15.1	84.10	9.3	7.90	55.1	33.7
SCP 066	*	TOC	mg/L	2.01	3.31	52.0	5.05	2.17	1.31	12.0	1.84
SCP 052		Conductivity	µS/cm @ 20°C	670	790	854	982	454	530	560	659
SCP 027		**Alkalinity**	mg/L	374	**1623**[Note 5b]	547	128	252	306	222	255
SCP 053		Iron	mg/L	<0.010	<0.010	1.79	0.011	<0.010	0.025	0.010	<0.010
SCP 027b		Chloride	mg/L	13.6	54.1	42.4	196	9.54	8.66	39.2	47.9

ANALYSIS REPORT

CUSTOMER:	**TIPPERARY COUNTY COUNCIL**	**SAMPLE TYPE:**	**GROUND WATER**
ADDRESS:	Civic Offices, Limerick Road, Nenagh, County Tipperary	**CONDITION OF SAMPLE ON RECEIPT:**	Satisfactory
		DATE SAMPLED:	12 December 2017
REPORT TO:	**PETER CONROY**	**DATE RECEIVED:**	12 December 2017
SAMPLED BY:	**Peter Conroy**	**DATE ANALYSED:**	12 – 19 December 2017
SAMPLING PT:	**1092 Burial Grounds Hydrogeological Assessments**	**DATE REPORTED:**	08 January 2018
ORDER NO:	-	**WORK NO.:**	**39508 C**

Ruth Murphy
Chemistry Laboratory Manager

Index to symbols used:

*	Analysis is not INAB Accredited
(D)	Analysis carried out at our Dunrine Laboratory.
(F)	Analysis carried out at our Farranfore Laboratory.
Note 5	Result outside scope of accreditation for Alkalinity (5-800 mg/L $CaCO_3$)
Note 5a	Result outside scope of accreditation for Calcium (1-250 mg/L)
Note 7	Insufficient Sample Available.

- **The results relate only to the items tested.**
- **Opinions and interpretations expressed herein are outside the scope of INAB accreditation.**
- **The analysis report shall not be reproduced except in full without written approval of the laboratory.**

Table of Results

Method:		Parameter:	Unit	C17 Dec 336 **BH01**	C17 Dec 337 **BH02 Shallow**	C17 Dec 338 **BH02 Deep**	C17 Dec 339 **BH03**
		Chemical Analysis: (F)					
SCP 038		Cadmium dissolved	µg/l	<0.45	<0.45	<0.45	<0.45
SCP 038		Chromium dissolved	µg/l	<1	<1	22.3	<1
SCP 038		Copper dissolved	µg/l	<1	1.9	71.4	1.9
SCP 038		Lead dissolved	µg/l	<1	<1	4.1	<1
SCP 038		Nickel dissolved	µg/l	<1	<1	25.9	<1
SCP 038		Zinc dissolved	µg/l	<8	11.0	<8	<8
SCP 038		Manganese dissolved	µg/l	7.8	16.7	33.8	9.6
SCP 053a		**Calcium**	mg/l	168	**342**[Note 5a]	**695**[Note 5a]	**304**[Note 5a]
SCP 053a		Magnesium	mg/l	10.5	34.7	4.2	9.8
SCP 053a		Sodium	mg/l	16.2	125	237	109
SCP 053a		Potassium	mg/l	3.5	7.64	3.24	14.2
SCP 052		pH	pH Unit	7.4	8.0	11.2	8.5
SCP 015	*	DO	mg/L	9.67	9.05	9.37	8.68
SCP 027a		Ammonium	mg/L N	0.02	<0.02	0.87	0.06
SCP 016		COD	mg/L	44	85	245	42
SCP 015		BOD	mg/L	1.62	2.4	2.29	3.76
SCP 027c		Orthophosphate	mg/L P	0.02	0.03	7.5	0.01
SCP 027g		Nitrate	mg/L N	2.61	4.76	0.36	0.69
SCP 027f		Nitrite	mg/L N	0.006	<0.005	<0.005	<0.005

Table of Results

Method:		Parameter:	Unit	C17 Dec 336 **BH01**	C17 Dec 337 **BH02 Shallow**	C17 Dec 338 **BH02 Deep**	C17 Dec 339 **BH03**
		Chemical Analysis: (F)					
SCP 027d		Sulphate	mg/L	11.4	132	<0.5	104
SCP 066	*	TOC	mg/L	1.64	9.42	76.6	5.61
SCP 052		Conductivity	µS/cm @ 20°C	666	1368	1188	873
SCP 027		**Alkalinity**	mg/L	386	428	**931**[Note 5]	243
SCP 027b		Chloride	mg/L	10.8	214	53.7	127
SCP 038		Iron, Dissolved	µg/L	0.012	0.009	0.73	0.04
		Microbiological Analysis: (D)					
SMP 019		Total Coliforms	MPN/100mL	4884	9208	<10	8864
SMP 052	*	Pseudomonas Auriginosa	cfu/100mL	20	Note 7	<10	<10
SMP 124	*	Faecal Coliforms	MPN/100mL	31	173	20	213
SMP 069	*	Clostridium Perfringens	cfu/100mL	200	Note 7	<100	<100
SMP 068	*	Faecal Streptococci	MPN/100mL	41	177	10	10

ANALYSIS REPORT

CUSTOMER:	**TIPPERARY COUNTY COUNCIL**	**SAMPLE TYPE:**	**GROUND WATER**
ADDRESS:	Civic Offices, Limerick Road, Nenagh, County Tipperary	**CONDITION OF SAMPLE ON RECEIPT:**	Satisfactory
		DATE SAMPLED:	11 April 2018
REPORT TO:	**PETER CONROY**	**DATE RECEIVED:**	12 April 2018
SAMPLED BY:	**Peter Conroy**	**DATE ANALYSED:**	13 – 24 April 2018
SAMPLING PT:	**1092 Burial Grounds Hydrogeological Assessments**	**DATE REPORTED:**	10 May 2018
ORDER NO:	-	**WORK NO.:**	**40356 C**

Ruth Murphy
Chemistry Laboratory Manager

Index to symbols used:

(D)	Analysis carried out at our Dunrine Laboratory.
(F)	Analysis carried out at our Farranfore Laboratory.
*	Analysis is not INAB accredited.
Note 1	Sample received at laboratory outside the maximum holding time. As a result, it is possible that the analysis results may have been compromised.

- **The results relate only to the items tested.**
- **Opinions and interpretations expressed herein are outside the scope of INAB accreditation.**
- **The analysis report shall not be reproduced except in full without written approval of the laboratory.**

Table of Results

Method:		Parameter:	Unit	C18-Apr 300 **Fethard BH01**	C18-Apr 301 **Fethard Shallow BH02**	C18-Apr 302 **Fethard Deep BH02**	C18-Apr 303 **Fethard BH03**
		Chemical Analysis: (F)					
SCP 038		Cadmium dissolved	µg/l	<0.45	<0.45	1.1	<0.45
SCP 038		Chromium dissolved	µg/l	<1	<1	17.9	<1
SCP 038		Copper dissolved	µg/l	1.1	1.3	18.2	1.1
SCP 038		Lead dissolved	µg/l	<1	<1	11.5	<1
SCP 038		Nickel dissolved	µg/l	1.0	3.2	34.8	2.2
SCP 038		Zinc dissolved	µg/l	<8	28.7	33.0	<8
SCP 038		Manganese dissolved	µg/l	6.1	55.5	45.1	<1
SCP 038		Iron dissolved	mg/l	0.02	0.03	1.45	0.02
SCP 053a		Calcium	mg/l	524	11.1	504	438
SCP 053a		Magnesium	mg/l	10.6	0.40	6.40	13.3
SCP 027h		Alkalinity Note 1	mg/l	388	459	530	366
SCP 027b		Chloride	mg/l	109	184	163	125
SCP 053a		Sodium	mg/l	16.0	1.61	288	78.3
SCP 053a		Potassium	mg/l	6.16	0.08	9.49	16.9
SCP 052		pH Note 1	pH Unit	7.2	7.5	11.0	8.0
SCP 015	*	DO	mg/L	6.8	9.09	9.24	5.36
SCP 027a		Ammonium Note 1	mg/L N	<0.02	<0.02	1.41	<0.02
SCP 016		COD	mg/L	10	194	340	25
SCP 015		BOD	mg/L	1.9	2.4	4.2	2.9
SCP 052		Conductivity	µS/cm @ 20°C	626	1328	1114	736
SCP 027c		Orthophosphate	mg/L P	0.02	0.05	13.8	0.09
SCP 027g		Nitrate	mg/L N	2.78	3.96	0.41	1.63
SCP 027f		Nitrite	mg/L N	<0.005	<0.005	<0.005	<0.005
SCP 027d		Sulphate	mg/L	116	209	<0.5	80.1
	*	TOC	mg/L	4.19	40.53	243.7	25.40

ANALYSIS REPORT

CUSTOMER:	**TIPPERARY COUNTY COUNCIL**	**SAMPLE TYPE:**	**GROUND WATER**
ADDRESS:	Civic Offices, Limerick Road, Nenagh, County Tipperary	**CONDITION OF SAMPLE ON RECEIPT:**	Satisfactory
		DATE SAMPLED:	19 June 2018
REPORT TO:	**PETER CONROY**	**DATE RECEIVED:**	20 June 2018
SAMPLED BY:	**Peter Conroy**	**DATE ANALYSED:**	21 – 28 June 2018
SAMPLING PT:	**1092 Burial Grounds Hydrogeological Assessments**	**DATE REPORTED:**	11 July 2018
ORDER NO:	-	**WORK NO.:**	**40967 C**

Ruth Murphy
Chemistry Laboratory Manager

Index to symbols used:

(D)	Analysis carried out at our Dunrine Laboratory.
(F)	Analysis carried out at our Farranfore Laboratory.
*	Analysis is not INAB accredited.
Note 5	Result outside scope of accreditation for calcium >500mg/L
#	Not enough sample for analysis.

- **The results relate only to the items tested.**
- **Opinions and interpretations expressed herein are outside the scope of INAB accreditation.**
- **The analysis report shall not be reproduced except in full without written approval of the laboratory.**

Table of Results

Method:		Parameter:	Unit	C18-Jun 554 **Fethard BH01**	C18-Jun 555 **Fethard BH02 Shallow**	C18-Jun 556 **Fethard BH02 Deep**	C18-Jun 557 **Fethard BH03**
		Chemical Analysis: (F)					
SCP 038		Cadmium dissolved	µg/l	<0.45	<0.45	<0.45	<0.45
SCP 038		Chromium dissolved	µg/l	<1	<1	14	<1
SCP 038		Copper dissolved	µg/l	<1	2	19	<1
SCP 038		Lead dissolved	µg/l	<1	<1	<1	<1
SCP 038		Nickel dissolved	µg/l	<1	1	4	<1
SCP 038		Zinc dissolved	µg/l	9	14	8	<5
SCP 038		Manganese dissolved	µg/l	2	13	11	51
SCP 038		Iron dissolved	µg/l	14	9	265	20
SCP 053		Calcium	µg/l	437	1165 Note 5	4.50	852 Note 5
SCP 053		Magnesium	µg/l	9.04	31.5	0.48	18.06
SCP 027h		Alkalinity	mg/l	395	579	686	495
SCP 027b		Chloride	mg/l	4.62	187	36.2	58.9
SCP 053		Sodium	µg/l	9.81	204	252	69.2
SCP 053		Potassium	µg/l	2.60	8.12	31.8	16.4
SCP 052		pH	pH Unit	6.7	#	11.8	7.7
	*	DO	mg/L	6.97	#	6.89	6.53
SCP 027a		Ammonium	mg/L N	<0.02	<0.02	0.62	<0.02
SCP 016		COD	mg/L	<10	44	35	<10
SCP 015		BOD	mg/L	<1.0	#	<1.0	<1.0
SCP 052		Conductivity	µS/cm @ 20°C	439	#	1793	658
SCP 027c		Orthophosphate	mg/L P	<0.01	<0.01	2.61	<0.01
SCP 027g		Nitrate	mg/L N	3.12	3.45	<0.25	<0.25
SCP 027f		Nitrite	mg/L N	<0.005	<0.005	0.34	<0.005
SCP 027d		Sulphate	mg/L	2.27	196	3.33	53.9
SCP 065	*	TOC	mg/L	9.51	15.4	16.0	17.6

APPENDIX 4

Fethard Phase 01 Report

Tipperary County Council

Burial Ground Extensions Hydrogeological Assessments

Fethard Phase 1 Report

May 2017

Prepared by:

Hidrigeolaíocht Uí Chonaire Teoranta

On behalf of

Tipperary County Council

Hidrigeolaíocht Uí Chonaire Teoranta
Oifig Chláraithe: Shantraud, Killaloe, Co. Clare. Cláraithe in Éireann Uimhir: 592043
Stiúrthóir: Peter Conroy

Document control information

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AUTHOR(S):	Peter Conroy
SIGNED:	 ***EurGeol. Peter Conroy PGeo*** ***Stiúrthóir***
DISCLAIMER:	This report has been prepared by Hidrigeolaíocht Uí Chonaire with all reasonable skill, care and diligence within the terms of the contract with the client, incorporating our terms and conditions and taking account of the resources devoted to it by agreement with the client. We disclaim any responsibility to the client and others in respect of any matters outside the scope of the above. This report is confidential to the client and we accept no responsibility of whatsoever nature to third parties to whom this report, or any part thereof, is made known. Any such party relies upon the report at their own risk.

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Appendix 1 Trial Pit Logs

1 Introduction

Tipperary County Council appointed Hidrigeolaíocht Uí Chonaire to carry out hydrogeological assessments of proposed burial ground extensions at Fethard, Cahir and Cloghprior in Co. Tipperary.

A phased approach was adopted for the hydrogeological assessment. During Phase 1 an initial investigation was carried out to determine the general suitability of each site for the proposed development. On completion of Phase 1, sites that are considered likely to be suitable for the proposed development will proceed to Phase 2 of the assessment. Phase 2 will comprise a detailed site investigation and risk assessment in line with the relevant guidance documents.

This report documents the Phase 1 investigation and assessment of the proposed extension at the Fethard burial ground, in Fethard, Co. Tipperary.

2 Methodology

The Phase 1 hydrogeological assessment is set out in Table 1.

Table 1 Phase 1 Hydrogeological Assessment

Phase 1	
Desk Study	Assess relevant national and local scale databases and GIS datasets to develop a preliminary site hydrogeological conceptual model. E.g. • GSI maps and databases; • OSi current & historical maps & aerial photography; • TCC existing site reports and data, and anecdotal info; • EPA databases
Site Investigation	Carry out the initial site visit: • Carry out site walkover survey with TCC personnel; and, • Carry out interview of key stakeholders with knowledge of site characteristics
	Supervise Excavation of Trial Pits • Direct Excavator contractor • Log trial pit geology in line with BS5930 • Log groundwater behaviour during excavation
Reporting	• Prepare preliminary report in line with Guidance Documents ○ Assessing the Groundwater Pollution Potential Of Cemetery Developments (UK Environment Agency 2004) ○ The Impact of Cemeteries on the Environment & Public Health (WHO 1998) • Make recommendations on suitability of site and need (if any) for Phase 2 investigations

The site walkover and trial pit investigation were carried out on 20 December 2016.

3 Site Location

The site is located on the northern edge of Fethard town on the east side of the R689 road to Killenaule, 1.1 km north of the town centre (Figure 1). The proposed extension area occupies part of an agricultural field adjacent to the north side of the existing cemetery. The proposed area is approximately 105 m long east to west and 40 m wide north to south, aligned with the existing cemetery boundary. The proposed area is set back 20 m from the adjacent R689 road and will be accessed from the existing cemetery. Photos of the proposed extension area are shown below.

Photo 1. Panoramic view northeast across site (boundary with existing cemetery on RHS of photo; boundary with R689 on LHS of photo)

Photo 3. View west across site along existing cemetery boundary, showing TP02 with TP01 and playing fields beyond

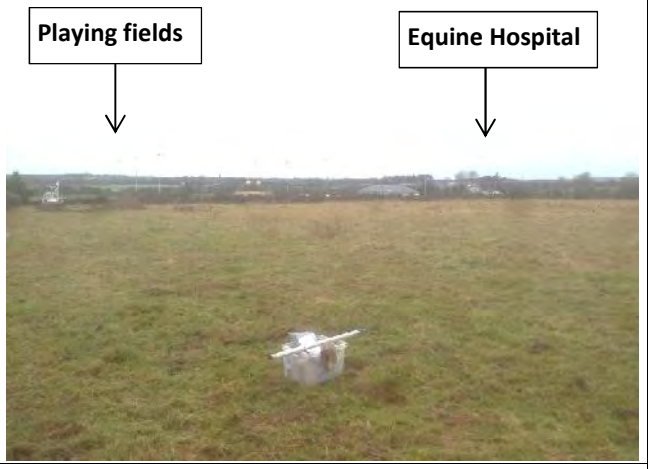


Photo 4. View northwest across site, showing TP01 with playing fields and equine hospital in the distance

Photo 5. View southeast across TP04 with TP03 and northeast corner of existing cemetery beyond.

Photo 6. Typical subsoil profile, as represented by TP01

3.1 Hydrogeological Setting

Table 2 Hydrogeological Setting

	Description/Comments
Topography (**Figure 1**)	The site is at an elevation of about 80 mOD. Kilknockan Hill rises to 130 mOD, 800 m north of the site. A ridge extends south-southwest from the hill towards Fethard, with the ridgeline sloping gently to about 60 mOD at the Clashawley River in the town centre. The site lies on the western side of the ridge, close to the ridgeline. In the vicinity of the site the ridgetop and flank is broad with a gentle west-southwest slope.
Land use	Landuse to the north and east is agricultural, with a mix of pasture for silage and grazing. The existing cemetery forms the southern site boundary. A Tipperary Co. Co. depot and a food processing industry are present south of the burial ground in turn. On the west side of the R689 there are various playing pitches. To the north of the playing pitches there is an equine hospital. Domestic residences also occur along the road.
Surface Hydrology (**Figure 1**)	The land in the vicinity of the site is well drained, with no agricultural land drains or vegetative indicators of poor drainage. There are no streams in the vicinity of the site. A storm water drain runs along the western side of the R689 road adjacent to the site. The Clashawley River flows south towards Fethard approximately 1 km west of the site. The river turns east in the town centre. The Killenaule Stream flows south 350 m east of the site on the opposite side of the Kilknockan ridge and joins the Clashawley River on the eastern side of Fethard.
Topsoil http://gis.epa.ie/envision	The soils on the ridge in the vicinity of the site are mapped as deep well-drained soils.
Subsoil (**Figure 2**) www.gsi.ie/mapping	The subsoils are dominated by moderately permeable glacial till (boulder clay) derived mainly from limestone. Bedrock outcrop occurs at the top of Kilknockan Hill to the north of the site and in places moving south along the ridge line, to the south east of the site.
Groundwater Vulnerability (**Figure 3**) www.gsi.ie/mapping	The areas of bedrock outcrop on the hilltop and ridgeline are mapped as extreme (X) with a halo of extreme (E) vulnerability. The remainder of the area around the site is mapped as high vulnerability (H). Groundwater vulnerability concepts are described in detail in GSI guidance (GSI 1999).
Geology (**Figure 4**) www.gsi.ie/mapping	The site and surrounding area are underlain by Dinantian Pure Bedded Limestone (DPBL) rock types.
Aquifer Classification (**Figure 5**) www.gsi.ie/mapping	The DPBL bedrock is classified as a Regionally Important Aquifer – Karstified Diffuse (Rk_d).
Groundwater Body (GWB) www.wfdireland.ie	The borehole is located in the Clonmel groundwater body. The risk status of the groundwater body is currently under review by the EPA. (www.gsi.ie/Programmes/Groundwater/Projects/Groundwater+Body+Descriptions)

Recharge (mm/yr) www.gsi.ie/mapping	117	The national recharge map indicates a recharge value of 117 mm/yr in the vicinity of the site

3.2 Site Walkover

The initial site walkover survey was carried out on 20 December 2016. The day of the investigations started off dry; however heavy rain set in from noon onwards. Further site walkover during dry conditions was carried out on 15, 16 and 20 March 2017.

The site walkover information is summarised in Table 2, in terms of the setback distances recommended in the EA (2004) guidance document. Additional recommended setback distances from the Northern Ireland Environment Agency Guidance Document "Cemeteries, Burials and the Water Environment" (NIEA, 2016) are shown in brackets and italics in Table 3. The setback distances for features identified during the site walkover are shown in Figure 6.

Table 3 Recommended Setback Distances and Other Criteria

Walkover Survey Feature	Recommended Setback Distance (EA 2004)	Walkover Survey Findings
Potable Groundwater Supply Source	250 m	Fethard Equine Hospital water supply borehole: • Borehole in use • Exact location to be confirmed, possibly <250 m from site boundary • Probably upgradient to lateral gradient from site Ribworld Water Supply Boreholes: • 2 no. Boreholes not in use
Watercourse or Spring (*or other boreholes or wells*)	30 m (*50 m*)	None
Field Drains	10 m	None
No burials in standing water	n/a	Watertable > 4.0 mbgl and below maximum burial depth of 2.7 mbgl
>1.0 m of soil/subsoil cover		Depth to bedrock >4.0 m
>1.0 m of subsoil below maximum burial depth		Depth to bedrock >4.0 m with maximum burial depth of 2.7 mbgl.
No sand and gravel subsoil		SILT subsoil encountered in Trial Pits

3.3 Trial Pit Site Investigation

Five trial pits were excavated across the proposed extension area on 20 December 2016. The trial pits were labelled TP01 to TP05 and the locations are shown on Figure 1. The trial pit findings are summarised in Table 4. Trial pit logs and photos are shown in Appendix 1.

Table 4 Summary of Trial Pit Data

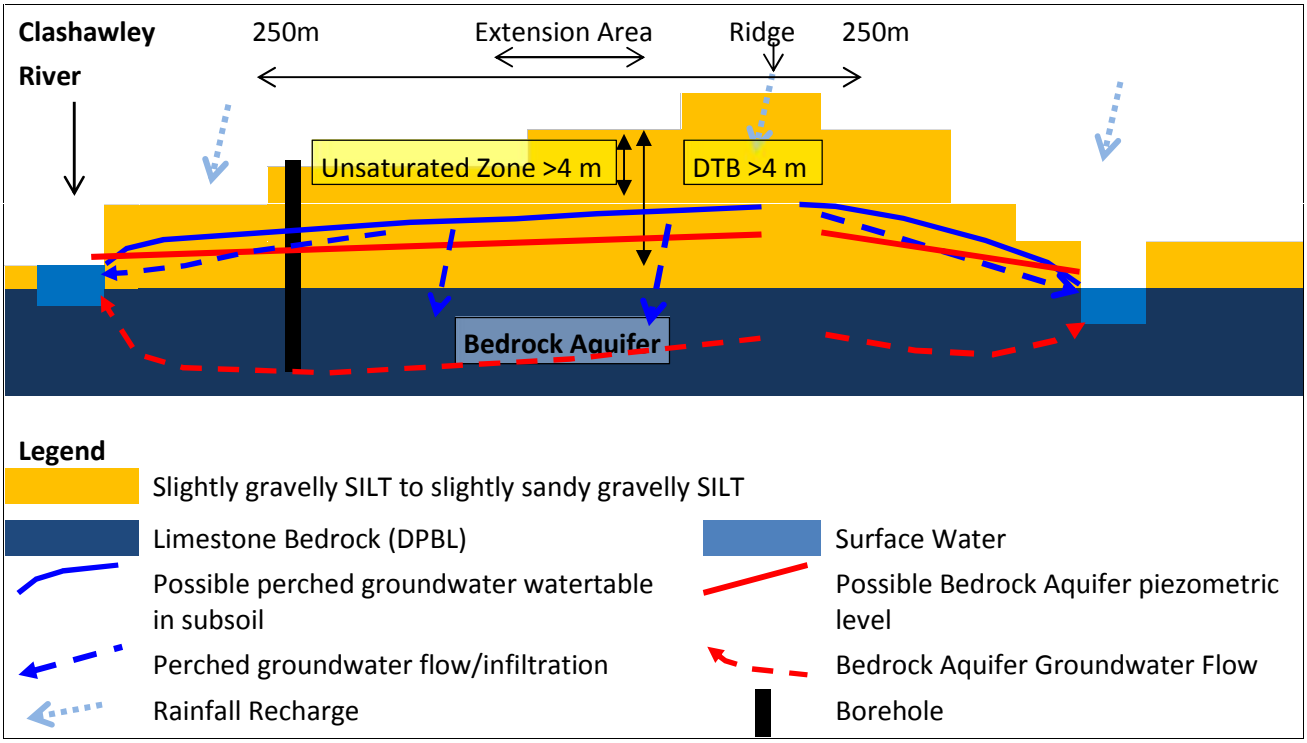
Location	Summary Geology	Depth to Bedrock	Groundwater	Suitability for Grave Digging
TP01 X: 221022; Y: 135953	0 to 0.25 m: Topsoil 0.25 to 1.2 m: Slightly gravelly SILT 1.2 to 4.0 m: Slightly sandy gravelly SILT	> 4.0 m	Dry. No water encountered	No collapse, stable during excavation. Boulders up to 0.5 m diameter.
TP02 X: 221067; Y: 135961	0 to 0.25 m: Topsoil 0.25 to 1.1 m: Slightly gravelly SILT 1.1 to 4.0 m: Slightly sandy gravelly SILT	> 4.0 m	Dry. No water encountered	No collapse, stable during excavation. Boulders up to 0.5 m diameter.
TP03 X: 221121; Y: 135970	0 to 0.25 m: Topsoil 0.25 to 0.9 m: Slightly gravelly SILT 0.9 to 3.8 m: Slightly sandy gravelly SILT	> 3.8 m	Dry. No water encountered	No collapse, stable during excavation. Boulders up to 0.5 m diameter.
TP04 X: 221092; Y: 135998	0 to 0.25 m: Topsoil 0.25 to 0.9 m: Slightly gravelly SILT 0.9 to 4.0 m: Slightly sandy gravelly SILT	> 4.0 m	Dry. No water encountered	No collapse, stable during excavation. Boulders up to 0.5 m diameter.
TP05 : 221045; Y: 135988	0 to 0.25 m: Topsoil 0.25 to 1.4 m: Slightly gravelly SILT 1.4 to 4.0 m: Slightly sandy gravelly SILT	> 4.0 m	Dry. No water encountered	No collapse, stable during excavation. Boulders up to 0.5 m diameter.

4 Preliminary Site Conceptual Model

4.1 Conceptual Model Diagram

A basic 2D conceptual model diagram is shown in Figure 7. The diagram shows the relationship between the proposed extension area and the underlying hydrogeology.

Figure 7 Basic 2D Schematic Hydrogeological Conceptual Model Diagram



Rainfall infiltration to the subsoil potentially creates a perched water table in the subsoil above the bedrock aquifer, and/or water in the subsoil infiltrates down into the bedrock aquifer. Groundwater in the bedrock aquifer and any perched groundwater in the subsoil flows south-southwest from below the site towards the Clashawley River.

Infiltration from the ground surface through active burial areas acts as a pathway for contaminants associated with burials to migrate down into the groundwater. The contaminants may then migrate laterally in the direction of groundwater flow in the perched ground (if it occurs) and in the bedrock aquifer, towards any downgradient boreholes and the Clashawley River.

Site investigations show that there will be greater than 1 m of unsaturated subsoil below the maximum burial depth. There are no watercourses or drains within the recommended setback distances. As such, contaminants are likely to be attenuated in the subsoil so that the proposed development is unlikely to result in negative impacts at down gradient surface water receptors.

There may be one borehole (i.e. the Equine Hospital) in use as a water supply within 250 m of the site; however it is likely to be upgradient to side gradient of the site in terms of the groundwater hydraulic gradient and groundwater flow direction. This would make it unlikely to be impacted by the proposed development.

There are two currently unused water supply boreholes within 250 m of the site, but greater than 50 m from the site. These boreholes are likely to be downgradient of the site. Contaminant attenuation in the unsaturated subsoil may be sufficient to prevent site related contaminants from impacting on these wells.

4.2 Conceptual Model Uncertainty

Due to gaps in the site specific data set there is a degree of uncertainty with respect to several components of the hydrogeological conceptual model.

Data gaps include:

- The full thickness of the subsoil layer and depth to bedrock;
- Data on the presence or absence of perched water in the subsoil, and the seasonal variation in the perched groundwater level if it occurs;
- The seasonal variation in the bedrock aquifer piezometric level and the degree to which water can infiltrate to the bedrock aquifer;
- The hydraulic gradient and groundwater flow direction in the bedrock aquifer, and in perched groundwater if it occurs; and,
- Baseline groundwater quality in any perched groundwater if it occurs, and in the bedrock aquifer.
- The degree of contaminant attenuation below the site at the potential for negative impacts on downgradient private borehole groundwater supplies.

Due to the uncertainty in the preliminary hydrogeological conceptual model and the potential to impact on downgradient private borehole groundwater supplies, a Tier 2 site investigation and quantitative risk assessment of the proposed development is recommended to be carried out in line with the EA guidance document (EA 2004).

5 Conclusions

A preliminary hydrogeological conceptual model has been developed for the proposed extension to the Fethard Burial Ground Site.

Several indicators suggest that the site may be suitable for the proposed development:

- The subsoils were stable during excavation of the trial pits and are likely to be suitable for excavation of graves;
- There is greater than 1 m of unsaturated subsoil below the maximum burial depth; and;
- There are no watercourses or drains within the recommended setback distances.

Private water supply boreholes occur within 250 m downgradient of the proposed extension area.

There is a degree of uncertainty with respect to several components of the hydrogeological conceptual model, due to data gaps in the site characterisation data.

The presence of private water supply boreholes within 250 m downgradient of the proposed extension area and the uncertainty in the preliminary conceptual model mean that further investigation is needed to determine whether or not the site is suitable for the proposed development.

Due to the presence of several favourable indicators, it is considered worthwhile to proceed to a Phase 2 investigation at the site.

6 Recommendations

Note: After these recommendations, it was decided to commission a Tier 2 investigation!!

It is recommended Phase 2 further investigation of the proposed burial ground should be carried out as follows:

- Install 3 no. bedrock groundwater monitoring wells at the site.
- If perched groundwater occurs in the subsoil install additional monitoring wells in the saturated subsoil.
- Carry out a falling head slug test at each groundwater monitoring well to determine the hydraulic conductivity of the surrounding subsoil or bedrock.
- Carry out a well survey within 500 m of the site.
- Carry out a topographic survey of the site investigation locations.
- Carry out baseline groundwater level monitoring as follows:
    - Due to below average rainfall between October 2016 and May 2017 it is considered that the conditions observed onsite to date do not represent the worst case scenario for high groundwater levels.
    - It is recommended that monthly groundwater level monitoring should be carried out for 12 months from June 2017 in anticipation of very low summer groundwater levels and potentially a wet subsequent winter which may give an indication of worst case, minimum unsaturated zone conditions at the site. At least one monitoring round should be after a heavy rainfall event.
- Carry out baseline water quality monitoring as follows:
    - There are no surface water courses in the vicinity of the site. As such, no surface water monitoring is proposed for the Phase 2 investigations.
    - Groundwater quality monitoring should be carried out at quarterly intervals at each groundwater monitoring well, for a 12 month period, starting in June 2017.
    - The recommended water quality parameter suite is:
        - pH, Dissolved O_2, Electrical Conductivity, COD, BOD, Orthophosphate, Total Phosphorous, Total Organic Carbon, Total Alkalinity, Chloride, Nitrate, Nitrite, Sulphate, Ammonia, Dissolved Metals (Cd, Cr, Cu, Fe, Pb, Mn, Ni, Zn, Ca, Mg, Na, K).
        - The winter monitoring round should include the bacterial indicators pseudomonas aeruginosa, faecal streptococci, Clostridium spp., and fecal and total coliforms.

7 References

EA, 2004. Assessing the groundwater pollution potential of cemetery developments. UK Environment Agency. Product Code SCHO0404BGLA-E-P.

GSI/DELG/EPA, 1999. Groundwater Protection Schemes. Geological Survey of Ireland.

NIEA, 2016. Cemeteries, Burials and the Water Environment. A good practice guide for applicants and planning authorities when planning cemetery developments or extensions. Version 1.1 / April 2016. Northern Ireland Environment Agency.

Figures

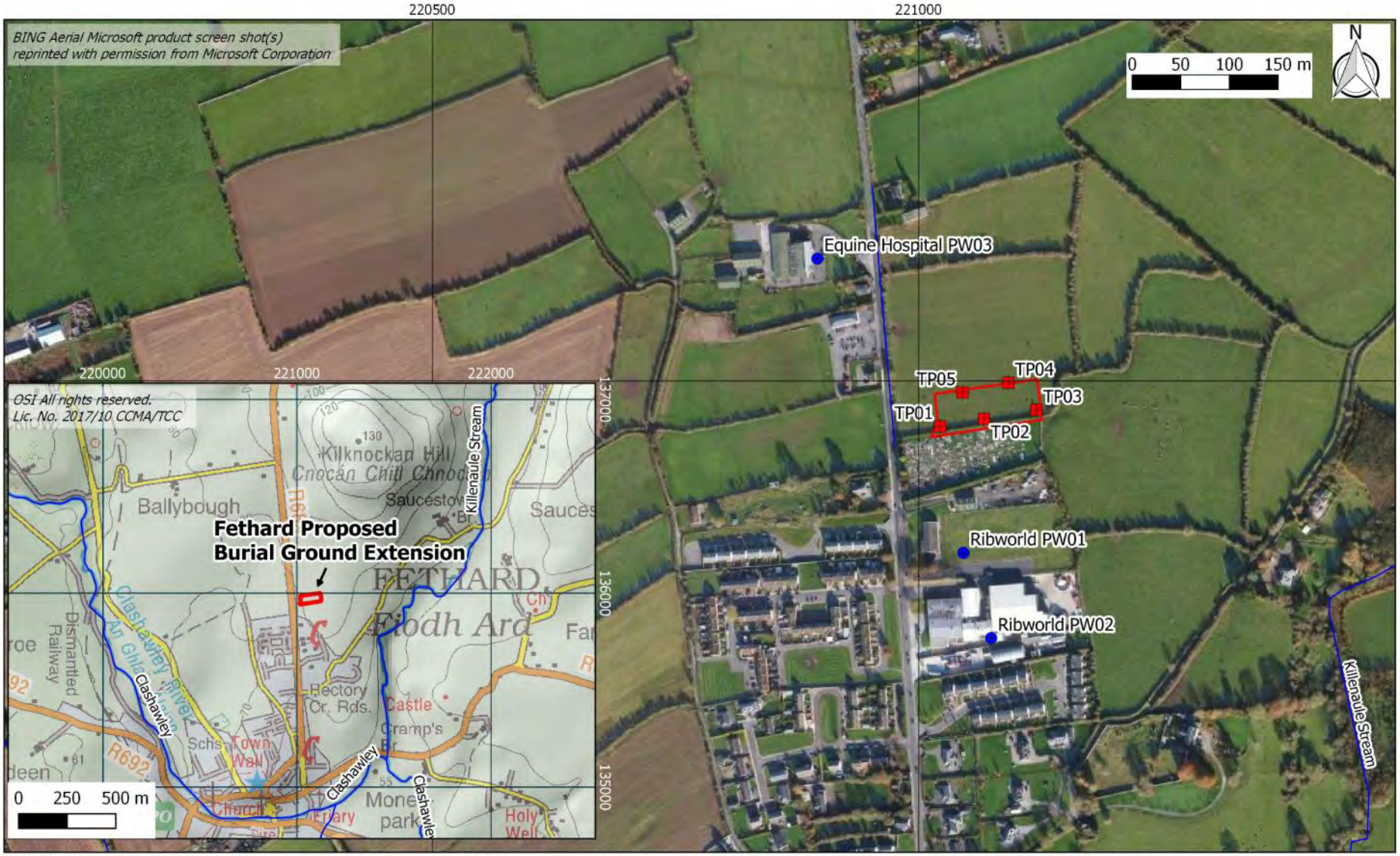


Figure 1. Site Location and Site Investigation Locations

Burial Ground Extension Boundary

Trial Pit

Borehole

Strom Drain

Hidrigeolaíocht Uí Chonaire Teoranta
Project No. & Name: 1092 Tipperary Burial Ground Extensions
Stage: Fethard Phase 1
Drawn By: Peter Conroy
Date: 20170509
Revision No: A

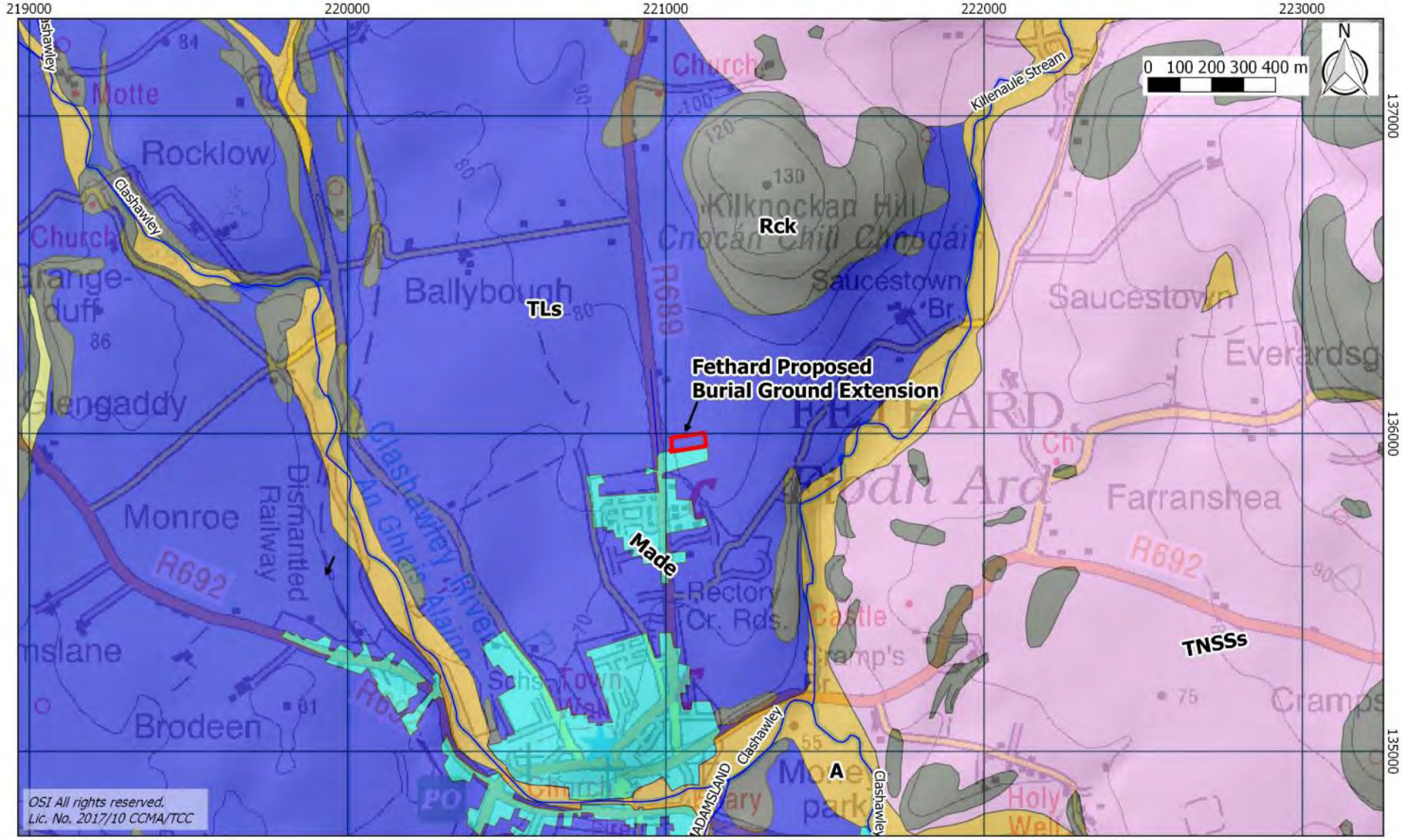


Figure 2. Subsoil

- Burial Ground Extension Boundary
- River
- Limestone Till (TLs)
- Alluvium (A)
- Made Ground (Made)
- Bedrock Outcrop (Rck)
- Namurian Sandstone and Shale Till (TNSSs)

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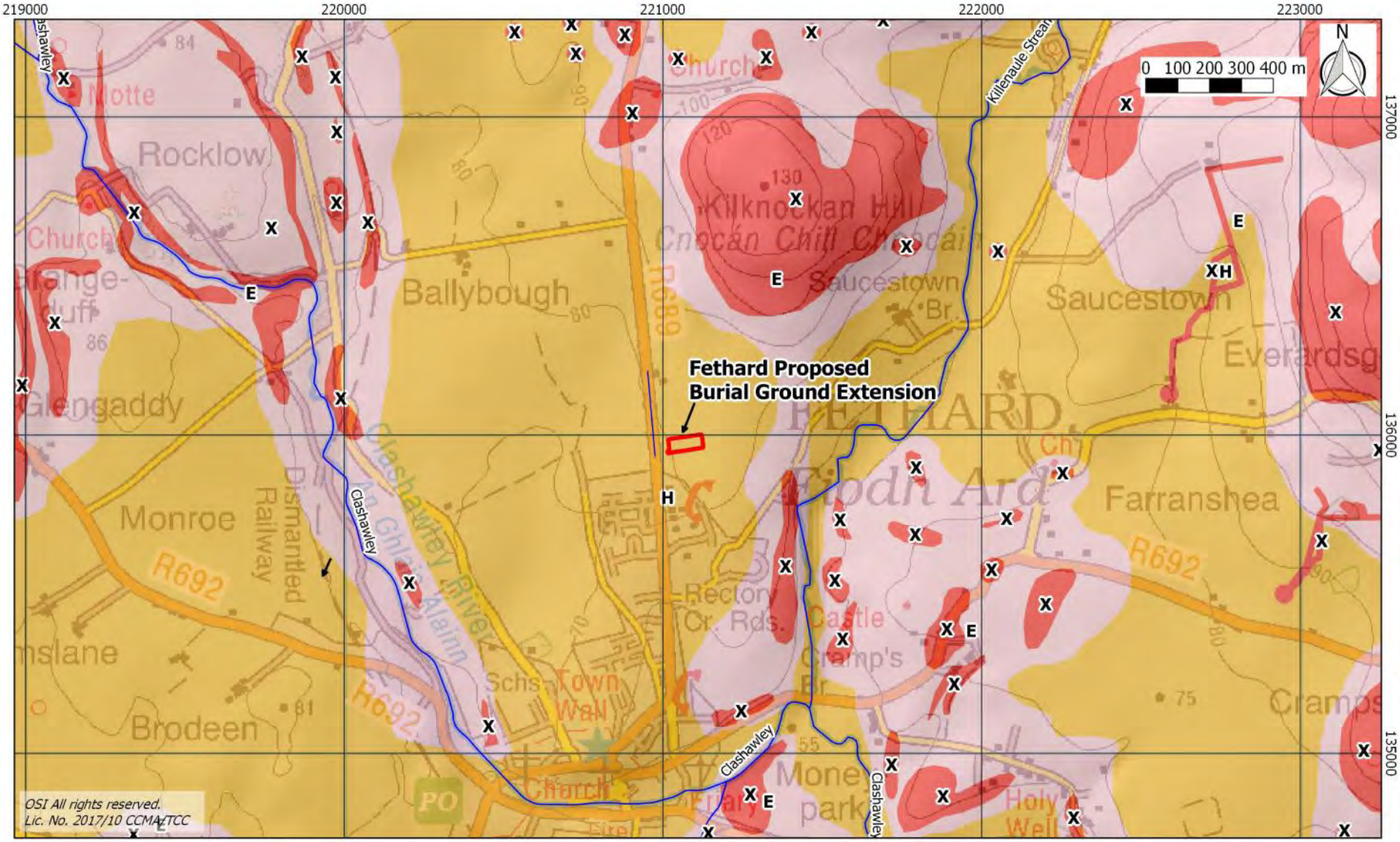

Figure 3. Groundwater Vulnerability

Burial Ground Extension Boundary
River
Extreme (X)
Extreme (E)
High (H)
Moderate (M)
Low (L)

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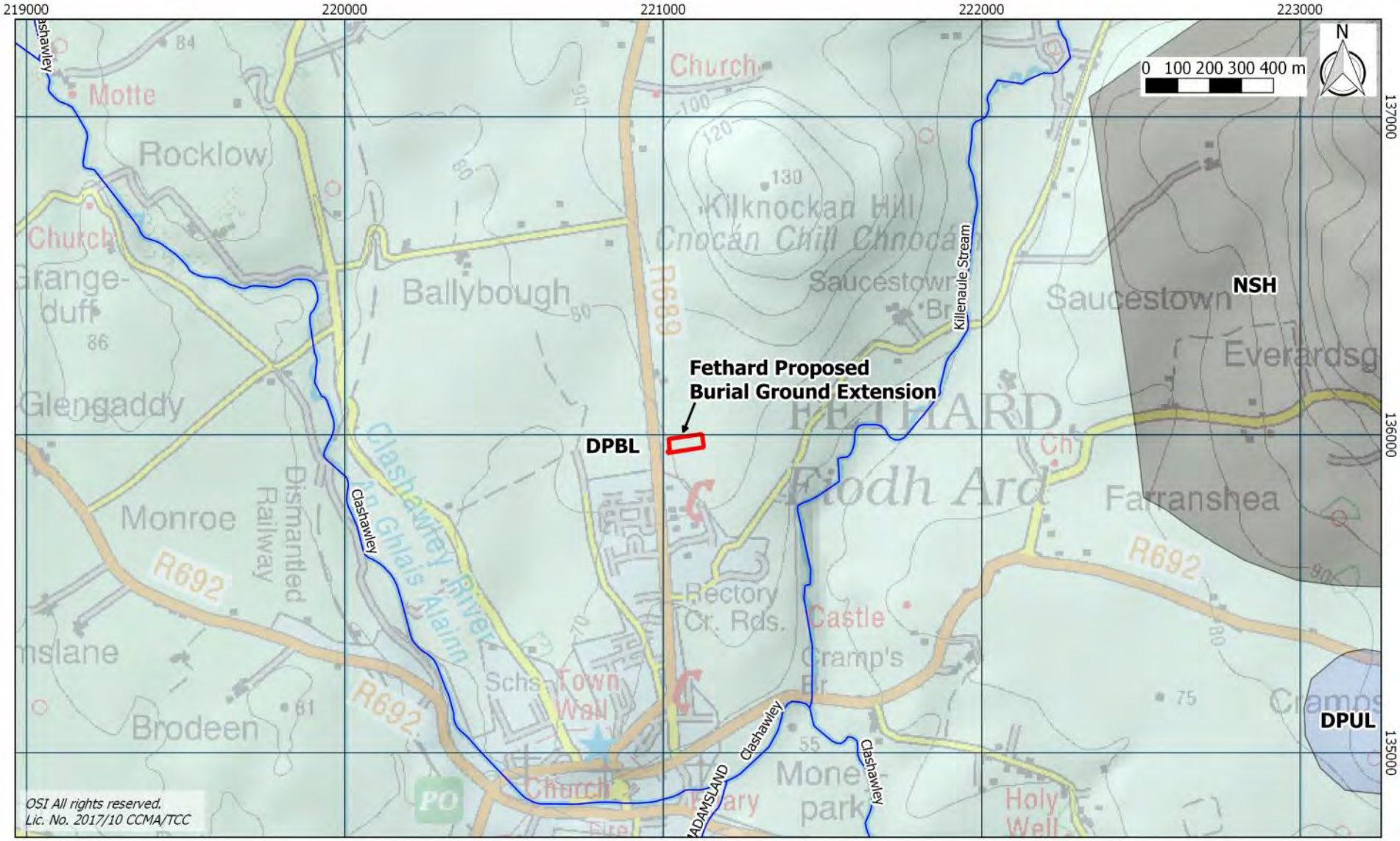

Figure 4. Bedrock Units

Burial Ground Extension Boundary

River

Dinantian Pure Bedded Limestone (DPBL)

Dinantian Pure Unbedded Limestone (DPUL)

Namurian Shale (NSH)

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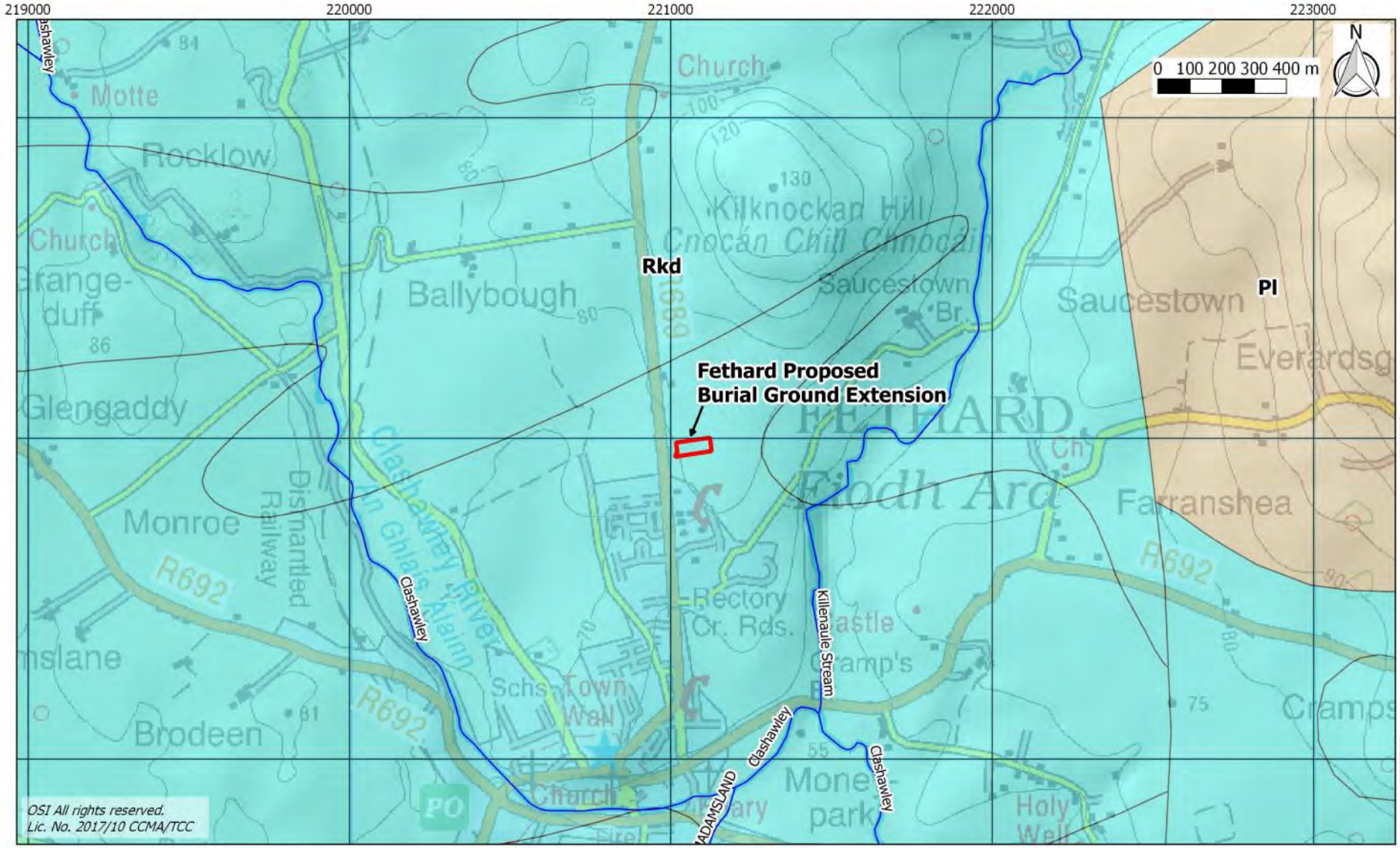

Figure 5. Bedrock Aquifer

Burial Ground Extension Boundary

River

Regionally Important Aquifer - Karstified Diffuse (RKd)

Poor Aquifer - Bedrock Which Is GEnerally Unproductive Except in Local Zones (Pl)

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Figure 6. Water Feature Buffer Zones

Burial Ground Extension Boundary
Trial Pit
Borehole
Strom Drain
Buffer Zone Boundary

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Project No. & Name: 1092 Tipperary Burial Ground Extensions
Stage: Fethard Phase 1
Drawn By: Peter Conroy
Date: 20170509
Revision No: A

Appendix 1

TRIAL PIT LOG

TP01

Client:	Tipperary County Council	***Date excavated:***	20/12/2016
Project:	Tipperary Burial Ground Extensions	***Logged by:***	Peter Conroy
Site:	Fethard Burial Ground	***Equipment used:***	8 ton Tracked Excavator

Soil (S)/ Water (W) Sampling and/or Monitoring: Sample No.	PID Readings	Pit Completion	Groundwater occurrence	Depth (mbGL)	Geology - graphical log	Description
		Backfilled with arisings		1.0		0 to 0.25m: TOPSOIL.
						0.25 to 1.2m: Firm, moist, orange brown, slightly gravelly SILT. Gravel clasts are subangular blue grey micrite limestone and grey shale, fine gravel size.
				2.0		1.2 to 4.0m: Firm to stiff, moist, pale brown, slightly sandy gravelly SILT with cobbles and boulders. Gravel clasts are subangular to subrounded, fine to coarse size blue grey and grey black micrite limestone.
				3.0		
				4.0		End of Hole: 4.0m
				5.0		
				6.0		

Comments

ING, X: 221022; Y: 135953. Ground Elevation: Approx 80 mAOD
Located in southwest of proposed extension area. Trial Pit long axis oriented west-east
Topography: On flat ground sloping gently to southwest.
Vegetation: Grass cover.
Preferential Pathways: No Mottling
No water encountered, dry.
Pit stable during excavation, no collapse.
Some boulders up to 0.5 m diameter and difficult to excavate.
Hole terminated at maximum reach of excavator.

▽ Water Strike ▼ Approx. Rest Water Level

Hidrigeolaíocht Uí Chonaire Teoranta

Shantraud
Killaloe
Co. Clare
Mobile: 085 7786864
Email: peterconroy@groundwater.ie

	
TP01 – View west over pit towards playing fields	TP01 – View down into pit at full depth. Pit is dry.
	
TP01 – Close up view down into pit at full depth.	

TRIAL PIT LOG

TP02

Client:	Tipperary County Council	***Date excavated:***	20/12/2016
Project:	Tipperary Burial Ground Extensions	***Logged by:***	Peter Conroy
Site:	Fethard Burial Ground	***Equipment used:***	8 ton Tracked Excavator

Soil (S)/ Water (W) Sampling and/or Monitoring: Sample No.	PID Readings	Pit Completion	Groundwater occurrence	Depth (mbGL)	Geology - graphical log	Description
		Backfilled with arisings		1.0		0 to 0.25m: TOPSOIL.
						0.25 to 1.1m: Firm, moist, orange brown, slightly gravelly SILT. Gravel clasts are subangular blue grey micrite limestone and grey shale, fine gravel size.
				2.0		1.1 to 4.0m: Firm to stiff, moist, pale brown, slightly sandy gravelly SILT with cobbles and boulders. Gravel clasts are subangular to subrounded, fine to coarse size blue grey and grey black micrite limestone.
				3.0		
				4.0		End of Hole: 4.0m
				5.0		
				6.0		

Comments

ING, X: 221067; Y: 135961. Ground Elevation: Approx 80 mAOD
Located in mid-south of proposed extension area. Trial Pit long axis oriented west-east
Topography: On flat ground sloping gently to southwest.
Vegetation: Grass cover.
Preferential Pathways: No Mottling
No water encountered, dry.
Pit stable during excavation, no collapse.
Some boulders up to 0.5 m diameter and difficult to excavate.
Hole terminated at maximum reach of excavator.

▽ Water Strike ▼ Approx. Rest Water Level

Hidrigeolaíocht Uí Chonaire Teoranta

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TP02 – View east over pit towards Kilknockan ridge crest	TP02 – View down into pit at full depth. Pit is dry.
	
TP02 – Close up view down into pit at full depth.	View west along southern site boundary over TP02 with TP01 beyond

TRIAL PIT LOG

TP03

Client:	Tipperary County Council	***Date excavated:***	20/12/2016
Project:	Tipperary Burial Ground Extensions	***Logged by:***	Peter Conroy
Site:	Fethard Burial Ground	***Equipment used:***	8 ton Tracked Excavator

Soil (S)/ Water (W) Sampling and/or Monitoring: Sample No.	Soil (S)/ Water (W) Sampling and/or Monitoring: PID Readings	Pit Completion	Groundwater occurrence	Depth (mbGL)	Geology - graphical log	Description
						0 to 0.25m: TOPSOIL.
						0.25 to 0.9m: Firm, moist, orange brown, slightly gravelly SILT. Gravel clasts are subangular blue grey micrite limestone and grey shale, fine gravel size.
		Backfilled with arisings		1.0 2.0 3.0		0.9 to 3.8m: Firm to stiff, moist, pale brown, slightly sandy gravelly SILT with cobbles and boulders. Gravel clasts are subangular to subrounded, fine to coarse size blue grey and grey black micrite limestone. Very large boulder with approx. 1.5m diameter at 3.0 to 3.8 mbgl.
				4.0 5.0 6.0		End of Hole: 3.8m

Comments

ING, X: 221121; Y: 135970. Ground Elevation: Approx 80 mAOD
Located in southeast of proposed extension area. Trial Pit long axis oriented west-east
Topography: On flat ground sloping gently to southwest.
Vegetation: Grass cover.
Preferential Pathways: No Mottling
No water encountered, dry.
Pit stable during excavation, no collapse.
Some boulders up to 1.5 m diameter and difficult to excavate.
Hole terminated due obstruction by large boulder.

▽ Water Strike ▼ Approx. Rest Water Level

Hidrigeolaíocht Uí Chonaire Teoranta

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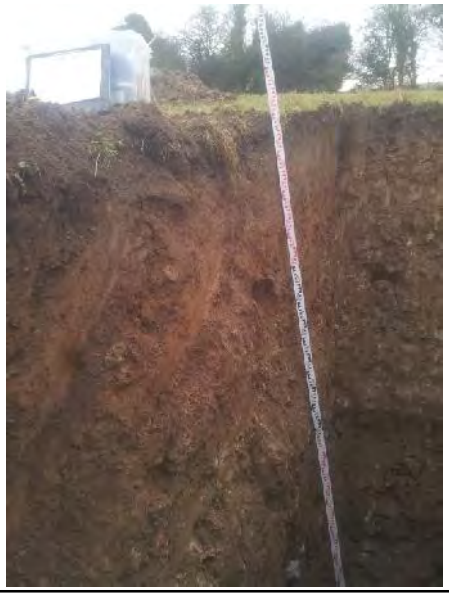
TP03 – View west over pit towards TP02 and TP01	TP03 – View down into pit at full depth. Pit is dry.
	
TP03 –View east over pit towards eastern site boundary.	TP03 – Close up view down into pit at full depth.
	
TP03 – Close up view of top of pit	

TRIAL PIT LOG

TP04

Client:	Tipperary County Council	***Date excavated:***	20/12/2016
Project:	Tipperary Burial Ground Extensions	***Logged by:***	Peter Conroy
Site:	Fethard Burial Ground	***Equipment used:***	8 ton Tracked Excavator

Soil (S)/ Water (W) Sampling and/or Monitoring: Sample No.	PID Readings	Pit Completion	Groundwater occurrence	Depth (mbGL)	Geology - graphical log	Description
		Backfilled with arisings		1.0		0 to 0.25m: TOPSOIL.
				2.0		0.25 to 0.9m: Firm, moist, orange brown, slightly gravelly SILT. Gravel clasts are subangular blue grey micrite limestone and grey shale, fine gravel size.
				3.0		0.9 to 4.0m: Firm to stiff, moist, pale brown, slightly sandy gravelly SILT with cobbles and boulders. Gravel clasts are subangular to subrounded, fine to coarse size blue grey and grey black micrite limestone.
				4.0		End of Hole: 4.0m
				5.0		
				6.0		

Comments

ING, X: 221092; Y: 135998. Ground Elevation: Approx 80 mAOD
Located in northeast of proposed extension area. Trial Pit long axis oriented west-east
Topography: On flat ground sloping gently to southwest.
Vegetation: Grass cover.
Preferential Pathways: No Mottling
No water encountered, dry.
Pit stable during excavation, no collapse.
Some boulders difficult to excavate.
Hole terminated at maximum reach of excavator.

▽ Water Strike ▼ Approx. Rest Water Level

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TP04 – View southwest over pit towards TP01	TP04 – View down into pit at full depth. Pit is dry.
	
TP04 –View southeast over pit towards TP03.	TP04 – Close up view down into pit at full depth.
	
TP04 – Close up view of top of pit	

TRIAL PIT LOG

TP05

Client:	Tipperary County Council	***Date excavated:***	20/12/2016
Project:	Tipperary Burial Ground Extensions	***Logged by:***	Peter Conroy
Site:	Fethard Burial Ground	***Equipment used:***	8 ton Tracked Excavator

Soil (S)/ Water (W) Sampling and/or Monitoring: Sample No.	Soil (S)/ Water (W) Sampling and/or Monitoring: PID Readings	Pit Completion	Groundwater occurrence	Depth (mbGL)	Geology - graphical log	Description
		Backfilled with arisings		0		0 to 0.25m: TOPSOIL.
				1.0		0.25 to 1.4m: Firm, moist, orange brown, slightly gravelly SILT. Gravel clasts are subangular blue grey micrite limestone and grey shale, fine gravel size.
				2.0		1.4 to 4.0m: Firm to stiff, moist, pale brown, slightly sandy gravelly SILT with cobbles and boulders. Gravel clasts are subangular to subrounded, fine to coarse size blue grey and grey black micrite limestone.
				3.0		
				4.0		End of Hole: 4.0m
				5.0		
				6.0		

Comments

ING, X: 221045; Y: 135988. Ground Elevation: Approx 80 mAOD
Located in northwest of proposed extension area. Trial Pit long axis oriented west-east
Topography: On flat ground sloping gently to southwest.
Vegetation: Grass cover.
Preferential Pathways: No Mottling
No water encountered, dry.
Pit stable during excavation, no collapse.
Some boulders difficult to excavate.
Hole terminated at maximum reach of excavator.

▽ Water Strike ▼ Approx. Rest Water Level

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TP05 – View southwest over pit towards playing fields with TP01 in LHS of frame	TP05 – View down into pit at full depth. Pit is dry.
	
TP05 –View west over pit towards playing fields.	TP05 – Close up view down into pit at full depth.
	
TP05 – Close up view of top of pit	

APPENDIX 5

Rainfall Trends

	Moore Pk (mm/mth)	Fethard Avg mm/mth (MetIE Grid 1981 to 2010)
15/01/2016	168	88
15/02/2016	153	65
15/03/2016	47	67
15/04/2016	104	57
15/05/2016	56	62
15/06/2016	79	66
15/07/2016	51	61
15/08/2016	72	75
15/09/2016	99	71
15/10/2016	28	101
15/11/2016	45	86
15/12/2016	85	84
15/01/2017	85	88
15/02/2017	108	65
15/03/2017	116	67
15/04/2017	19	57
15/05/2017	72	62
15/06/2017	93	66
15/07/2017	54	61
15/08/2017	72	75
15/09/2017	116	71
15/10/2017	102	101
15/11/2017	66	86
15/12/2017	110	84
15/01/2018	138	88
15/02/2018	40	65
15/03/2018	89	67
15/04/2018	175	57
15/05/2018	49	62
15/06/2018	32	66
15/07/2018	44	61
15/08/2018	43	75
15/09/2018	60	71
15/10/2018	72	101
15/11/2018	167	86
15/12/2018	168	84

APPENDIX 6

Unsaturated Zone Travel Time Calculations

Details	Units	Value	Justification
Consim Plug Flow Unretarded Travel Time			
D	m	1.7	D is the average observed Unsaturated Zone thickness, minus burial depth of 2.4 m, minus 1 m denitrification zone
Alpha	m	0.17	Alpha is the UZ vertical dispersivity, value taken as 10% of D
n	[-]	0.46	Typical effective porosity for SILT = 0.46 (from Fetter 1990, Table 4.1, p180)
Inf	m/yr	0.349	Infiltration (i.e. Recharge Estimate). The estimated infiltration rate is less than the estimated maximum possible plug flow infiltration rate.
Tuz	**yr**	**2.0**	**Tuz = (D-alpha)*n/Inf**, where Tuz is the Unsaturated Zone unretarded travel time for infiltration