Templederry Water Supply Scheme

Groundwater Source Protection Zones

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April 2002

1. Introduction

The objectives of this report are:

- To delineate source protection zones for the Templederry Water Supply Scheme borehole.
- To outline the principal hydrogeological characteristics of the area.
- To assist North Tipperary County Council in protecting the water supplies from contamination.

2. Location and Site Description

The site is situated in the townland of Loughane Lower, North County Tipperary, in the foothills southeast of the Silvermine Mountains. The topography is undulating and the drainage is generally poor, with a small stream passing just a few metres from the borehole. The site, which measures about 5 m x 5 m, is beside the road and surrounded by concrete walls on three sides. There is a pumphouse. The SP5 pump, fitted on 28th November 1996, has 2 horse-power rating, and a maximum pumping rate of 1800 gph (196 m^3/d).

The water is not yet chlorinated, although there are plans to do so.

3. Summary of Well Details

GSI no.	1715NEW086	1715NEW091
Grid ref. (1:25,000)	19399 16875	19396 16872
Townland	Loughane Lower	Loughane Lower
Owner	North Tipperary County Council	
Well type	Borehole	Piezometer (observation borehole)
Elevation (top of casing)	146.47 m OD	147.25 m OD
Depth and screening	16.9 m; open interval probably 15-16.9 mbgl	25 m, screened 15-25 mbgl
Diameter	200 mm (8”)	76 mm
Depth-to-rock	14.8 m	11 m
Static water level	141.52 m OD	142.08 m OD
Daily Abstraction	82 m^3/d (18,000 gal/d)	-
Hours pumped per day	10	-
Pumping rate	200 m^3/d	-
Pumping test summary	(i) Abstraction rate: 115 m^3/d (constant rate test)	-
	(ii) Drawdown: 6.68 m (at 115 m^3/d after 445 minutes pumping)	0.365 m (at 115 m^3/d after 445 minutes pumping)
	(iii) Specific capacity 17.1 m^3/d/m (after 445 minutes pumping)	-
	(iv) Transmissivity: 4.75 m^2/d	-

4. Methodology

Desk study

Bedrock geology information was compiled from the GSI Geology 1:100,000 Sheet 18 (Archer *et al.*, 1996) and soils were compiled from Teagasc (Finch & Gardiner, 1993). Basic well details were obtained from GSI records and County Council personnel; such details include borehole depth, elevation and abstraction details.

Site visits and fieldwork

The second stage of investigation comprised site visits and fieldwork in the area. This included a walkover survey in order to investigate further the subsoil and bedrock geology, the hydrogeology, the vulnerability to contamination and potential hazards. Water samples taken were analysed by the State Laboratory. Five auger holes were bored to ascertain the depth to bedrock in the area, with a monitoring piezometer installed to a depth of 25 m (13 m into bedrock) in a further drilling of one of them (TNTD5). A pumping test was carried out on 12 July 2001. The pumping phase of the test lasted for 7 hours 25 minutes, and the water level recovery was monitored for a further 2¼ hours.

Data analysis

The assessment stage utilised analytical equations and hydrogeological mapping to delineate protection zones around the public supply well.

5. Topography and Surface Hydrology

Templederry WSS source lies within the catchment of the Nenagh River. The Nenagh River and a parallel Mill Race stream merge into the Nenagh River in the Moanraha Glen, about 620 m east of the public supply well. The borehole is a few metres from the Loughane Upper - Curreeny road.

The source is situated in undulating pasture, on a meadow between the two rivers. The ground rises relatively gently west-southwest up the river valley from an elevation of about 146.5 m aOD at the borehole, to 183 m OD where the Nenagh River emerges from a narrow valley between Cooneen and Long John’s Hills, approximately 2.8 km away. These hills are at the east of the Silvermines Mountain ridge. Up the valley sides to the southwest of the borehole, the ground rises more steeply to an elevation of 305 m OD 2.1 km away.

A small spring emerges approximately 55 m north-northeast of the borehole at a break in slope caused by down-cutting of the river; it flows into the Nenagh River

6. Geology

6.1 Bedrock Geology

The bedrock geology of the area comprises sediments of Silurian age (425 million years old), which were subsequently folded and faulted. The rock units of the area, which are shown in Figure 1, are summarised in Table 1.

Table 1: The bedrock geology in the vicinity of Templederry WSS

Rock Formation	Rock Material	Thickness	Occurrence
Hollyford Formation (HF)	Greenish-grey mudstones interbedded with thin, laminated siltstones predominate in some places, but in others the mudstones and siltstones are interbedded with numerous thin, fine sandstones. Occasional thick-bedded and usually coarser sandstones.	>200 m	Underlies the source and for many km in the surrounding area, forming the core of both the Silvermines and Slieve Felim mountains. Outcrops about 1.8 km to the southwest of the borehole.

6.1.1 Geological Structure

The borehole is situated approximately in the middle of a fault-bounded rectangle about 13 km^2 in area and oriented NE-SW. The block is defined by major faults running in a NE-SW direction and crosscutting faults trending NW-SE. Just outside the fault block, on the other side of the southwest bounding fault, the layered sandstones and mudstones are tilted towards the northwest and north, with dips between 15° and 25°.

6.2 Subsoils (Quaternary) Geology

The subsoils in the vicinity of the source and its zone of contribution comprise glacial deposits, and probably also river deposits. The soil compositions are influenced by both the underlying rock type (mudstones and sandstones) and by the nature of the deposit (glacial or river). The characteristics of each category are described briefly below.

6.2.1 Shale and sandstone Till and Colluvium

Teagasc (1993) indicate that the topsoils in this area have parent materials (i.e. subsoils) of shale/sandstone till and colluvium (material deposited by gravity at the foot of a slope). The topsoils are predominantly gleys, meaning that they generally are saturated. In the vicinity of the Templederry WSS borehole, the saturation relates to the high water table and the location in a flat-bottomed river valley, rather than to the permeability of the subsoils.

6.2.2 Sands & Gravels

Auger-hole drilling by the GSI determined sand and gravel as comprising the subsoil cover in much of the region in the vicinity of Templederry WSS (see Figure 3). From the proximity to the Nenagh River, it is likely that some of the sands and gravels are alluvial. At the base of several of the auger holes (TNTD2, TNTD4 and TNTD5) there is a clay or clayey gravel layer overlying the bedrock. This is interpreted as glacial till material.

6.3 Depth-to-rock

The depth to rock is known at selected localities from a drilling program undertaken for this study by the GSI to ascertain the thickness and type of the subsoils. The locations of the five auger holes are shown on Figure 2, and the logs are summarised in Figure 3. Measured depths to bedrock range from 3.2 to 11 m.

7. Hydrogeology

7.1 Data availability

Hydrogeological and hydrochemical information for this study was obtained from the following sources:

- Hydrogeology

  Data such as flows, and water levels in the boreholes were gained from Co. Co. personnel, and collected by the GSI as part of this study.

- Hydrochemistry/water quality

  GSI targeted sampling (August 2000)

  EPA (March 1997)

  County Council analyses of Public supplies (1990 – 1999)

The hydrochemical data are summarised fully in the accompanying report “An assessment of the quality of public, group scheme and private groundwater supplies in North Tipperary”.

7.2 Rainfall and Recharge

Rainfall data for the area were obtained from Met Éireann. The mean annual rainfall (R) for the area (1961-90) was 1200 mm. Potential Evaporation (PE) is estimated from a Met Éireann national contoured map as 505 mm/yr. Actual evapotranspiration (AE) is estimated by taking 90% of the potential figure, to allow for soil moisture deficits, as 455 mm/yr. Using these figures, the potential annual recharge (R - AE) is taken as approximately 745 mm. Runoff is assumed to be 50% of available recharge, i.e. 372 mm. This assumption is an empirical standard used in GSI (Wright *et al.*, 1983) for till subsoils of moderate permeability. These calculations are summarised below:

Average annual rainfall	1200 mm/yr
Estimated P.E.	505 mm/yr
Estimated A.E. (90% P.E.)	455 mm/yr
Potential recharge	745 mm/yr
Surface Runoff	372 mm/yr
Recharge	372 mm/yr

7.3 Groundwater levels

Water level data were obtained during surveys carried out in July 2001:

- The static water level at the site was 4.5 m below ground level (141.52 m OD) on 12 July 2001.
- The recovered water level in the piezometer 25 m west-southwest of the borehole was 142.08 m OD.
- The spring to the north of the borehole emerges at a height of 142.37 m OD in late July 2001.
- The water level in the Nenagh River adjacent to the spring was 142.23 m OD in late July 2001.
- The Mill Race stream has an elevation of 145.53 m OD adjacent to the road bridge.

A schematic drawing and alternative interpretations of the surface water and groundwater levels in the vicinity of the source are shown in Figure 4 (a) and (b) and discussed further in section 7.8.

7.4 Groundwater Flow Directions and Gradients

The groundwater piezometric surface in the area is assumed to broadly reflect topography, with groundwater generally flowing toward and discharging into the Nenagh River. The overall slope downhill, hence groundwater flow direction, is to the east-northeast. However, in the vicinity of the borehole, there is a northward component of groundwater flow due to the steeper river valley walls and rapidly increasing elevation to the south driving groundwater flow.

The natural hydraulic gradient in the area is estimated to average 0.02 (2%), directed in an (east-) northeasterly direction.

7.5 Hydrochemistry and Water Quality

Field measurements in August 2000 indicated an electrical conductivity of 287 µS/cm and a temperature of 10.4^{o}C. After 4½ hours of pumping during the July 2001 pumping test, groundwater electrical conductivity was 301 µS/cm, and the temperature was 11.7^{o}C. The spring electrical conductivity was 200 µS/cm.

Results of laboratory analyses of water samples are presented in Appendix 1. Data that reflect water quality are shown graphically in Figure 5. The following key points are identified from the data:

- The groundwater has a calcium-bicarbonate (Ca - HCO_3) hydrochemical signature (one sample).
- The groundwater is 'slightly hard' (total hardness 136.8 mg/l as $CaCO_3$).
- Nitrate concentrations (as NO_3) range between 5.4 and 10.5 mg/l, with an average concentration of 6.9 mg/l (8 samples) over the period September 1990 to August 2000. These nitrate levels do not give cause for alarm.

- A single chloride measurement records a concentration of 10.9 mg/l. Chloride is a constituent of organic wastes and (away from coastal areas) levels higher than 25 mg/l may indicate contamination, and higher than 30 mg/l usually indicate significant contamination. As far as is measured, the chloride level does not give cause for alarm.
- No faecal contamination of the source in the period November 1990 to August 2000 has been detected by bacteriological sampling, but only two samples have been taken. In the period January 1990 to August 2000, general coliforms were detected on two occasions (out of 12 samples).
- A potassium:sodium (K:Na) ratio of 0.07 can be calculated from the available data. A K:Na ratio of >0.4 (along with other parameters) may indicate contamination. To provide sufficient data to assess the source, it should be measured routinely in the future.
- Iron concentrations were below the method detection limit (MDL) of 0.05 mg/l in all eight samples taken. Manganese concentrations exceeded the MDL of 0.02 mg/l once (0.025 mg/l) in eight samples.

7.6 Aquifer Parameters

To estimate the aquifer parameters in the vicinity of Templemore WSS, a constant rate pumping test was conducted by the GSI on 12th July 2001. Pumping for 445 minutes was followed by water level recovery monitoring for 140 minutes. After 445 minutes pumping at 115 m^3/d, the water level in the pumping well had approximately stabilised, but at the observation piezometer, 25 m away, it was continuing to decline (slowly).

The time-drawdown curve for the pumping well shows two distinct segments, each with a different slope. The first segment extended for 10 minutes of pumping, at which point the water level had fallen by some six metres. After this time, the rate of drawdown reduced markedly, and over the remainder of the test (7½ hours) the water level was drawn down a further 70 cm or so. The recovery measurements showed a similar feature in reverse, with the water level rising only slowly up to the 6 m (drawdown) level, and then recovering much more quickly.

The data from the observation well showed only a small drawdown, with a slope similar to that of the later stages of the pumping well graph.

From these data, it is inferred that the well is drawing water from both the poor bedrock aquifer and the more permeable (but thinner) gravel deposits that overlie the bedrock. The initial drawdown in the pumping well was rapid because the bedrock aquifer is poorly permeable. After about 10 minutes, the rate of drawdown was reduced because water was draining down from the gravel into the bedrock to replace the water which had already been extracted from the well. For the remainder of the test, the rate of withdrawal from the well was almost matched by the drainage of water from the gravel into the bedrock.

The Jacob analysis method (Cooper and Jacob, 1946) was used to analyse the variation of water level with time in both the pumping and observation wells, in order to derive values for aquifer transmissivity and permeability. An aquifer effective thickness of 10 m is assumed.

As can be seen from the values listed in Table 2, computed permeabilities vary by up to a factor of about 20, ranging between 0.5 and 9.7 m/d. There are various reasons for the observed differences. The main one is that there is gravel and sandy gravel (*c.* 5 m saturated thickness) over parts of the aquifer. Water will flow from the gravel to the mudstone/sandstone bedrock aquifer, in response to the additional pressure gradient imposed when the wells are pumped. This 'extra' water entering the aquifer will cause the drawdowns in the pumping and observation wells to be less than they would otherwise, particularly in the observation well and especially at the intermediate times measured here.

For the reasons outlined above, a permeability of 0.5 m/d, estimated from the GSI pumping test in the Templederry supply source borehole, is assigned to the Hollyford Formation aquifer.

The permeability of the gravel, assuming an effective saturated thickness of 10 m, is estimated as 5 m/day.

Table 2: Estimated aquifer parameters for the rock units at Templederry WSS

Parameter	Data source	Permeability values *
Permeability	445 minutes pumping test Pumping well (GSI) • Jacob analysis of drawdown • Jacob analysis of recovery	 0.48 – 5.2 m/d 0.38 – 6.5 m/d
	445 minutes pumping test Piezometer (GSI) • Jacob analysis of drawdown • Jacob analysis of recovery	 5 – 5.37 m/d 9.27 – 5 m/d
Porosity Hollyford Formation Porosity gravel	estimated from regional experience estimated from regional experience	0.02 0.2
Hydraulic gradient	estimated from topography	2% (west of borehole) 0.2% (east of borehole)

** first value is early time, second value is intermediate ('leaky') time*

7.7 Aquifer Category

The Hollyford Formation (HF), which forms the aquifer that supplies part of the water to the spring is characterised in North Tipperary is classified as '**Pl**' (Bedrock aquifer that is generally unproductive except for local zones)

7.8 Conceptual Model

- The Templederry source is likely fed from both the Hollyford Formation and from the overlying gravel deposits. The Hollyford Formation is classified as a 'bedrock aquifer that is generally unproductive except for in local zones' **(Pl)**. The areal extent of the gravel deposit is unknown; it is assumed that the area is less than 1 km^2, therefore the gravel deposit is not defined as an aquifer.
- The permeability in the bedrock aquifer depends on the development of faults, fissures and fractures. Permeability in the saturated gravels depends largely on the particle size distribution.
- The shapes of the pumping test drawdown and recovery curves measured in the pumping and observation boreholes indicate that the gravels and sands overlying the bedrock aquifer around the source contribute to the groundwater abstracted from the borehole.
- Groundwater electrical conductivity (EC) is quite low (287-301 µS/cm), reflecting the poorly soluble nature of the underlying non-limestone rock. Coupled with the calcium-bicarbonate (Ca–HCO_3) hydrochemical signature (section 7.5) a relatively short groundwater residence time in the aquifer is indicated (and therefore greater vulnerability of the source to bacterial or viral pathogens). The measured spring EC was 200 µS/cm, indicating that water emerging from the spring has an even shorter residence time.
- The degree of hydraulic communication between the aquifer and the overlying saturated gravel deposits depends on the vertical permeability of the sandy gravel, the vertical permeability of the bedrock aquifer, and on the absence or presence (and lateral extent) of a low permeability barrier between the gravels and the bedrock aquifer (see section 6.2.2 and Figure 3, auger holes TNTD2, TNTD4 and TNTD5).
- Water levels in the rivers that flow either side of the site appear to be higher than the static water level in the production well and the piezometer. Groundwater levels measured in the pumping and

observation boreholes (bedrock aquifer), auger hole TNTD4 (gravel subsoil), and the elevation of surface water features (the Nenagh River, the Mill Race stream and a small spring next to the Nenagh River) allow two interpretations:

  - *Scenario 1:* The bedrock aquifer and the overlying sandy gravel subsoils are in hydraulic continuity, and share a common water table. There is surface water–groundwater interaction at both the Nenagh River and the Mill Race stream, with recharge from the rivers causing slight recharge mounds in the bedrock aquifer (Figure 4.a). The thin (c. 1 m) clay layer at the base of the gravels observed in auger holes TNTD2, TNTD4 and TNTD5 is probably not laterally extensive and does not constitute a general barrier to flow between the overlying gravels and the bedrock, although locally there will be some impedance. The spring is fed by water from a local perched water table in the gravels. Therefore, the aquifer can be considered to be unconfined over much of the extent of the source's ZOC (zone of contribution, see section 8). The southern boundary of the ZOC is defined by the Mill Race Stream.
  - *Scenario 2:* The water table in the gravel subsoil is separate from the groundwater surface in the bedrock aquifer. There is surface water–groundwater interaction only at the Nenagh River, with recharge from the Nenagh River causing a slight recharge mound in the bedrock aquifer (Figure 4.b). The Mill Race stream is in hydraulic communication with the gravel subsoils only, and the spring adjacent to the Nenagh River is fed from water in the subsoils. In the vicinity of the source, there is a downward-directed head difference between the gravels and the bedrock aquifer. The head difference (about 1.3 m) is maintained by the thin (1 m) clay layer at the base of the gravels (observed in auger holes TNTD2, TNTD4 and TNTD5). Therefore, the aquifer can be considered to be semi-confined ('leaky') over much of the extent of the source's ZOC (zone of contribution). The southern boundary of the ZOC may extend south of the Mill Race Stream.

- In general, there are few drains and surface streams apart from the Nenagh River and the Mill Race stream, indicating the free draining nature of the subsoils. Teagasc (1993) have mapped the soils as 'gley' (saturated soils) for the area between the rivers, although this saturation relates to the proximity of the water table to the ground surface rather than poor drainage.
- The groundwater flow in the area broadly reflects topography, flowing east-northeast and probably discharging into the Nenagh River. The natural hydraulic gradient in the area is estimated to average 0.02 (2%), directed in an (east-) northeasterly direction.

8. Delineation of Source Protection Areas

8.1 Introduction

Two source protection areas are delineated:

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

8.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the complete catchment area to the source, i.e. the zone of contribution (ZOC), which is delineated 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 rock permeability and (d) the recharge in the area. The ZOC is delineated as follows:

i) An estimate of the area size is obtained by using the average recharge and the abstraction rate.

ii) To allow for errors in the estimation of groundwater flow direction and to allow for an increase in the ZOC in dry weather, a safety margin is incorporated by assuming a higher abstraction rate than the current rate.

Average daily abstraction at the site is 82 m^3/d at an estimated pumping rate of 200 m^3/d. The ZOC is delineated for the 'instantaneous pumping rate, rather than for the daily average, for the following reasons:

- to allow for increased water demand due to expansion.
- to allow for an increase in the ZOC during dry weather.

The two scenarios described in the conceptual model (section 7.8) require different consideration of the recharge ***only*** if the permeability of the clay layer that may separate the gravel and bedrock is less than 0.001 m/d. At a higher permeability, a head difference of 1.3 m allows sufficient water through. Additionally Figure 6 shows that, while the well is pumping, for an assumed average increase in head gradient of 2.5 m over a radius of 20 m (around the pumping well), the increase in flow through the clay layer to the well would range between 3.1 m^3/d to 782 m^3/d for clayey layer permeabilities between 0.001 – 0.25 m/d (the latter permeability would be for a sandy-gravelly clay).

The boundaries of the ZOC are delineated as follows:

Northern Boundary: this boundary is defined by the Nenagh River.

Southern Boundary: formed by the Mill Race stream (*Scenario 1*) or passing just south of the Mill Race Stream (*Scenario 2*).

Western Boundary: this is defined by the 'null point', i.e. the downstream limit of the cone of depression under pumping conditions. The maximum extent can be estimated by:

$X_L = Q/(2\pi K.b.i.)$ where

Q = pumping rate, K = permeability, b = aquifer thickness and i = hydraulic gradient.

If Q = 200 m^3/d, K = 0.5 m/d, b = 10m, and i = 0.02, then X_L = 318 m.

Using the aquifer parameters for the gravel, then X_L = 32 m.

Given the inherent uncertainties in the calculations, the downstream limit of the cone of depression (X_L) is more conservatively taken as 100 m.

Eastern Boundary: the upstream limit of the zone of contribution.

Taking the recharge to be 372 mm as indicated in Section 7.2, the area required to supply a pumping rate of 200 m^3/d is calculated to be 0.20 km^2 (20 ha). This area compares with around 0.32 km^2 (32 ha) computed from topographic considerations and constrained by the recharge rate for *Scenario 1* and 0.33 km^2 (33 ha) for *Scenario 2*.

These boundaries are based largely on topography, our current understanding of groundwater conditions in the area and on the available data. The ZOC boundary illustrated in Figure 1 relates to '*Scenario 2'*. The (not drawn) ZOC for *Scenario 1* is very similar in overall shape.

8.3 Inner Protection Area

The Inner Protection Area (SI) is the area defined by a 100 day time of travel (TOT) from a point below the water table to the source, and is delineated to protect from potentially contaminating activities which may have an immediate influence on water quality at the source, in particular from microbial contamination. The SI is shown in Figure 1 and is computed as follows:

Taking the permeability as 5 m/d, average pumping Hydraulic Gradient as 0.04, and Effective Porosity as 0.02, the groundwater flow velocity is estimated as 1 m/day (0.5 x 0.04/0.02), so the 100-day travel time distance is approximately 100 metres.

The Inner Protection Zone (SI) has an area of about 0.036 km^2 (36 ha). Down-gradient of the borehole, the SI covers about 90 % of the ZOC. Overall, Approximately 11 % of the ZOC falls within the Inner Protection Zone (SI).

9. Groundwater Vulnerability

Vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities. It depends on the thickness, type and permeability of the subsoils. A detailed description of the vulnerability categories can be found in the Groundwater Protection Schemes (GWPS) document (DoELG/ EPA/GSI, 1999).

Areas of rock outcrop and where rock is less than 3 m from the surface are rated 'Extreme' vulnerability. Where subsoil permeabilities are high (e.g., sands and gravels) or moderate, and subsoils are between 3 and 10 m thick, aquifer vulnerability is 'High'. As this is an interim report, a distinction is made only between Extreme and other vulnerability categories.

The groundwater vulnerability in the area is considered to be 'High to Low'. Vulnerability of groundwater in the vicinity of Templederry WSS is shown in Figure 7.

10. Groundwater Protection Zones

The groundwater protection zones are obtained by integrating the two elements of land surface zoning (source protection areas and vulnerability categories), i.e. by superimposing the vulnerability map on the source protection area map. Since this is an Interim GWPS, in which only the extremely vulnerable areas are delineated, there are a total of only four possible source protection zones (Table 3). Each zone is represented by a code e.g. **SO/E**, which represents an Outer Source Protection area where the groundwater is extremely vulnerable to contamination. There are two groundwater protection zones present around the Templederry WSS source (see Figure 8), as shown in Table 3.

Table 3: Matrix of Source Protection Zones

VULNERABILITY RATING	**SOURCE PROTECTION**	
	Inner	***Outer***
Extreme (E)	SI/E (absent)	SO/E (absent)
High to Low (H-L)	SI/H-L	SO/H-L

11. Land Use and Potential Pollution Sources

Pastoral agriculture is the principal activity in the area. Other hazards include farmyards, septic tank systems, application of fertilisers (organic and inorganic) and pesticides, and possible spillages along the roads. No detailed assessment of hazards was carried out as part of this study.

12. Conclusions and Recommendations

- The borehole at Templederry abstracts water from both a small local gravel deposit of uncertain extent, and a sandstone/mudstone 'bedrock aquifer which is generally unproductive except for in local zones' **(Pl)**.

- Uncertainties as to the borehole construction, the extent of the local gravel deposit, the degree of inter-connection between the groundwater in the two deposits, and the extent of recharge from the two streams, mean that the delineation of source protection zones for the Templederry source is very tentative.

- The area around the supply has 'High to Low' vulnerability to contamination.

- The inner and outer 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.

- The groundwater quality is good. However, regular monitoring of the chemical and bacteriological quality of raw water (rather than treated water) should be carried out (every 3 - 6 months)

- Guidelines should be drawn up for dealing with spillages along the road that passes through the ZOC of the source.

13. References

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Figure 1: Bedrock geology in the Templederry area. Based on *Archer et al.* (1996).

Fig 2 – Site map, – water levels at site

Fig 3 – Driller logs

Fig 4 – Water levels

Fig 5 - Chemistry

Figure 6 – Graph of Q vs clay permeability

Fig 7 – ZOC and TOT map

Fig 8 – Vulnerability map

Fig 9 -Source Protection Zones

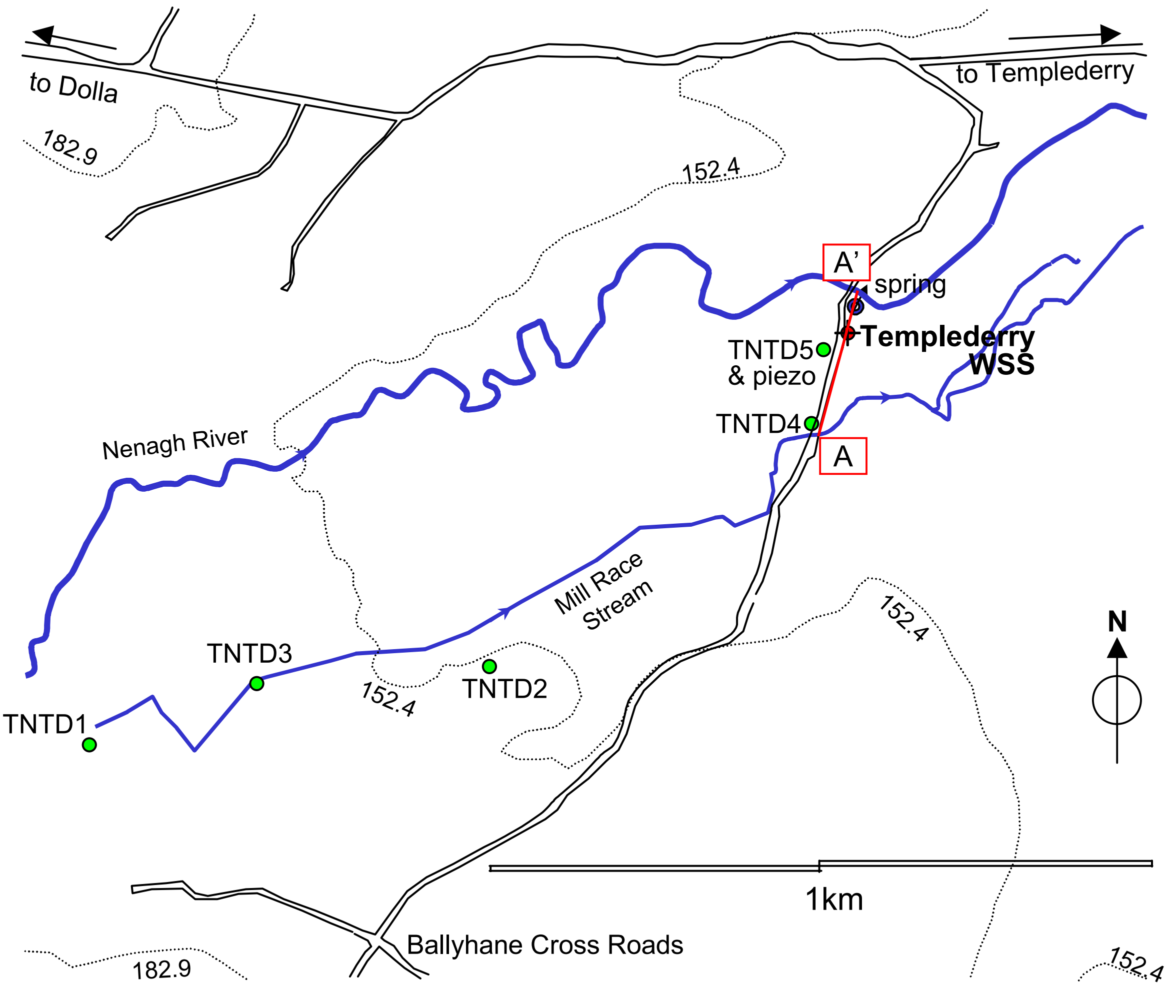
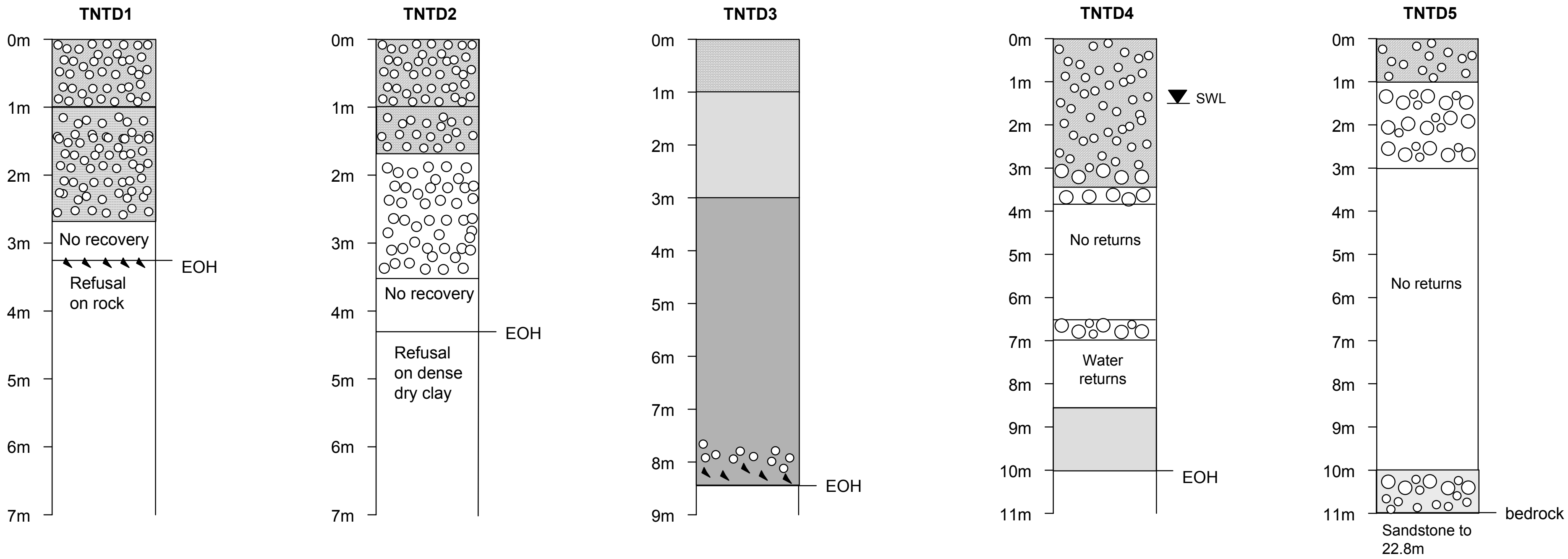


Figure 2: Location map of Templederry WSS production borehole.
Showing auger holes drilled by GSI to determine depth to bedrock in the vicinity (TNTD1 to TNTD5) and other hydrogeological features discussed in the text. Note section A-A', which is shown schematically in Figure 4 (a) and (b), from the bridge crossing the Mill Race stream south of TNTD4, through the spring, to the Nenagh River.



TNTD1

1.0m	Sand & Gravel
2.0m	Clay Slightly Damp Sand & Gravel
2.8m	NO RECOVERY very hard going
3.2m	REFUSAL. Rock Flour on bit

TNTD2

1.0m	Sand & Gravel
1.7m	GRAVEL with some clayey sand
2.0m	Larger Cleaner GRAVEL
2.5m	Easy Going
3.5m	NO RECOVERY
4.3m	REFUSAL on dense dry CLAY

TNTD3

1.0m	Sandy CLAY
2.0m	CLAY
3.0m	CLAY
3.5m	Damp very cohesive CLAY
5.0m	Damp very cohesive CLAY
6.0m	Damp very cohesive CLAY
7.0m	Damp very cohesive CLAY
7.8m	Gravelly Damp v. cohesive CLAY
8.0m	Damp very cohesive CLAY with angular frags
8.5m	Till/Gravel

On pull back last 2m was very dry silt.

TNTD4

1.0m	Sand & Gravel
2.0m	Damp Sand & Gravel
3.0m	Damp Sand & Gravel
3.5m	Large GRAVEL /Cobbles 50-100mm
3.8m	Easier going NO RETURNS
4.0m	NO RETURNS
5.0m	NO RETURNS
6.5m	Wet GRAVEL 20-70mm
7.0m	Water Return
7.2m	Water Returns
8.5m	Wet Clayey TILL
10.0m	EOH

SWL 1.5m

TNTD5 Corehole

1.0m	Sandy GRAVEL
3.0m	Coarse Gravel
3-10m	no returns
10m	Damp GRAVEL with some Clay
11m	Slow going.

Coring

11-22.8m	Greywacke Sandstone.

Figure 3: Summary logs and lithological descriptions of auger holes to assess depth to bedrock near Templederry WSS boreholes. See Figure 2 for the locations of the auger holes.

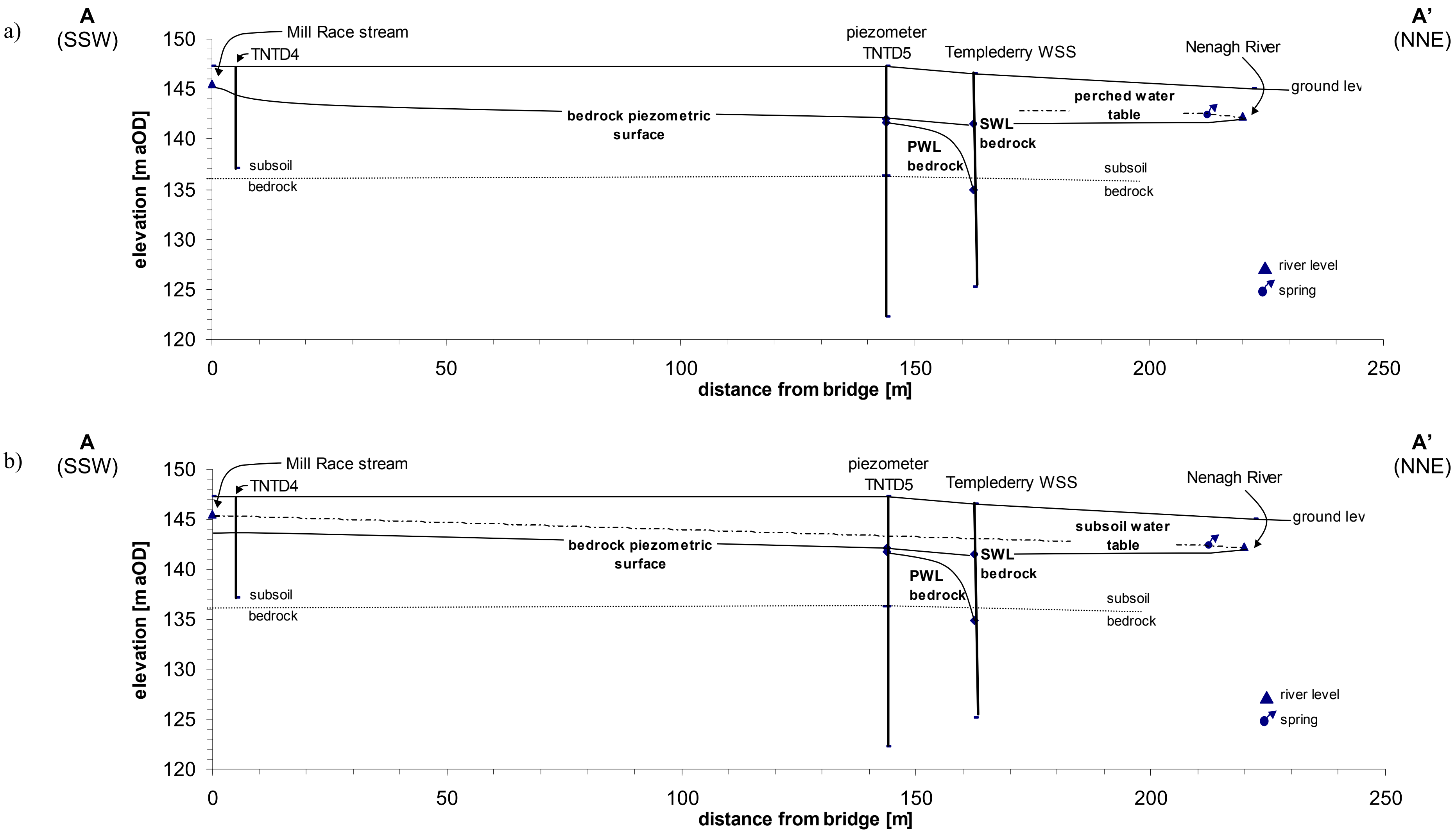


Figure 4: Two scenarios for the nature of the interaction between aquifer and surface water features, and potential existence of a separate subsoil water table and aquifer groundwater level.

Scenarios (a) very limited perched subsoil water table feeding spring, & (b) separate subsoil water table – are discussed in the text (section 7.8). Based on interpretations of ground and surface water levels in the vicinity of Templederry WSS. See Figure 2 for location of section. TNTD4 and piezometer TNTD5 are projected on to the line of section.

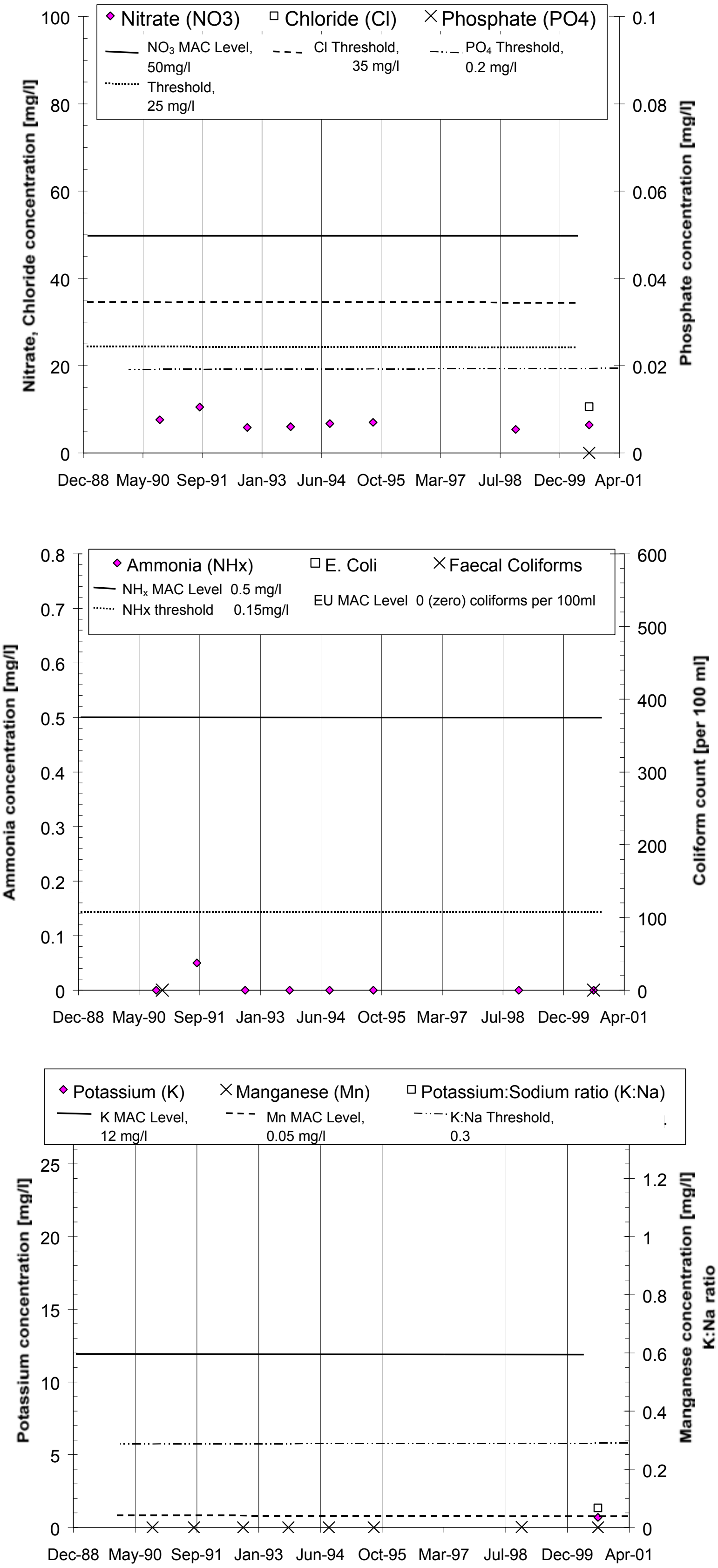


Figure 5: Key indicators of agricultural and domestic groundwater contamination at Templederry WSS

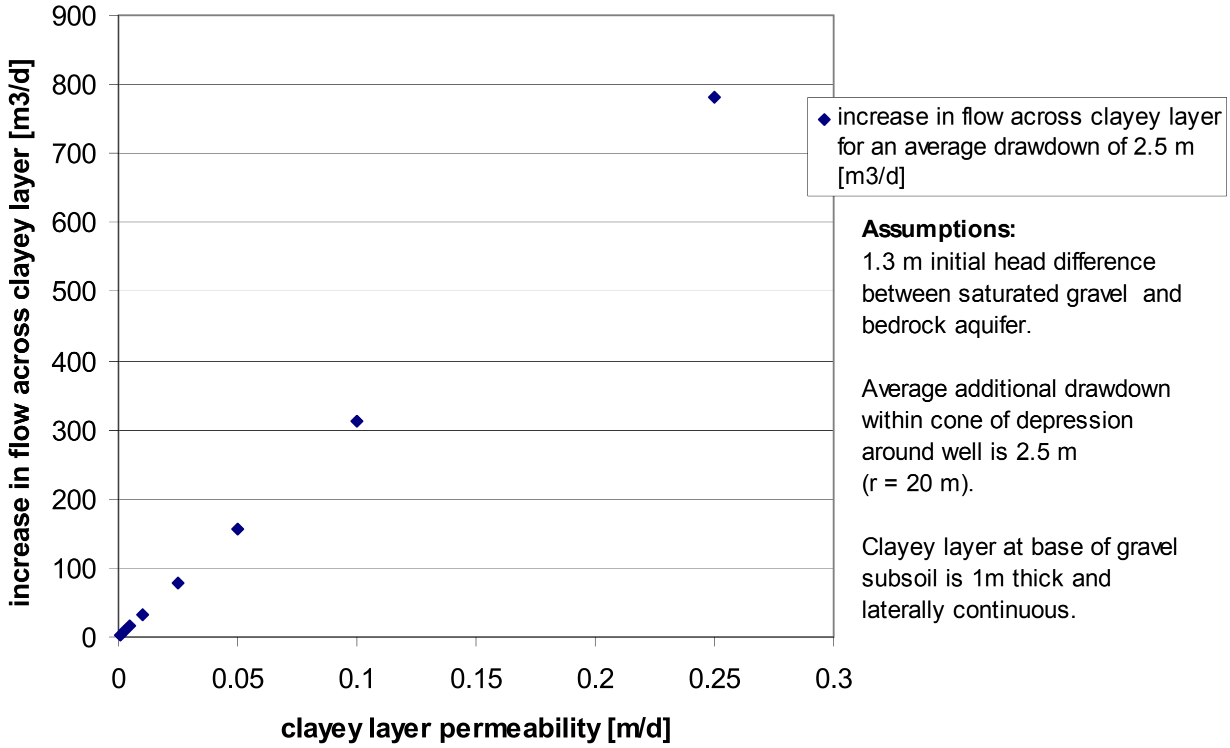


Figure 6: Increase in flow across clayey layer postulated to separate the gravel subsoil from the bedrock aquifer in the *Scenario 2* conceptual aquifer model (section 7.8, Figure 4.b) as a function of the permeability of the clayey layer.

Appendix 1: Laboratory Analyses of Groundwater at Templederry WSS

Parameter	**Results of Laboratory Analyses**																
Laboratory	North Tipperary Co. Co																State Lab
Sample treatment	NS	NS	-	NS?	NS?	NS?	NS?	NS?	-	NS?	-	NS	-	NS	-	NS	S
Date	03/01/90	04/04/90	25/09/90	14/11/90	26/08/91	19/11/91	18/08/92	01/09/92	28/09/92	24/08/93	28/09/93	23/08/94	21/08/95	19/05/98	01/12/98	27/04/99	09/08/00
EC (µS/cm)			312		318				311		317	317	417		315		289
pH (lab.)			7.4		7.4				7.6		7.6	7.8	7.8		7.7		
Total Hardness (mg/l $CaCO_3$)																	136.8
Total Alkalinity (mg/l $CaCO_3$)																	138
Calcium (mg/l)																	41.01
Magnesium (mg/l)																	8.1
Chloride (mg/l)																	10.6
Sulphate (mg/l)																	5.5
Sodium (mg/l)																	10.4
Potassium (mg/l)																	0.7
K:Na																	0.07
Nitrate (mg/l NO_3)			7.6		10.5				5.8		6	6.7	7		5.4		6.4
Iron (mg/l)			<MDL		<MDL				<MDL		<MDL	<MDL	<MDL		<MDL		<MDL
Manganese (mg/l)			<MDL		<MDL				<MDL		<MDL	<MDL	<MDL		0.025		<MDL
E/F coli per 100 ml.				0													0
Total Coli /100ml	0	0		13	0	0	1	0		0		0		0		0	0
Total Ammonia (mg/l NHx)			<MDL		0.05				<MDL		<MDL	<MDL	<MDL		<MDL		<MDL
Comments	Apparently uncontaminated and of good quality; monitoring of water quality parameters should continue.																

Note: **Bold type denotes E.U. MAC exceedances.** *Italic type denotes GSI threshold exceedances* 'NS'/ 'S' denotes Non-source (treated) or Source (raw) water samples