Pettigo Source

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County Donegal
Groundwater Protection Scheme

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December 2005

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6 PETTIGO PUBLIC WATER SUPPLY SCHEME

6.1 Introduction

The objectives of the report are as follows:

- To delineate source protection zones for the Pettigo Water Supply Scheme; namely the two boreholes.
- To outline the principal hydrogeological characteristics of the surrounding area.
- To assist Donegal County Council in protecting the water supply from contamination.

The protection zones are delineated to help prioritise certain areas around the source in terms of pollution risk to the abstraction points. This prioritisation is intended to provide a guide in the planning and regulation of development and human activities. The protection of public water supplies is also mentioned in Circular letter SP 5-03, which was issued from the DEHLG to all County/City Managers in July 2003. The circular states that source protection zones around public water supplies should be included in all county development plans. The implications of these protection zones are further outlined in 'Groundwater Protection Schemes' (DELG/EPA/GSI, 1999).

The report forms part of the groundwater protection scheme for the county. The maps produced for the scheme are based largely on mapping techniques that use inferences and judgements based on experience at other sites. As such, the maps cannot claim to be definitively accurate across the whole county covered, and should not be used as the sole basis for site-specific decisions, which will usually require the collection of additional site-specific data.

6.2 Summary of Supply Details

GSI Number	2035NWW011	2035NWW012
Grid reference (GPS)	210524 368365	210531 368366
Townland	Aghalough	Aghalough
Source type	Borehole (No. 1 (PW))	Borehole (No. 2 (TW))
Drilled	2001	1998
Owner	Donegal Co. Co.	Donegal Co. Co.
Elevation (ground level)	86.8 m	87.3 m
Depth	45 m	80 m
Depth of Casing	Unknown	
Diameter of Casing	18 cm	10 cm
Depth to rock	c.3.7 m	c.3.7 m
Static water level	Overflowing	0.24 m bgl
Depth of pump [22]	c. 24 m	c. 43 m
Pumping water level [23]	5.04 m bgl	12.95 m bgl
Consumption (Co.Co. records)	-	c. 100-130m^3/d
Pumping test summary: (i) abstraction rate	-	305 m^3/d
(ii) specific capacity	-	24 m^3/d/m
(iii) transmissivity [24]	13 m^2/d	14 m^2/d

[22] Estimated by County Council personnel.

[23] Measured after 12 hour pumping test (GSI, November 2004).

[24] Based on pumping of trial well only.

6.3 Methodology

6.3.1 Desk Study

Details about the boreholes such as depth, date commissioned and abstraction figures were obtained from Donegal County Council personnel and the drilling contractor (Dullea Well Drilling). Additional geological and hydrogeological information was provided by the GSI and Teagasc mapping programmes (Long and McConnell, 1999; Meehan, 2004 respectively) and also by site investigation work carried out by GSI staff.

6.3.2 Site visits and fieldwork

This included the following:

- Meetings with County Council personnel in October 2002, July 2003, November 2004 and January 2005.
- Water quality sampling in November 2002 and March 2003.
- A 12-hour pumping test in November 2004 to determine any influence from the nearby stream. Temperature and conductivity were measured.
- Depth to bedrock drilling programme and site walkover in July 2003 to further investigate the subsoil geology, the hydrogeology and vulnerability to contamination.
- Site walkover in January 2005 to resolve discrepancies in the mapped bedrock geology.

6.3.3 Assessment

Analysis of the data utilised field studies and previously collected data to delineate protection zones around the source.

6.4 Location and Site Description

The Pettigo Water Supply Scheme comprises:

Two boreholes: the trial well, which was developed in 1998, and the production well, which is c.7 m down-slope of the trial well (Figure 6.1);

Two reservoirs: an old reservoir located along the course of the un-named stream, c.250 m north of the boreholes, and a new reservoir (constructed in 2000) located on the crest of the adjacent drumlin, c.250 m east of the boreholes;

A new pump house: constructed c. 40 m east of the boreholes; not yet in use.

As present, the trial well and old reservoir are used to supplies the town (see *Existing and Proposed Scheme* below).

The boreholes are located approximately 1.5 km north-northwest of Pettigo Town, in the townland of Aghalough (Figure 6.2). The boreholes and pump house are situated in a small field that is secured from the surrounding grazed field, by barbed wire fencing. The un-named stream runs from north to south along the eastern site boundary, along which the old reservoir is situated. Access is gained from a trackway via a locked gate. The stand pipes for both boreholes are c.0.2 m above ground, and the production borehole has the additional protection of a concrete culvert surround. Neither borehole has a permanent covering although a large plastic cover is placed over the trial well.

The new pump house is located in the south-eastern corner of the field (approximately 10 m west of the stream), but is unused. The pump controls are presently located in a control box that is c.50 m north of the boreholes.

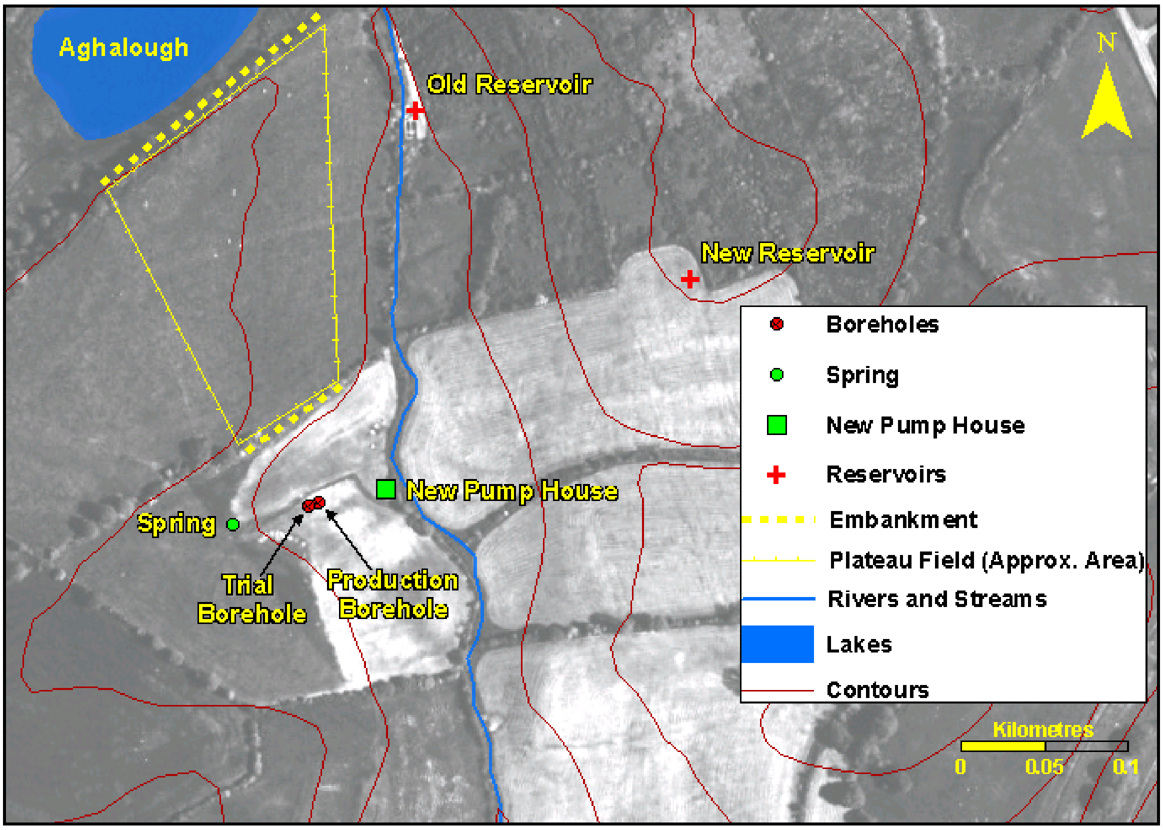

Figure 6.1. Pettigo Public Supply Scheme Well Field and Features.

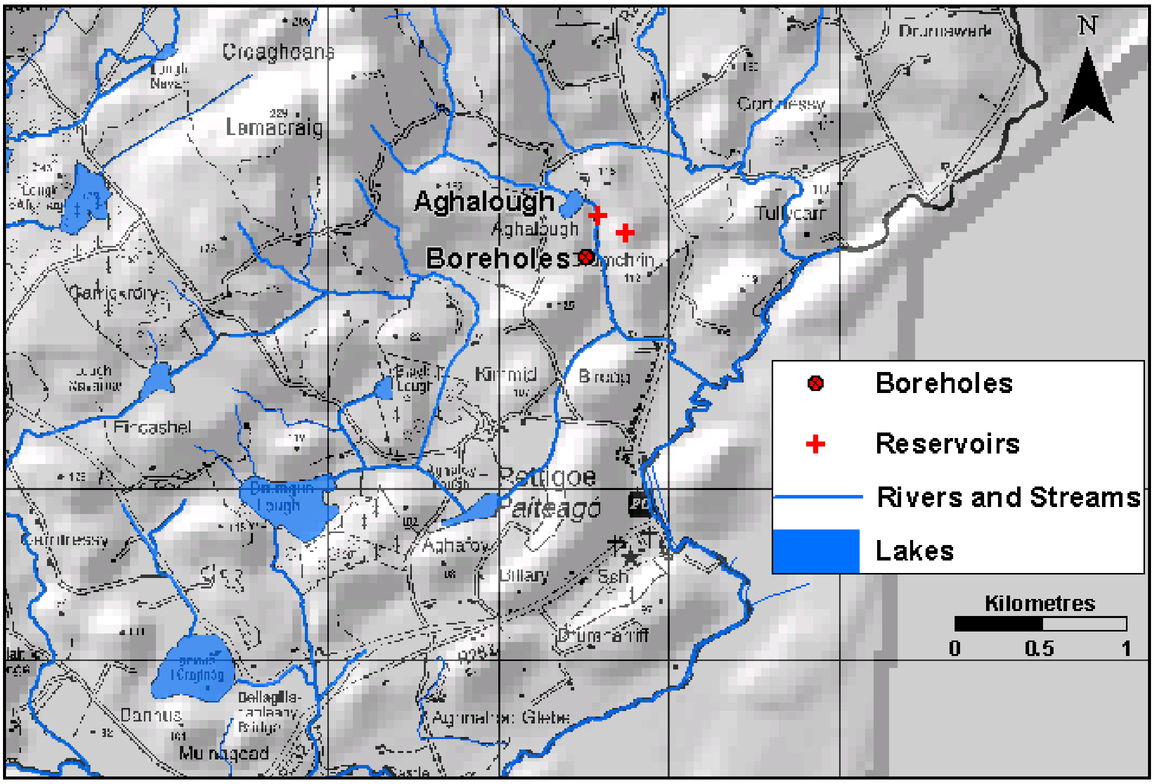

Figure 6.2 Pettigo Public Supply Scheme Location Map.

Existing and Proposed Scheme

At present, the trial well pumps groundwater to the older reservoir prior to water entering the distribution system. The pumping rate responds automatically to the level is the old reservoir, resulting in an abstraction of c.100–130m^3/d (22,400–28,000 gal/d), over 8-10 hours (i.e. c.300 m^3/d over a 24 hour period).

The production well, which is capable of pumping c.270 m^3/d, and the new, larger reservoir are presently only used as a backup system. When used, the production well pumps water up to the new reservoir until full. From here, the water is redirected back to the old reservoir and into the present distribution system. It is thought that the existing pipework will require replacing before the production well/new reservoir can be utilised full-time, in order to cope with the additional pressure of using this system.

The pump controls and any equipment will eventually be moved into the new pump house; however, there are no immediate plans to undertake this work.

6.4.1 Topography, Surface Hydrology and Land Use

The boreholes are situated on a gentle, east-west slope, which is part of the north-south trending (un-named) stream valley. More generally, the site is located in an inter-drumlin area, with steep-sided drumlins immediately to the east and southwest. The drumlins rise to a maximum of 125 m OD in the vicinity of the site, and are 20-30 m higher than the borehole themselves. The field north of the site is at a higher elevation by c.2-3 m, forming a plateau-like feature. The 'plateau' field is bounded by almost vertical embankments at the field boundary and adjacent to Aghalough (Figure 6.1).

In this part of Donegal (i.e. Pettigo to Ballyshannon), the stream density is high and lakes are a common feature. In the vicinity of the site, the lakes are interconnected by streams that are tributaries of the Termon and Waterfoot Rivers. These rivers eventually discharge into Lower Lough Erne, 2 km south of Pettigo. Aghalough is located 250 m north of the site and is the source of the un-named stream running along the eastern site boundary. This stream discharges directly into the Termon River.

Previously, water from a spring was used to improve the water quality of the original water supply from Aghalough. The spring (Figure 6.1) is located 50 m west of the boreholes however, since the boreholes were installed, the spring has ceased to flow, although occasional seeps are noted. The well-vegetated spring channel is still evident.

Grazing is the main land use in this general area. Where land is unmanaged, rushes are abundant (e.g. drumlin to the southwest). The surrounding fields are drained and managed resulting in fewer rushes, although the ground was noted as soft/wet underfoot, depending on the time of year. The elevated 'plateau' field to the north appeared to be drier.

The site and surrounding fields are enclosed by minor roads, along which are individual houses and farms. The closest of these are located 500 m to the south (down-gradient) and to the northwest (up-gradient) of the boreholes.

6.5 Geology

6.5.1 Introduction

This section briefly describes the relevant characteristics of the geological materials that underlie the site. It provides a framework for the assessment of groundwater flow and source protection zones that will follow in later sections.

Geological information was taken from a desk-based survey of available data, which comprised the following:

- Bedrock Geology 1:100,000 Map Series, Sheet 3, South Donegal, Geological Survey of Ireland (Long and McConnell, 1999).

- Information from geological mapping in the nineteenth century (on record at the GSI).
- Forest Inventory and Planning System – Integrated Forestry Information System (FIPS-IFS) Soils Parent Material Map, Teagasc (Meehan, 2004).

Site visits were also undertaken in early 2005 to resolve a discrepancy between the mapped bedrock geology and information obtained in recent drilling programmes.

6.5.2 Bedrock Geology

One of the few mapped geological features in this region is the northeast-southwest trending Pettigo Fault, which is located c.600 m east of the boreholes (Figure 6.3). Old metamorphosed rock (Precambrian Quartzites, Gniesses and Schists Rock Group (SWQ), >c.700 million years old) is mapped to the west of the fault, with younger limestone (Ballyshannon Limestone, c.65-355 million years old) to the east. The Precambrian rocks are described as light coloured, fine-grained metamorphosed sandstone rocks. The Ballyshannon Limestone is a pale grey, massively bedded coarse-grained, limestone. Units of other lithologies (cherty beds, sandy beds, impure limestone) are interspersed with the principal limestone lithology, which can be subdivided where there is enough evidence.

The existing map shows that both boreholes are located in the Precambrian metamorphic rock however, information from the drilling contractor suggested that the boreholes themselves encountered limestone. Furthermore, the available hydrochemistry data had high levels of hardness (404 mg/l $CaCO_3$), which would be more indicative of a limestone aquifer. To resolve this contradiction, a shallow borehole was drilled in the adjacent field during the GSI depth to bedrock drilling programme (July 2003). The shallow borehole (12.5 m deep) recorded topsoil/subsoil to 1.8 m b.g.l, which is underlain by dark grey, well fractured, impure limestone bedrock to 7.5 m b.g.l. Beneath this, the bedrock is a harder, light grey dolomitised[25] limestone, with few fractures.

Due to the discrepancy between the mapped geology and drilling information, site visits with GSI Bedrock Section personnel resulted in further interpretation of the geology in this area. From the on-site evidence (outcrops, topography), borehole information and known geological history in the region, it would appear that folding, faulting and subsequent erosion have left bands of Lower Impure Limestone (BSag) and Ballyshannon Limestone Basal Unit (Sandstones, Limestones and Shales; BSbc) in certain locations although the *western* side of the Pettigo Fault. These rocks are found at the base of the Ballyshannon Limestone, and sit unconformably on the older Precambrian metamorphic rock. This pattern of bedrock succession is also seen immediately east of Donegal Town and Laghy. The rock core obtained during the GSI drilling indicates that the boreholes are in predominantly within the Lower Impure Limestone, although the greater depths of the production and trial boreholes are likely to penetrate down into the underlying Ballyshannon Limestone Basal Unit.

Based on the new information, the geology around the site has been re-evaluated (Figure 6.4). However, additional drilling will be required to determine the actual extent of these rocks.

[25] Dolomitisation (replacement of calcium ions by magnesium ions in the crystal lattice, to form dolomite (Ca Mg $(CO_3)_2$), can be associated with an increase in the porosity and permeability of the rock. In general, the purer the original limestone, the greater the degree of dolomitisation.

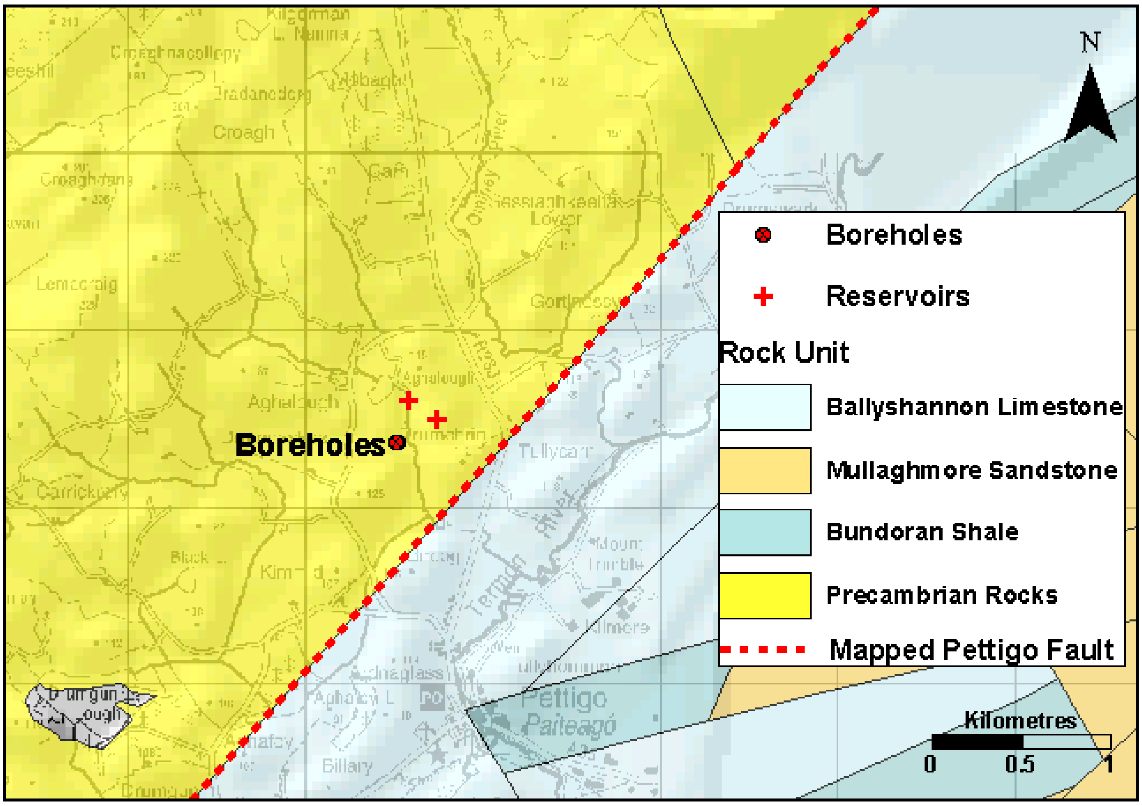

Figure 6.3. Original Mapped Bedrock Geology of the Pettigo Area.

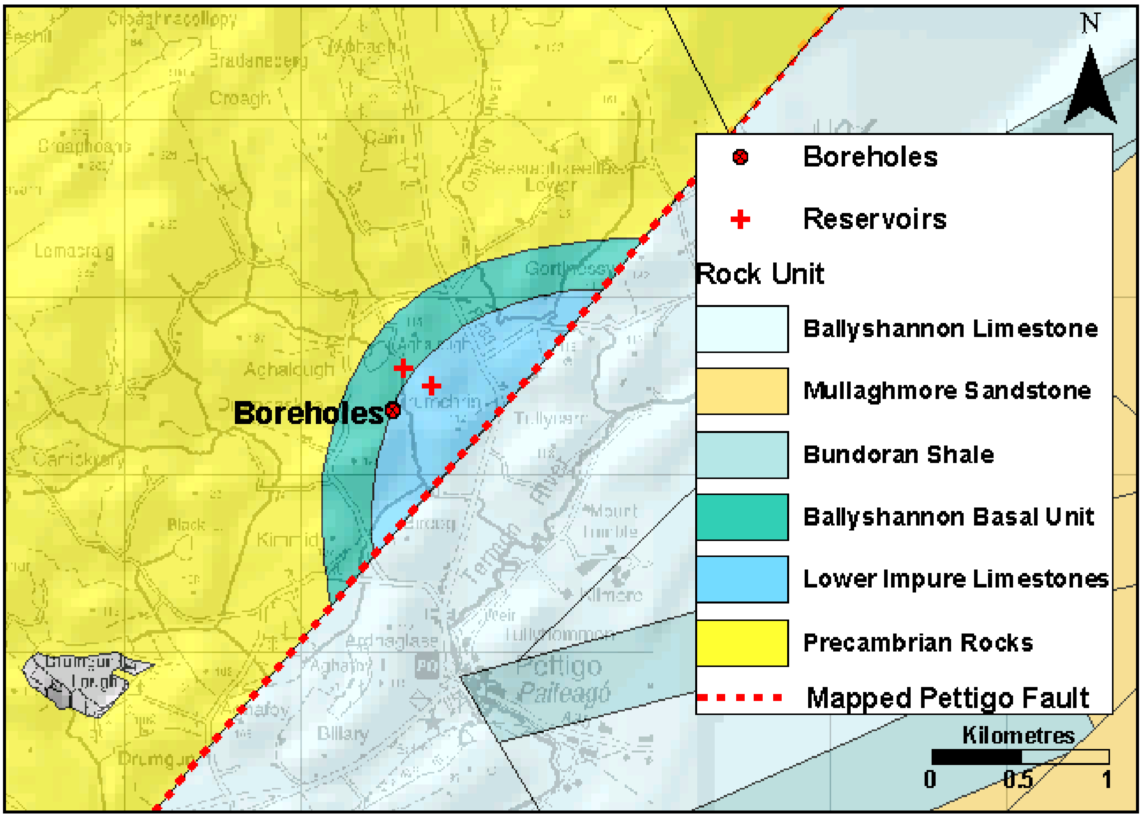

Figure 6.4. Re-Evaluated Bedrock Geology of the Pettigo Area (2005).

6.5.3 Subsoil Geology

As shown in Figure 6.5, the main subsoil category underlying the drumlin and inter-drumlin topography around the site is 'till' (or boulder clay). Till is an unsorted mixture of coarse and fine materials laid down by ice. In this part of Donegal, thicker areas of till (>3 m) are frequently characterised by clay-sized material. Samples from the nearest boreholes (four from within 2.5 km of the site) have been described as CLAY (BS 5930), two of which have Particle Size Distribution (PSD) data that support these descriptions:

Number	Approximate Distance and Direction from Crossroads	BS 5930 Description	PSD (%) [26] (Gravel:Sand:Fines:Clay)
11-03	2.25 km south	CLAY	–
11-04	1.4 km east	CLAY	–
11-05	0.9 km east	CLAY	35:24:41:17
11-06	2.0 km south	CLAY	12:32:56:21

Peat deposits are located within the larger, lower-lying, inter-drumlin zones e.g. around Aghalough, as well as being the dominant subsoil in the upland areas to the northwest.

Till is not classed as an aquifer and thus its main significance is in relation to the protection it provides to the underlying bedrock aquifers from infiltrating contaminants.

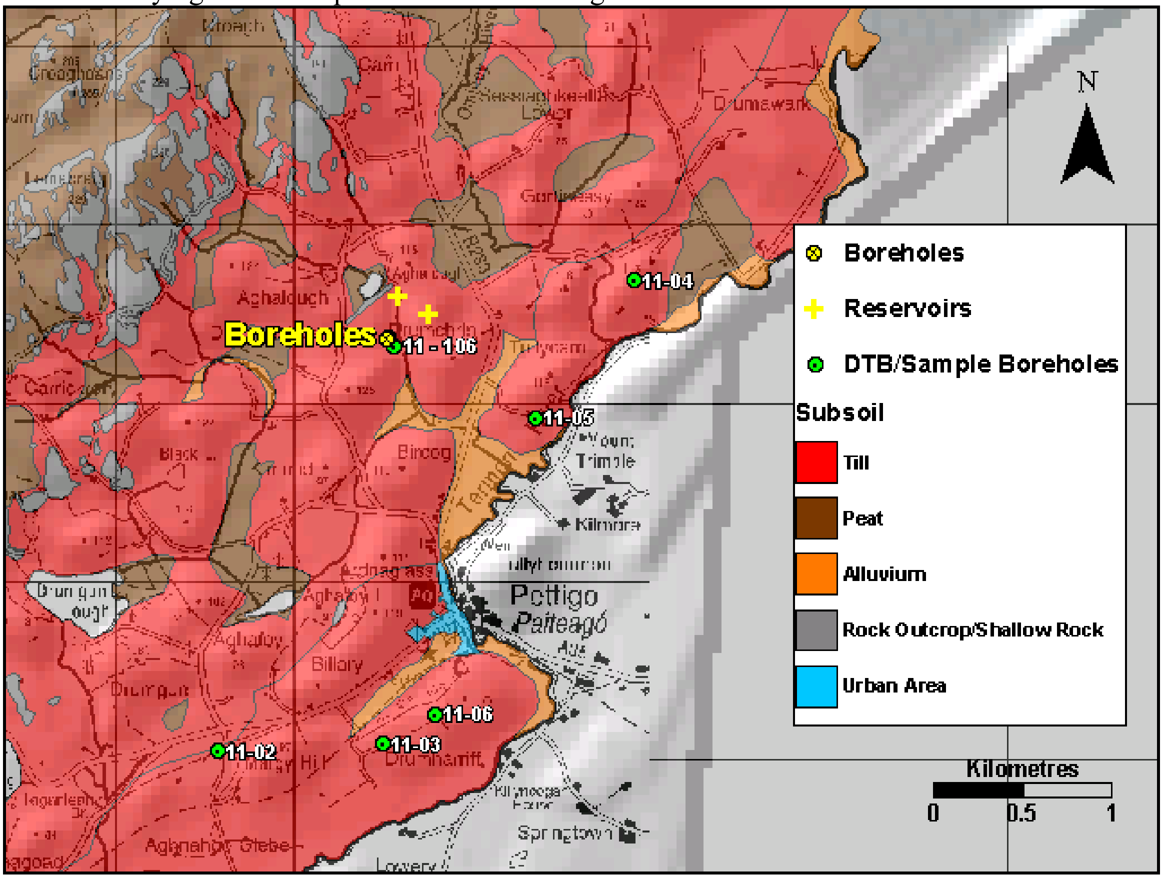

Figure 6.5. Mapped Subsoil Geology of the Pettigo Area.

[26] A particle size distribution test provides data that can indicate the likely permeability of subsoil. For the required permeability of 1×10^{-8} m/s, the clay content should be greater than 13% (where the particle size distribution is adjusted by excluding materials larger than 20 mm). In circumstances where the clay content is >13% clay but there is evidence of a higher permeability, e.g. the area is free draining or the BS5930 description of the subsoil is SILT, it may be advisable to assume that the 1×10^{-8} m/s requirement is not met.

6.5.4 Depth to Bedrock

All available drilling information was previously compiled and a drilling programme undertaken by the GSI to ascertain the general changes in subsoil thickness and permeability throughout County Donegal.

There are six depth to bedrock boreholes in this part of the county as well as the mapped rock outcrops (Figure 6.5). From these data, it is inferred that the site, the surrounding field and the 'plateau' field to the north only have a thin layer of subsoil. The trial and production boreholes themselves record a depth to bedrock of 3.7 m, suggesting that the subsoil may become slightly thicker towards the base of the stream valley. The drumlins comprise greater thicknesses (> 10 m) of the CLAY till. Thick drumlin deposits and thinner inter-drumlin zones appears to reflect the general pattern observed in this part of Donegal.

6.5.5 Groundwater Vulnerability

The concept of vulnerability is discussed in Section 5 (Volume I). In summary, the vulnerability category mainly relates to the protection afforded by the material overlying the aquifer, which in this instance is the subsoil. The till in this general region is generally described as CLAY (BS 5930), which is categorised as having a 'low' permeability. Where the till is thicker (>3 m), the vulnerability categorises range from 'high' to 'low'[27], with the thickest subsoil providing the greatest protection to the underlying aquifer.

Where the subsoil is less than 3 m thick, the vulnerability is classified as 'extreme'. In such instances, the bulk permeability becomes less relevant because infiltration is more likely to occur through 'bypass flow' mechanisms, such as cracks in the subsoil. The mapped vulnerability for the area of interest is shown in Figure 6.6, below.

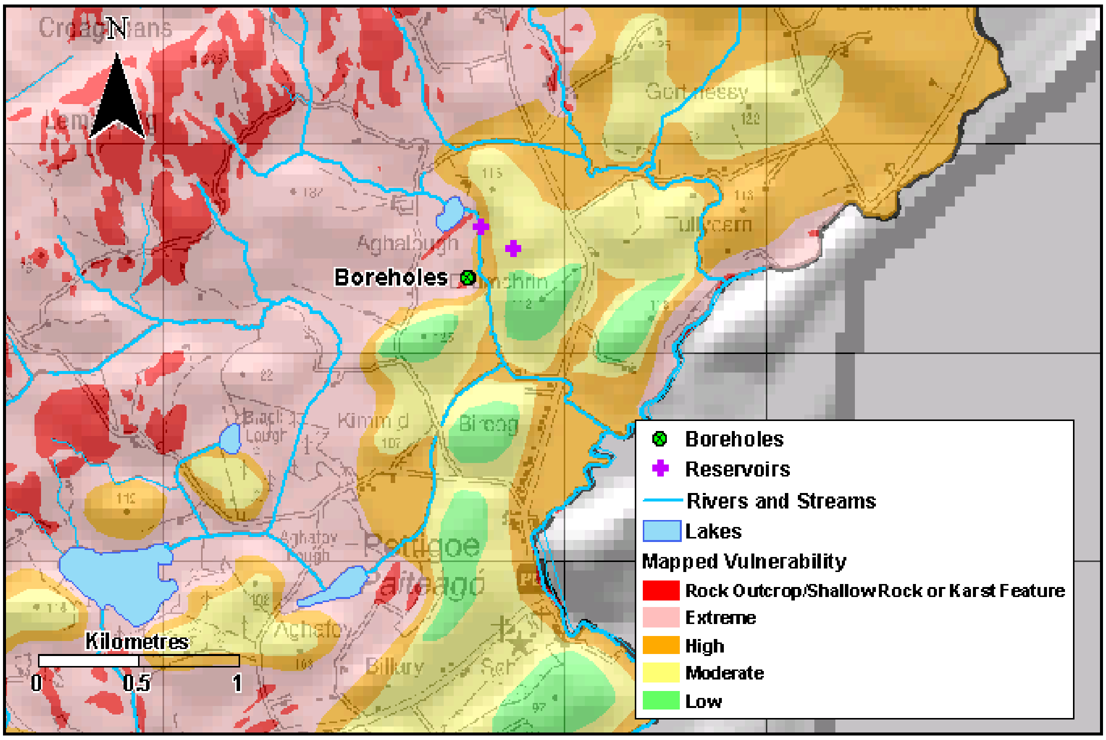

Figure 6.6. Vulnerability Categories in the Pettigo Area.

[27] The permeability and depth to rock interpretations are based on regional-scale evaluations. The mapping is intended only as a guide to land use planning and hazard surveys, and is not a substitute for site investigation for specific developments. Classifications may change as a result of investigations such as trial hole assessments for on-site domestic wastewater treatment systems. The potential for discrepancies between large-scale vulnerability mapping and site-specific data has been anticipated and addressed in the development of groundwater protection responses (site suitability guidelines) for specific hazards.

6.6 Hydrogeology

6.6.1 Introduction

This section presents our current understanding of groundwater flow in the area around the Pettigo Public Supply boreholes. The hydrogeological and hydrochemical information for this study was obtained from the following sources:

- Pumping tests carried out by the drilling contractor (Dullea Well Drilling) in the late 1990s.
- A 12-hour pumping test undertaken by the GSI in November 2004 to determine any influence from the stream. Temperature and conductivity were measured.
- Hydrogeological mapping carried out by the GSI in May and October 2002, November 2004 and January 2005.
- Depth to bedrock and subsoil permeability drilling programme, and a field walkover carried out by GSI in July 2003.
- GSI/County Council water quality sampling in November 2002 and March 2003.
- Water quality analyses from the EPA (2000 – 2003).
- Donegal County Council water quality analyses (1998 – 2004).
- GSI files and archival Donegal County Council data.
- Met Eireann rainfall and evapotranspiration data.

6.6.2 Rainfall, Evaporation and Recharge

The term ‘recharge’ refers to the amount of water replenishing the groundwater flow system. The recharge rate is generally estimated on an annual basis and is assumed to consist of input (i.e. annual rainfall) less water losses (i.e. annual evapotranspiration and runoff) prior to entry into the groundwater system. The estimation of a realistic recharge rate is important in source protection delineation as it is used to estimate the size of the zone of contribution (i.e. the outer source protection area). The calculations are summarised in below.

- *Average Annual rainfall:* **1450 mm**

  The nearest rainfall gauging station (Pettigo) is situated approximately 2 km to the south of the source, at a similar elevation (Fitzgerald, D., Forrestal., F., 1996). Therefore the average annual rainfall (1971-2000; Met Eireann, 2004) is thought to be representative of that experienced at the source. The average based on the 1961-1990 data was 1280 mm/yr. The increased rainfall in more recent times is in keeping with national trends.

- *Annual evapotranspiration losses:* **450 mm**.

  Actual evapotranspiration (A.E.) is estimated to be 450mm. This value is taken from a contour map, which is derived from point values of potential and actual evapotranspiration from 22 stations around the country (Met Eireann, 2004).

- *Annual effective rainfall:* **1000 mm**

  This figure is based on subtracting estimated evapotranspiration losses from average annual rainfall. It represents an estimation of the excess soil moisture available for either vertical downward flow to groundwater or runoff.

- *Estimated actual recharge:* **360 mm**

  The amount of water that will infiltrate to groundwater (recharge) is influenced by the subsoil permeability and thickness, as well as the aquifer characteristics. Recharge coefficients (rc) have been derived for various combinations of these factors (GWWG, November 2004). Over the entire area of interest, recharge estimates are thought to be in the order of 36% of the effective rainfall.

The calculations are summarised as follows:

Average annual rainfall (R)	1450 mm
Estimated A.E.	450 mm
Effective rainfall (R – A.E.)	1000 mm
Overall recharge coefficient	36%
Estimated Actual Recharge	**360 mm**

6.6.3 Groundwater Levels, Flow Directions and Gradients

Static, pumping test (November 2004) and present day abstraction water levels were measured in the two boreholes (Appendix D).

After a 12 hour recovery period i.e. pumping was stopped for 12 hours to allow groundwater levels to return to their natural level, the static water level in the trial well was 0.24 m b.g.l. (87.06 m OD). Groundwater in the production well, which is c.7 m down-slope of the trial well, was recorded as artesian (overflowing), from which it is inferred that the groundwater at this location is confined. The confining layer probably comprises the 3.7 m of overlying clay-rich subsoil and is likely to be limited to a small area surrounding the boreholes. In terms of relative water levels, it is assumed that the groundwater in both of the boreholes rises to similar, if not the same, static level, although is artesian at the production well due to the lower ground level.

Immediately after the 12 hour pumping test (November 2004) the water levels were 12.95 m b.g.l. and 5.04 m b.g.l. in the trial (pumping) and production wells respectively. Due to a) the close proximity of the wells to each other, and b) the quick response observed in the production well to the pumping in the trial well (observed after one minute), well interference would be expected to occur *if* both boreholes were pumping at the same time i.e. each pumping well would reduce the amount of water available to the other well.

A 12-hour GSI pumping test was undertaken in November 2004 primarily to ascertain whether there was induced recharge from the un-named stream, located c.50 m to the east of the boreholes. Although changes in temperature and conductivity were noted over the period, they were minor and did not indicate that water from the stream was entering the borehole.

Groundwater Flow Directions

In the vicinity of the boreholes, the flow direction inferred from the topography, surface drainage patterns and available static water levels is generally in an easterly direction, towards the stream. However, as the southerly flowing stream is relatively close to the boreholes (c.50 m), it may also have an influence on the flow direction i.e. the resultant direction around the boreholes and stream is likely to be in a east to south-easterly direction.

Groundwater Gradients

Without additional groundwater levels data, the actually hydraulic gradients cannot be ascertained. However, given the shallow depth of fracturing identified in the GSI borehole (top 5-6 m), and that the aquifer is not highly permeable, flow is likely to mainly occur in the upper portion of the aquifer. It is therefore anticipated that the groundwater gradients are likely to reflect the local topography. Thus a value of 0.05 is assumed.

6.6.4 Hydrochemistry and Water Quality

Hydrochemical data for the Pettigo Water Supply Scheme have been obtained from the County Council (1998-2004), the Environmental Protection Agency (2000-2003) and the GSI in conjunction with the County Council (2000-2003). The data are summarised graphically in Figure 6.7 below.

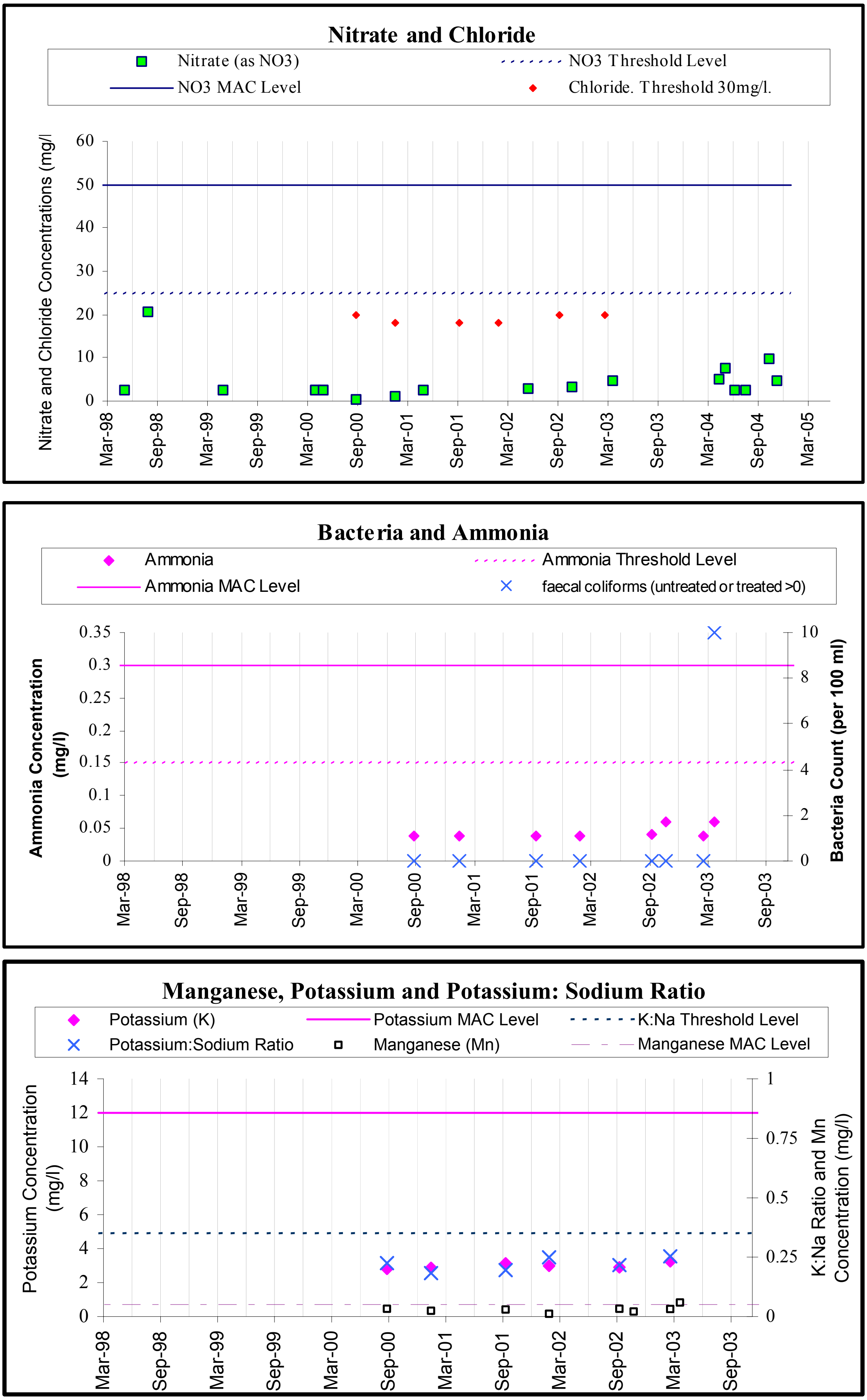

Figure 6.7. Key Indicators of Agricultural and Domestic Contamination.

The following key points have been identified from these data.

- Analysis of hardness indicate a hard to very hard (300-470 mg/l $CaCO_3$) calcium bicarbonate hydrochemical signature. This reflects the high calcium content associated with a limestone, rather than metamorphic sandstone, aquifer. Conductivity ranges from 650-800 μS/cm.
- Reported nitrate concentrations range from 0.5-9.5 mg/l, with the average being 3.5 mg/l (20 samples between 1992-2004). These data are below the MAC and guideline levels (50 and 25 mg/l respectively). However, one sample taken in August 1998 records a value of 20.6 mg/l, which is significantly elevated above the average. No other data are available for this date that could have suggested possible causes for this apparent anomaly.
- Of the other contaminant indicators examined, there is one reported incident of elevated faecal coliforms: 10 counts/100 ml in March 2003, which is classed as gross contamination (Keegan *et al*., 2002). There were also slightly elevated levels of manganese (0.059 mg/l) in the same sample (MAC is 0.05 mg/l). There were three other occasions when total coliforms were detected (all <5 counts/100 ml) – September 2000, January 2001 and February 2002.

The available data suggest that the incidents of bacteria are isolated and do not specifically highlight on-going problems. The presence of bacteria and manganese suggest the source of contamination is organic wastes, and may reflect releases from point and/or diffuse hazards upslope of the boreholes, such as on-site wastewater treatment systems, landspreading of organic wastes or grazing animals in areas of shallow rock. Although the well field is comprehensive fenced off, poor sanitary protection at the well heads may also be a concern as neither of the boreholes are sealed off. This is especially the case for the trial well, which is presently as the primary supply borehole.

6.6.5 Aquifer Characteristics

Pettigo Water Supply Scheme comprises two boreholes that appear to be abstracting groundwater from the Lower Impure Limestone (BSag) and probably from the underlying Ballyshannon Limestone Basal Unit (BSbc). Both of these rock units are classified as **Locally Important Aquifers** that are moderately productive only in **local zones (Ll)**. Refer to Section 4 (Volume 1) for further details.

Borehole logs highlight that the top 5-6 m of the Impure Limestone is well fractured, although few fractures were identified in the underlying harder, dolomitised limestone. From the depth of fracturing and the presence of the spring, it is inferred that much of the groundwater flow within this rock unit in likely to be at the top of the rock. However, it is probable that the underlying Basal Unit is also contributing to the abstraction. Based on the lithology, this rock unit is likely to be a slightly more productive aquifer than the Impure Limestone.

The aquifer parameters (Table 6.1) have been estimated from pumping tests undertaken by the drilling contractor (late 1990s) and the GSI (2004; Appendix D). The specific capacity (Sc) ranges from 20-25 $m^3/d/m$. A transmissivity (T) of 10-15 m^2/d was calculated from both sets of pumping test data. Permeability (K) is calculated by dividing the transmissivity by the saturated thickness of the aquifer, which in this case, is taken as the depth of the borehole (80 m). The resulting permeability (K) is in the region of 0.15 m/d (ranging from c. 0.1-0.2 m/d). The velocity of water moving through this aquifer to the boreholes can be estimated from Darcy's Law:

$$\text{Velocity (V)} = \frac{\text{(K x groundwater gradient (i))}}{\text{porosity (n)}}$$

The groundwater gradient is assumed to be in the region of 0.05. There is no information to estimate the effective porosity (n) for this rock unit. However, based on regional knowledge of similar permeability rocks, this is assumed to be 0.01 (1%). Thus the average velocity is calculated to be in the order of 0.5-1.0 m/d. This is based on the permeability value for the *entire* depth of borehole. Although no specific data exist for the highly fractured zones at the top of the rock, it is recognised that the permeability, and therefore the velocity, is likely to be higher within these zones.

Table 6.1. Estimated Parameters for the Lower Impure Limestone Aquifer.

Parameter	*Source of data*	*Value*
Specific Capacities (m^3/d/m)	Local	20-25
Transmissivity (m^2/d)	Local	10-15
Permeability (m/d)	Local	0.15
Porosity	Assumed	1%
Velocity (m/d)	Local/Assumed	0.5-1.0

6.6.6 Conceptual Model

- The Pettigo Water Supply Scheme consists of two boreholes. The trial well presently abstracts c.100–130m^3/d, with the newer production well being used as a backup system. The trial well is pumping for approximately 8-10 hours a day to an old reservoir (the new reservoir is only used in conjunction with the production well).
- The rocks from which the boreholes are likely to be abstracting groundwater (Lower Impure Limestone (BSag) and the Ballyshannon Limestone Basal Unit (BSbc)) are classified as **Locally Important Aquifers** that are moderately productive only in **local zones (Ll)**. Within this category, the lithology of the Basal Unit suggests that it is likely to be a slightly more productive aquifer than the Impure Limestone.
- The adjacent Precambrian metamorphic rock, which is classified as a **Poor Aquifer** that is generally unproductive except for **local zones (Pl)**, is not thought to significantly contribute to the abstraction.
- A large proportion of groundwater is likely to flow through a) a relatively shallow interconnected fracture system in the Impure Limestone (e.g. top 5-6 m of the rock), and b) the more productive lithological strata of the Basal Unit. Outside of these specific zones, groundwater may flow through smaller fractures and joints.
- Where there is shallow subsoil over the surrounding area, groundwater is generally thought to be unconfined. However, the artesian nature of the production well suggests confined groundwater flow at this particular location. The confining layer is likely to be the overlying low permeability till, which is thicker around production well.
- It is assumed that the confining till layer continues across the base of the local stream valley (eastern site boundary). The presence of a confining layer between the groundwater and the stream results in a lack of hydraulic continuity between the two water systems at this location.
- Based on the pumping test undertaken in November 2004, there is no induced recharge from the local stream to the boreholes. The results provide supporting evidence that the groundwater is confined and therefore, separate from the surface water system.
- Given the proximity of the boreholes to each other, and the monitoring data of the production well during the pumping of the trial well, the boreholes are likely to interfere with each other if both are pumped at the same time.
- The natural groundwater flow direction in the vicinity of the boreholes (western side of the local stream) is thought to be east to south-eastwards as suggested by the topography, drainage patterns and available water level data.
- Drumlins dictate the topography on the eastern bank of the local stream. However, outcrops identified at the base of one drumlin suggest that they are likely to be rock cored, even if the majority of the drumlins are till. Therefore, groundwater flow in this area is thought to be in a westerly to south-westerly direction.
- Diffuse recharge occurs over most of the land surface especially where the subsoil is thin, as indicated by the low density of surface drainage. Where the subsoil is thicker, or the rock

permeability is low, a more limited recharge is expected. Overall, recharge estimates for the area of interest are in the order of 360 mm/yr.

- Given the estimated recharge, topography, main surface drainage patterns in the general area, and the lack of connection between the groundwater and surface water in the vicinity of the boreholes, it is assumed that the boreholes are pulling in groundwater from the eastern side of the local stream, beneath the confining layer.

6.7 Delineation of Source Protection Areas

6.7.1 Introduction

This section delineates the areas around the source that are believed to contribute groundwater to it, and that therefore require protection. The areas are delineated based on the conceptualisation of the groundwater flow pattern, and are presented in Figure 6.8.

Two source protection areas are delineated:

- ♦ Inner Protection Area (SI), designed to give protection from microbial pollution;
- ♦ Outer Protection Area (SO), encompassing the zone of contribution (ZOC) to the boreholes.

6.7.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the well field, i.e. the zone of contribution (ZOC), which is defined as the area required to support an abstraction from long-term recharge. The ZOC is controlled primarily by (a) the pumping rate, (b) the groundwater flow direction and gradient, (c) the subsoil and bedrock permeability and therefore, the recharge in the area. The delineation of the ZOC uses:

v. hydrogeological mapping techniques to determine boundaries,

vi. a comparison of average discharge and recharge data to estimate the area required,

vii. a safety margin to allow for any variability in the groundwater flow direction, and

viii. a safety margin to account for the larger ZOC required during the drier summer months.

The derivation of the boundaries is described below.

The **western, north-western** and **central southern boundaries** are principally constrained by topography i.e. the gently-sloping, shallow rock valley area in which the boreholes are located. This assumes that surface and groundwater catchments are coincident. The topography divide is based on the highest points of the shallow rock areas.

Given the location the main surface water features e.g. Aghalough and unnamed stream c.750 m west of the boreholes, and the interpreted bedrock boundary between the Ballyshannon Limestone Basal Unit and the Precambrian rocks, it is unlikely that groundwater is coming from either further north of further west of this boundary.

The **south-western boundary** is based on the topographic catchment boundary for the gently sloping valley in which the boreholes are located i.e. the shallow rock area that is likely to be facilitating aquifer recharge. This boundary is based on the highest point of a till drumlin. It is therefore acknowledged that due to the thickness of low permeability drumlin material, negligible recharge is likely to occur through the drumlin itself. However, effective rainfall over the drumlin area will move downslope as surface water or through-flow (through the top layers of the topsoil/subsoil) until it reaches the shallow rock area, at which point it may move down vertically to recharge the aquifer.

The **eastern boundary**, which is on the eastern (opposite) side of the local stream, is also based on topography. As the estimated groundwater recharge is relatively low, the delineated ZOC upgradient of the boreholes (west of boreholes) does not provide enough recharge to meet the present abstraction rate. Therefore, additional groundwater must be coming from elsewhere. Given the topography, main surface water drainage patterns, and the pumping test results that indicate there is no induced recharge from the stream, the most likely additional zone contributing to the boreholes is on the eastern side of the stream.

As mentioned, the eastern boundary is based on topography, which is determined by the location of a drumlin. As with the south-western boundary, minimal recharge is likely to be occurring directly through the thick, low permeability drumlin. However, effective rainfall will move downslope towards the stream (and the boreholes) where the subsoil is thinner and aquifer recharge is more likely to occur.

Boundary Uncertainties. Due to the limited hydrogeological data available for this area, there is some uncertainty with both the south-western and eastern boundaries. Both of these boundaries are based on the topography of the drumlins, which are subsoil deposits. Interpretations of the groundwater flowing to the boreholes *irrespective of the drumlins* has been attempted to give the most likely boundaries i.e. direction of flow purely through the bedrock that takes account of the main surface water drainage patterns. However, it is recognised that groundwater is potentially being drawn from beyond and beneath the drumlins. Additional site investigations would be required to determine if this is occurring, and the extent to which it may be occurring.

The boundaries incorporates a safety margin to account for any variability in the flow direction by up to 20º.

ZOC Area. The discharge data are not comprehensive enough to undertake a water balance in order to accurately estimate the catchment area. However, based on the calculated annual recharge (360 mm/year), the area required to supply the average discharge (130 m^3/d) is c.0.13 km^2. The delineated ZOC is c.0.17 km^2, which is probably just adequate to support the long term abstraction rate when taking the seasonal variation of rainfall into account (i.e. drier summer months).

Based on the current understanding of the hydrogeology, it is unlikely that the production and trial wells at this site could supply a significant increase in the long term abstraction rate.

6.7.3 Inner Protection Area

According to "Groundwater Protection Schemes" (DELG/EPA/GSI, 1999), delineation of an Inner Protection Area is required to protect the source from microbial and viral contamination and it is based on the 100-day time of travel (ToT) to the supply.

Based on the aquifer parameters in Section 3.6.5, the average velocity is calculated as between 0.5-1.0 m/d, which would give a maximum 100 day ToT distance of 100 m from each borehole. However, as the upper part of the Impure Limestone is highly fractured, it is not only likely to facilitate higher groundwater velocities, but is also more likely to be susceptible to contamination than deeper fracture zones. Although no data are available for this particular zone of the aquifer, an arbitrary increase of 50% in the velocity is used to determine the SI in order to take account of this more fractured zone. Therefore the maximum 100 day ToT from each borehole is given as 150 m.

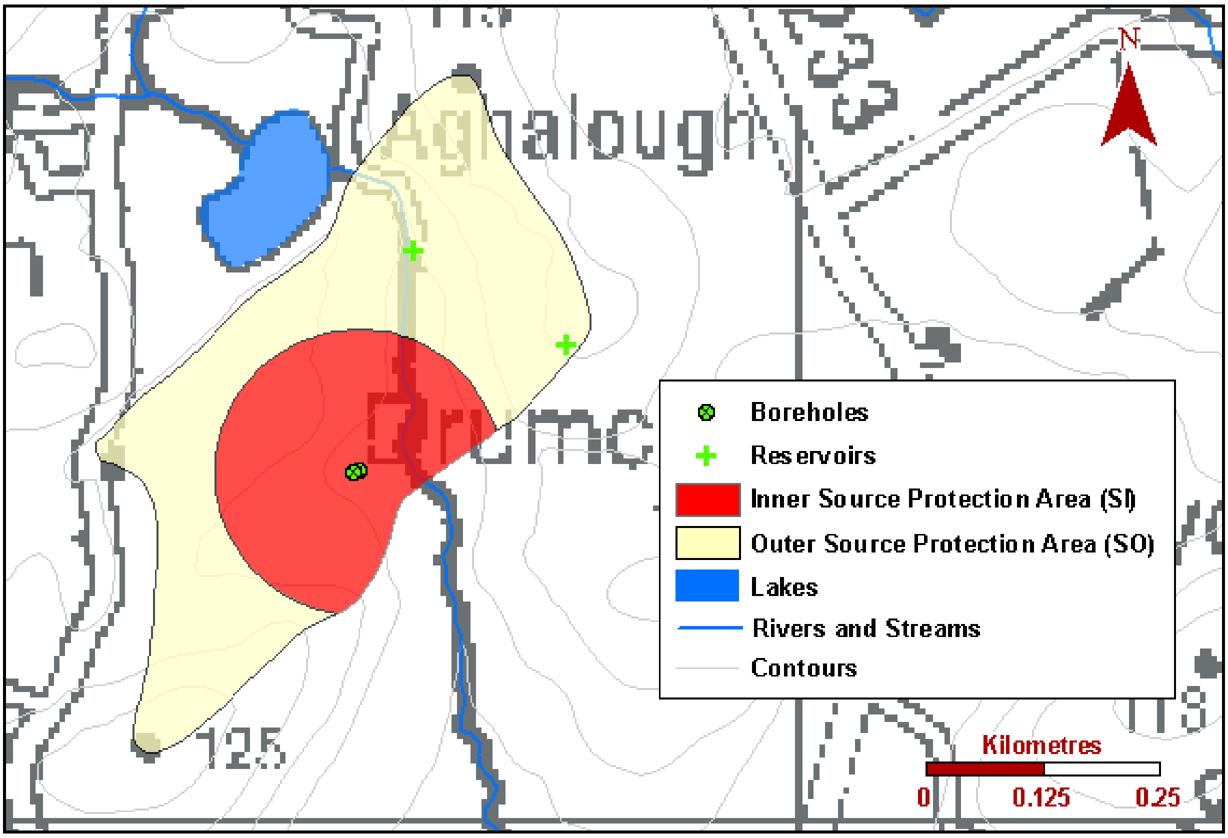

Figure 6.8. SO and SI Areas Around the Pettigo Public Supply Scheme Boreholes.

6.8 Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories), giving a possible total of 8 source protection zones. In practice, the source protection zones are obtained by superimposing the vulnerability map on the source protection area map. Each zone is represented by a code e.g. **SI/H**, which represents an Inner Protection area where the groundwater is highly vulnerable to contamination.

Seven groundwater protection zones are present around the Pettigo Water Supply Scheme (Figure 6.9), as shown in Table 6.2 below. Due to shallow rock over a large proportion of the ZOC, much the source protection area is considered to be extremely vulnerable to contamination. The drumlins represents areas of thicker, low permeability till, and therefore lower vulnerability.

Table 6.2 Matrix of Source Protection Zones for the Pettigo Public Water Supply Scheme.

VULNERABILITY RATING	SOURCE PROTECTION	
	Inner	*Outer*
Extreme (E)	SI/E	SO/E
High (H)	SI/H	SO/H
Moderate (M)	SI/M	SO/M
Low (L)	Not present	SO/L

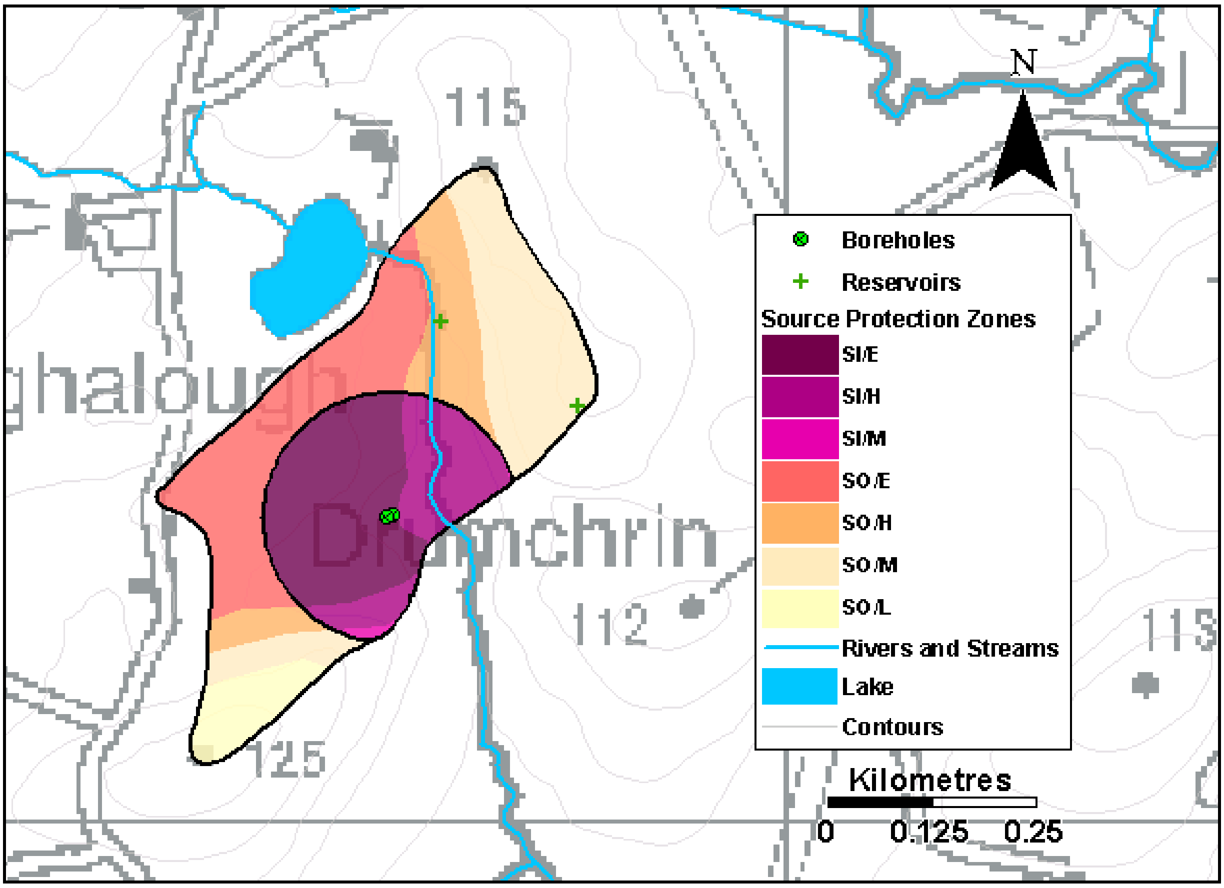

Figure 6.9. Source Protection Zones for the Pettigo Water Supply Scheme.

6.9 Potential Pollution Sources

Agriculture is the principal activity in this relatively small ZOC, with most of the land being used for pasture. One minor road crosses the north-western corner of the ZOC and there is an access track to the boreholes. No houses or farmyards are located within the ZOC.

The main potential hazards within the ZOC include the presence of grazing animals, application of fertilisers (organic and inorganic), pesticides and herbicides, and possible oil/diesel spillage along the road/track, especially where the shallow bedrock exists.

Of the contaminant indicators examined, none were persistently at significantly high levels in available samples and therefore, the data generally indicate good water quality. The occasional presence of bacteria and slightly elevated concentrations of manganese and nitrate may reflect releases from diffuse sources of pollution, such as those mentioned.

6.10 Conclusions and Recommendations

- Pettigo water supply consists of two boreholes: a trial well and a production well. Currently the trial well is abstracting 100-130 m^3/d. This abstraction is pumped to an older reservoir before entering into the distribution system.
- Both boreholes abstract water from the Lower Impure Limestone (BSag) and possibly from the underlying Ballyshannon Limestone Basal Unit (BSbc). Both of these rock units are classified as **Locally Important Aquifers** that are moderately productive only in **local zones (Ll)**.
- All of the ZOC boundaries are constrained by topography. The eastern boundary is on the opposite (eastern) side of the local un-named stream, as the area of recharge required to meet the abstraction rate is not achieved by the ZOC up-gradient of the boreholes alone, and pumping tests indicate that there is no induced recharge from the stream. Although the most likely ZOC boundaries have been

delineated, there is more uncertainty with the south-western and eastern boundaries. Both of these boundaries are based on drumlin topography, which does not necessarily influence the direction of groundwater flow in the underlying aquifer. The SI is based on the 100 day ToT to the boreholes, as estimated from the aquifer parameters.

- ♦ The groundwater vulnerability is categorised as extreme over c.50% of the ZOC due to the presence of outcrop, shallow rock and thin subsoil (< 3 m in thickness). Where the subsoil is thicker, the vulnerability ranges from high to low.
- ♦ The water supply is potentially susceptible to contamination from diffuse sources (grazing animals, spreading of inorganic and organic fertilisers, pesticides and herbicides) especially when these are located in the SI/E zone.
- ♦ The protection zones delineated in the report are based on our current understanding of groundwater conditions and on the available data. Additional data obtained in the future may indicate that amendments to the boundaries are necessary.
- ♦ It is recommended that:

  6. the present abstraction rate is not significantly increased, as the calculated recharge rate for the delineated ZOC is only likely to be large enough to meet this abstraction, especially when taking account of season variation i.e. drier summer months.
  7. particular care should be taken when assessing the location of any activities or developments which might cause contamination at the well field.
  8. the potential hazards (e.g. grazing animals) in the ZOC should be located and assessed especially with regard to the SI/E zone.
  9. full chemical and bacteriological analysis of the **raw** water at each abstraction point is carried out on a regular basis. The chemical analyses should include all major ions – ammonium, bicarbonate, calcium, chloride, magnesium, nitrate, potassium, sodium and sulphate.

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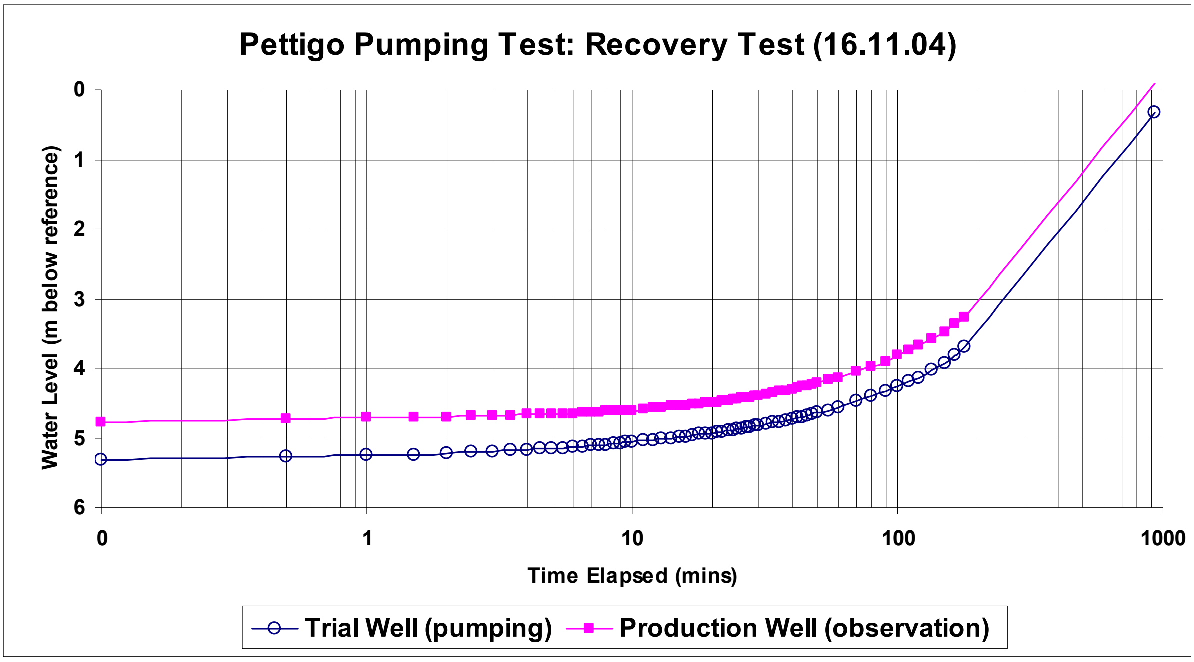
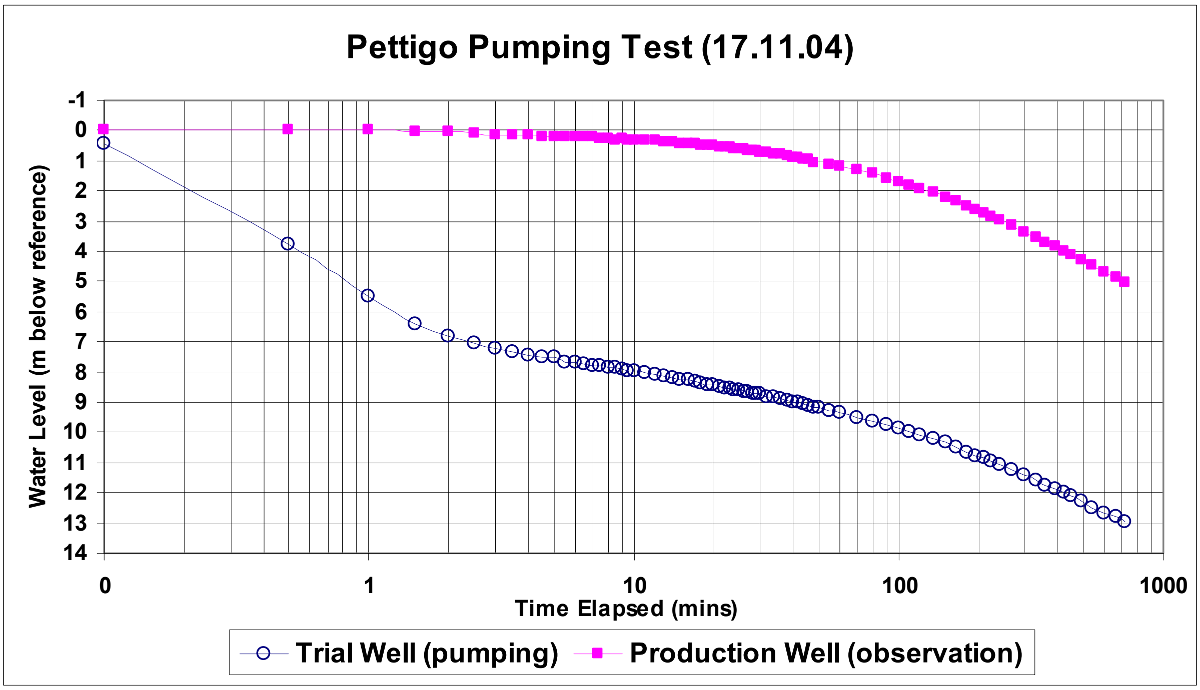
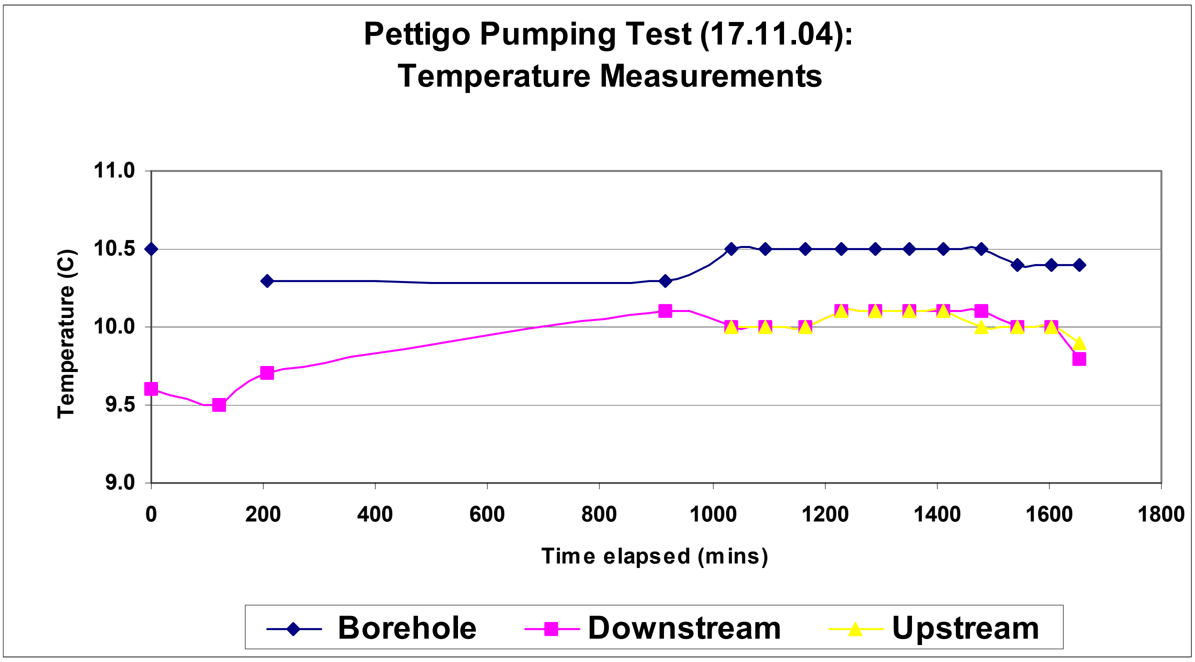
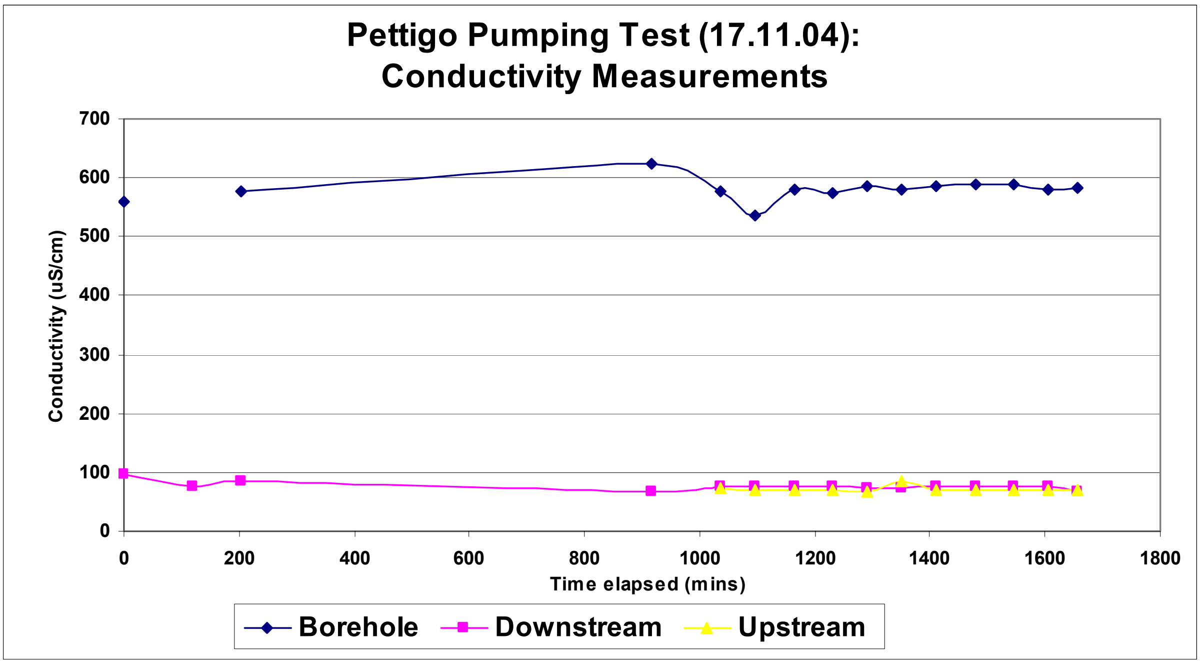
8 Appendices

Appendix D. Pettigo PWS: GSI Pumping Test Data.






Pettigo Pumping Test (17.11.04):
Temperature Measurements
Temperature (C)
11.0
10.5
10.0
9.5
9.0
0
200
400
600
800
1000
1200
1400
1600
1800
Time elapsed (mins)
Borehole
Downstream
Upstream


Pettigo Pumping Test (17.11.04):
Conductivity Measurements
Conductivity (uS/cm)
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
1400
1600
1800
Time elapsed (mins)
Borehole
Downstream
Upstream