Templemore Water Supply Scheme

Groundwater Source Protection Zones

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1. Introduction

The objectives of this report are:

- To delineate source protection zones for the Templemore (College Hill) Water Supply sources.
- 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 located 3 km north of the town of Templemore, about 57 m below the top of College Hill in the townland of Curraduff, North County Tipperary. There are two production boreholes 5 m apart, which are encased in a large brick and concrete pumphouse, and the whole site, including the sand-pit filters and treatment station, is fenced off. Only one borehole is pumped at a time, and one or the other of the boreholes are pumped overnight to a reservoir at the top of College Hill.

The water is chlorinated.

3. Summary of Well Details

** **Daily abstraction** value given below is for one borehole pumping alone. According to the pumping records, usually it is Production well # 2 that is pumped.*

GSI no.	2017SWW187 (Production well #1)	2017SWW232 (Production well #2)
Grid ref. (1:25,000)	21052 17468	21052 17467
Townland	Curraduff	Curraduff
Owner	North Tipperary County Council	North Tipperary County Council
Well type	Borehole	Borehole
Elevation (top of casing)	127.2 m OD	127.2 m OD
Depth	72.5 m	86.0 m
Diameter	300 mm	300 mm
Depth-to-rock	2.8 m	3.0 m
Casing	300 mm to 43.5 m	300 mm to 57 m
Screen	300 mm 43.5 m to 72 m	300 mm 57 m to 82 m
Static water level (SWL)	125 m OD (after winter recharge); 95 m OD (at end of summer)	125 m OD (after winter recharge); 95 m OD (at end of summer)
Drawdown	46 m on average	32 m on average
Daily Abstraction*	2180 m^3/d (480,000 gal/d) (reduced during summer 2001 to 1000 m^3/d)	2180 m^3/d (480,000 gal/d) (reduced during summer 2001 to 1000 m^3/d)
Hours pumped per day	6 - 14 (depends on SWL)	6 - 14 (depends on SWL)
Pumping rate	4360 m^3/d (assuming 12 hour pumping duration)	4360 m^3/d (assuming 12 hour pumping duration)
Pumping test summary	(i) pumping rate: up to 5900 m3/d (variable rate test); 4104 m3/d (constant rate test) (ii) Specific capacity: 138 m3/d/m (at 4536 m3/d); 179 m3/d/m (at 4104 m3/d after 450 minutes) (iii) Transmissivity: 169-297 m^2/d	no information available

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 Finch & Gardiner (1993). Basic public supply details were obtained from GSI records and County Council personnel; such details include borehole depth, elevation, abstraction rate, pumping test details and geophysical borehole logs.

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. A short pumping test was carried out (14/9/00) and five auger holes were bored to ascertain the depth to bedrock in the area.

Data analysis

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

5. Topography and Surface Water Hydrology

Templemore WSS source lies within the catchment of the south-flowing River Suir, which is about 1.5 km east of the site. The Devilsbit Mountains, rising to 480 m OD, are some 3-4 km to the west.

The site is located in an area of undulating pasture on a river meadow. About 100 m to the north of the site, the hill slope rises rapidly to the peak of College Hill, which is 800 m to the northeast and 57 m higher. Approximately 120 m south of the boreholes, a small stream flows eastwards. This ditch drains the boggy ground occupying the area to the south of the WSS site.

There are several soil and subsoil types in the vicinity of the source ranging from peat to sandy limestone glacial till.

6. Geology

6.1 Bedrock Geology

The bedrock geology of the area comprises limestones of Lower Carboniferous age (*ca.* 350 million years old) which were subsequently faulted. In fact, the wells were sited at this location to exploit an expected productive zone at the junction between the Waulsortian mudbank limestones (WA) and the underlying dark grey Ballysteen Formation (BA/BAld). 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 Templemore WSS.

Rock Formation	Rock Material	Thickness	Occurrence
Waulsortian Limestone (WA)	Clean limestone: massive, unbedded micrite.	200-300 m	A NE-SW oriented zone underlies the northern part of the source recharge area.
Ballysteen Formation (BA)	Muddy limestone*:* blue-grey to mid-grey well-bedded, ca. 0.5m thick beds.	~200 m	Surrounds the borehole and underlies the eastern part of the source recharge area.
Ballysteen Fmn - Lisduff Member (BAld)	Clean limestone: thick bedded, pale blue-grey, cross-bedded, well-jointed oolite.	up to 100 m	Underlies the south-western part of the source recharge area.

6.1.1 Geological Structure

The boreholes are situated within the muddy limestone of the Ballysteen Formation and immediately adjacent to a major NNW-SSE trending fault in a complexly faulted area. The NNW-SSE fault, which terminates against a major NE-SW trending fault about 330 m north of the site, juxtaposes the muddy limestone against the pure limestone of the Lisduff Oolite Member. A smaller splay off the NE-SW fault compartmentalises the Lisduff Oolite. The younger pure Waulsortian Limestones occur to the north of the NE-SW fault and are downthrown relative to the Ballysteen Formation. Bedding dips in the immediate vicinity are low ($0\text{-}5^{o}$).

6.2 Subsoils (Quaternary) Geology

The subsoils in the area are comprised largely of tills and re-worked alluvium. The majority of the area between College Hill and Templemore, 3 km to the south, is covered by limestone-sandstone till. The soil composition is influenced by both the dominant lithology in Tipperary (limestone) and the sandstone bedrock exposed in the Devilsbit mountains to the west. The top of College Hill comprises a different type of till that includes reworked glacial river deposits that have been transported southwards. Peat (a post-glacial deposit) occupies an area about 800 m in diameter to the south of the supply. The characteristics of each category are described briefly below.

6.2.1 Limestone Till (with some Sandstone and Shale)

Teagasc (1993) assign the soils covering most of the area around Templemore WSS to the 'Elton' Series. In the zone of contribution to the source, this soil occurs on the hill slopes. The soil is derived from the underlying glacial till, mainly derived from limestone, with some additional sandstone and shale fragments. The soil is well drained and the underlying till is considered to be moderately permeable.

6.2.2 Complex Fluvioglacial Gravel &Till

Soil from parent materials of this type occurs at the top of College Hill, where soil cover is thin (less than 3m). The soil is derived from a mixture of parent materials – the limestone-sandstone gravelly till described in the previous section and fine-grained fluvioglacial (sand/gravel) deposits. It contains sandstone and shale fragments in addition to limestone gravel. This till type is extremely well-drained and has moderate to high permeability.

6.2.3 Peat

Peat occupies the lower-lying, boggy areas to the south of the boreholes. The visible layer of peat is black, and slightly crumbly where not completely saturated. Teagasc (1993) assess that the peat has a fen origin, which implies a high water table. The peat has low permeability.

6.3 Depth-to-rock

The depth to rock is known at selected localities from a GSI drilling program undertaken for this study to ascertain the thickness and type of the subsoils. The locations of the four auger holes are shown on Figure 2, and the logs are summarised in Figure 3. Depths to bedrock range from 1.5 to 4.5 m.

7. Hydrogeology

7.1 Data availability

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

- Hydrogeology

  M.C. O'Sullivan Consulting Engineers (1994, 1990)

  K.T. Cullen & Co. Ltd. (March 1986)

  Dunnes Water Services Ltd. (1991)

- Hydrochemistry/water quality

    GSI targeted sampling (August 2000)
    EPA (March 1997 and in prep.)
    County Council analyses of Public supplies (1990 – 2000)
    EC STRIDE Sub-programme Measure 1 (September 1993)

Data such as continuous-record borehole flows and water levels were supplied by Council staff, and collected by the GSI as part of this study.

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 County Tipperary".

7.2 Rainfall, Evaporation and Recharge

Rainfall data for the area were obtained from Met Éireann. The mean annual rainfall (R) for the area (1961-90) was 975 mm/yr. Potential Evaporation (PE) is estimated from Met Éireann's national contoured map as 537 mm/yr. Actual evapotranspiration (AE), estimated by taking 90% of the potential figure to allow for soil moisture deficits, is 483 mm/yr. Using these figures, the potential recharge (R–AE) is 492 mm. The area around the boreholes appears to be one of largely internal drainage, from which little surface runoff escapes. Hence 80% of potential recharge is assumed to infiltrate.

These calculations are summarised below:

Average rainfall (R)	975 mm/yr
Estimated P.E.	537 mm/yr
Estimated A.E. (90% P.E.)	483 mm/yr
Potential recharge (R–AE)	492 mm/yr
Surface Runoff	98 mm/yr
Recharge	394 mm/yr

7.3 Groundwater levels

Water level data for the Templemore WSS source and local private supply boreholes were obtained by the GSI during well surveys carried out in September 2000. Data for the two production and one observation boreholes for selected periods were available. Surface water levels are estimated from base maps. Selected water level data are listed in Table 2, and records from the treatment station are shown on Figure 4. The locations of the boreholes are shown on Figure 2, and also on Figures 5 and 6.

Table 2: Water levels in the vicinity of Templemore WSS.

Location	GSI well name	Date	Water level [m aOD]	Comments
Production borehole #1	2017SWW187	18/9/91	123.45	SWL at start of MCOS 5 day pumping test.
		14/9/00	89.8	GSI dipping prior to pumping test (depressed by summer pumping)
Production borehole #2	2017SWW232	14/9/00	89.9	GSI dipping prior to pumping test (depressed by summer pumping)
"Observation borehole"[1]		16/10/89	123.5	MCOS records of pump test at proposed Templemore WSS; SWL at start of 7 day pumping test.
		14/9/00	89.79	GSI dipping prior to pumping test (depressed by summer pumping)
"Failed Borehole"		14/9/00	90.5	GSI dipping prior to pumping test (depressed by summer pumping)
Kennedy's	2017SWW036	25/7/00 14/9/00	133.4 113.22	Approximate dipping reference 138 m aOD
Greed's	2017SWW041	25/7/00 14/9/00	124.9 101.72	Approximate dipping reference 131 m aOD
Russell's[2]		14/9/00	123.52	Approximate dipping reference 126 m aOD
Stream (130m SW of bores, at stream junction)		31/10/01	~ 124.5	GSI site visit

Figure 4 shows that pre-pumping water levels vary seasonally by about 30 m, with the lowest water levels occurring just before the beginning of the recharge period, which usually occurs in late September/early October. Alex Cummings (Site Overseer) reports that the boreholes respond to rain after an approximate 2 week delay, this being particularly noticeable in the early autumn of 2001, when pumping groundwater levels were only a few metres above the pump intake level.

It is evident from the records that whereas in winter the borehole water levels recover more or less completely after each pumping period, in summer they do not fully recover, i.e. the cone of depression induced by pumping expands through the summer. This implies that the boreholes have effectively reached, or perhaps exceeded, their sustainable yield.

Both production wells exhibit a reduction in drawdown as the pre-pumping water level falls. This may be partly due to a reduction in pumping rate as the head decreases, and partly due to the lack of recovery before pumping (i.e. the apparent drawdown does not take account of the difference between the pre-pumping water level and the natural (fully-recovered) water level in the aquifer).

The natural annual water level fluctuation in the aquifer appears to be about 6-8 metres, i.e. between approximately 120 and 128 metres O.D.

Local private supply boreholes listed in Table 2 were monitored during the GSI 7-hour pumping test in September 2000. During that time, the water level in Kennedy's well, about 800 m east of Templemore WSS declined by 6 cm. At Greed's well, about 150 m northwest, the water level decreased by 3 cm.

[1] In the report by K.T.Cullen (1986), this well is known as 'Trial well number 4'.
[2] Dug well, *c.* 3m deep

The local private supply boreholes were also monitored during an extended 5-day pump test run by M.C. O'Sullivan (1991). They report that the pumping rate was cut back after the second day because two local farmers complained of lack of water in their own wells. These wells were Russell's, whose well showed a 1 cm drawdown during the GSI pump test in 2000, and Leahy's, reported as being "over 700 m to the east". Leahy's well is now disused because of poor performance and could not be monitored as part of this study.

7.4 Groundwater Flow Directions and Gradients

The water table in the area is assumed to be a subdued reflection of the topography, with groundwater flowing away from the local recharge mound of College Hill. Southwards flowing groundwaters discharge into the River Suir to the east, or into its tributaries. The average topographic gradient north of the boreholes is about 6.5%, and south, between the boreholes and the bog area is 1%. Boreholes drilled by M.C. O'Sullivan (1994) on and around the top of College Hill, to a maximum of 6.6 mbgl, didn't record water strike. From this, it is inferred that the water table is at least 6.5 m below the top of the hill, and probably considerably more. Therefore, the average natural hydraulic gradient is estimated to be in the range 0.026 to 0.049 north of the boreholes, and 0.005 between the boreholes and the bog.

7.5 Hydrochemistry and Water Quality

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 samples have a Calcium-Bicarbonate (Ca - HCO_3) hydrochemical signature.
- The groundwater is 'very hard' (total hardness 378 – 459 mg/l as $CaCO_3$).
- Nitrate concentrations range widely from 1.7-35.2 mg/l, though are generally low, with an average concentration of 9.7 mg/l (29 samples) over the period March 1990 to December 2000. The GSI threshold of 25 mg/l was exceeded twice in the sampling period. From these data, nitrate levels give some cause for concern, since the fluctuations to high values indicate that there is potentially a rapid pathway to groundwater from the source(s) of nitrate.
- Two chloride measurements record concentrations of 13.4 and 24 mg/l. Chloride is a constituent of organic wastes and (away from coastal areas) levels higher than 25 mg/l may indicate contamination, and above 30 mg/l usually indicate significant contamination. The difference between the measurements, however, does raise concern about potential contamination, and indeed, contamination by faecal bacteria is evidenced (see below).
- Bacteriological sampling indicates faecal contamination of the source on two occasions (out of two) in the period September 1993 to August 2000. Both samples were untreated.
- Two potassium:sodium (K:Na) ratios (0.16 and 0.21) can be calculated from the available data. The K:Na ratio helps to indicate (along with other parameters) if water has been contaminated and a ratio of >0.4 may indicate contamination. To provide sufficient data to assess the source, it should be measured routinely in the future.
- Iron and manganese concentrations are below the EU Drinking Water Directive maximum admissible concentrations (MACs) of 0.2 mg/l and 0.05 mg/l respectively.

7.6 Aquifer Parameters

Various sources of data are used to estimate the aquifer parameters of the Ballysteen Formation in the vicinity of College Hill:

- An extended (5 day) constant rate pumping test of Production Well #1 by M.C. O'Sullivan in 1991.

- An extended (7 day) pumping test conducted on a trial well (now the closest observation borehole) by K.T. Cullen & Co. Ltd. in 1989.
- A 7 hour 25 minutes pumping test conducted by the GSI on Production Well # 1 on 14/9/2000.

Different methods were applied to the data depending upon the level of detail available. For example, the 'Logan approximation' (Logan, 1964) was applied to all the pumping tests, as only one overall pumping water level plus the pumping rate is required. The Jacob analysis method (Cooper and Jacob, 1946) is used where the variation of water level with time was recorded. Unless otherwise stated, only data from the pumping well were available. Aquifer parameters such as permeability and porosity estimated from the various pump tests are summarised in Table 4.

As can be seen from the values listed in Table 4, estimated permeabilities vary by up to an order of magnitude, ranging between 2.1 and 23 m/d. There are various reasons for the observed differences:

- Borehole and pumping test factors

  Well construction impacts upon drawdown at any given pumping rate. The tests were conducted in different boreholes with different constructions and well efficiencies. It is probable that, during the 10 years of pumping for public water supply, the production well efficiencies have improved as fractures near the well bore have become cleaned out.

  Drawdown commonly increases disproportionately with respect to pumping rate in the pumping well due to turbulent losses. Pumping rates, on which the Logan approximation is based, were different in all tests.

  The pumping duration determines whether the aquifer has reached a 'steady state' in which the pumped water level (at a constant pumping rate) doesn't change. All pumping test durations are different.

- Aquifer factors

  Permeability is not the same throughout the aquifer. Lower permeabilities in the vicinity of the 'failed well' are indicated by the GSI pump test. Jacob pumping test analysis indicates a permeability of about 2.5 m/d, and the test results indicate that there is a lower permeability barrier to flow in this vicinity.

  Well depth and placement in fractured aquifers control the interception of water-yielding fractures. For example, the 60 m deep well ('Observation well') tested by K.T. Cullen had recorded inflows at just below the subsoil and at about 57 m. This compares with inflows at 69 m and 83 m in Production boreholes #1 and #2, respectively (about 72 and 86 m deep). These wells are separated by a maximum of five metres, showing how variable fracture development is in the aquifer.

  Estimating aquifer permeabilities (K, m/d) from the transmissivity values (T, m^2/d) calculated from analysing the pump test data requires knowledge of the average saturated thickness of the aquifer. (It is usually measured from the bottom of the well over the screened interval or to the water table, whichever is lower.) In an unconfined aquifer like this one, as the well is pumped the saturated thickness decreases.

  If most of the water is flowing into the well from fractures, then dividing the transmissivity by the saturated thickness of the aquifer to calculate permeability will increasingly overestimate the permeability as pumping rate increases.

For the reasons outlined above, a permeability of 10 m/d, estimated from the more recent pumping test in a production borehole, is assigned to the Ballysteen Formation aquifer.

Table 3: Estimated aquifer parameters for the rock units underlying Curraduff and Graiguebeg townlands, and supplying Templemore WSS

Aquifer parameter	**Data source**	**Ballysteen Formation (undifferentiated) parameter values**
Permeability (m/d)	75 hour "constant" rate pump test of 'Observation well' (KT Cullen) **– pumping well** • Logan approximation, 30 mins • --- " ----- " – 200 mins • --- " ----- " – 1440 mins	 • 9.5 (ave sat'd thickness 57.5m) • 6.5 (ave sat'd thickness 54m) • 5.6 (ave sat'd thickness 49.75m)
	7 day constant rate pump test of 'Observation well' (KT Cullen) **– pumping well** • Logan approximation, 7 days	 • 5.0 (ave sat'd thickness 47.1m)
	7 day variable rate pump test of Production well #1 (MCOS) **– pumping well** • Logan approximation, Q = 3456 m^3/d • --- " ----- " – Q = 4536 m^3/d • --- " ----- " – Q = 5184 m^3/d	 • 4.6 (ave sat'd thickness 49.42m) • 4.8 (ave sat'd thickness 35.33m) • 5.5 (ave sat'd thickness 29.9m)
	7 hour constant rate test Production well #1 (GSI) – **pumping well** • Logan approximation • Jacob analysis of pumping data • Jacob analysis of recovery data	*Analysis of production well #1 data* • 10.9 (ave sat'd thickness 20 m) • 11.2 – 23.0 (ave sat'd thickness 12.5-18.5 m) • 2.1 – 11.3 (ave sat'd thickness 26.5 - 32m)
	– **observation well** • Jacob analysis of pumping data • Jacob analysis of recovery data	*Analysis of production well #2 data* • 8.8 – 9.2 (ave sat'd thickness 42 - 46m) • 2.7 – 8.5 (ave sat'd thickness 40.4 – 46.7)
	– **observation well** • Jacob analysis of pumping data • Jacob analysis of recovery data	*Analysis of 'trial well' data* • 2.6 (ave sat'd thickness 71 m) • 3.5 (ave sat'd thickness 71.8m)
Porosity	estimated from regional experience	0.001 – 0.02
Hydraulic gradient	estimated from local topography and water level data	2.6-4.9% north of production boreholes 0.5% between wells and bog to south
Aquifer parameter	**Data source**	**Waulsortian Limestone parameter values**
Permeability (m/d)	estimated from regional experience	2.5
Porosity	estimated from regional experience	0.001 – 0.02
Hydraulic gradient	estimated from local topography and water level data	2.6-4.9% north of production boreholes

7.7 Aquifer Category

Overall in North County Tipperary, the Ballysteen Formation is classified as a 'bedrock aquifer which is moderately productive only in local zones' **(Ll)**. However, it is clear from the well performances at Templemore (and at Rathmoy Bridge) that the yields are excellent in this location. The Lisduff Oolite (BAld) is classified as 'Lm' (locally Important Aquifer, generally moderately productive).

The Waulsortian limestone is classified as a 'Locally important aquifer' (**Ll**). Karstification of the limestone, which is pervasive in more southerly areas of the country, is relatively minor in North Tipperary.

As mentioned in section 6.1.1, the College Hill boreholes are immediately adjacent to a NW-SE trending fault, and are in an intensely faulted area. Resistivity surveys by K.T. Cullen (1986) show a Y-shaped zone of lower resistivity running about 500 m along the Roscrea road in each direction from the WSS site, with a branch going northwest around the west side of College Hill. Resistivity, which is the opposite of electrical conductivity, is low when there is a high percentage of moist clay in the subsoil, where the water table is close to the surface, or where there is a fault zone carrying more water than the surrounding rocks. The low resistivity zone is probably related to the large-scale faults in the vicinity. An established drainage pattern in this area may also have contributed to enhancement of fracture apertures and flow conduits in the limestones.

7.8 Conceptual Model

The Templemore WSS boreholes draw water from the Ballysteen Formation and the Waulsortian limestone, both 'bedrock aquifers which are moderately productive only in local zones' **(Ll)**.

The permeability in these aquifers depends on the development of faults, fissures and fractures, as indicated by pumping tests and site investigations, in addition to regional experience.

That the fracture permeability is highly variable and channelised is suggested by the small response of Kennedy's and Greed's wells during the GSI pumping test, but the drying-up of Leahy's well, to which there may be better connection, during a pumping test conducted in 1991.

The pumping tests also indicate that the major NE-SW fault passing through College Hill does not cause a significant barrier to flow at right angles to it, and that parallel to the fault it is a significant conduit for flow. A lower permeability region to the south of the boreholes is suggested by the GSI pumping test. This could be due to fault-related mineralisation blocking up the fractures, a decrease in fracture density, or to a change in rock type.

The bedrock aquifers are largely overlain by highly to moderately permeable till. There are few drains and surface streams uphill from the site, indicating the free draining nature of the subsoils and the relatively high permeabilities of the bedrock.

A small patch of high permeability subsoil covers the top of College Hill, and low permeability peats cover the area to the south of the boreholes. Therefore, the groundwater can be considered unconfined over much of the area, and partially confined by the peats to the south.

The presence of boggy land in the area just to the south of the site indicates that the water table is very close to ground level in this vicinity. This area is a local internal drainage basin.

The groundwater flow in the area broadly reflects topography, flowing outwards from the top of College Hill, then south and eastwards towards the River Suir. However, the area appears to be one of largely 'internal drainage', i.e. with little surface outflow.

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) to the boreholes.

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 abstraction from long-term recharge. The ZOC is controlled primarily by (a) the pumping rate, (b) the groundwater flow direction(s) and gradient, (c) the rock permeability and (d) the recharge in the area. The ZOC is delineated as follows:

i) Topographic boundaries.

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

iii) To allow for possible future increases in abstraction, and an increase in the ZOC in dry weather, a safety margin is normally incorporated by assuming a higher abstraction rate than the current rate.

Average daily abstraction at the site is 2180 m^3/d over a pumping duration of about 12 hours.

Taking the recharge to be 394 mm as indicated in Section 7.2, the recharge area required to supply a pumping rate of 2180 m^3/d is calculated to be 2.02 km^2 (202 ha). This compares with a maximum area of 2.45 km^2 (245 ha) estimated from topographic considerations. This indicates that the inferred topographic catchment is close to the actual hydrogeological catchment. The fact that the boreholes are unable to sustain 2180 m^3/d in a dry summer, and that the summer pre-pumping water levels are substantially depressed from the natural water table, suggest that the sustainable yield of the boreholes is already being exceeded, and that no increase in average long term abstraction from this site should be allowed.

The inferred ZOC is roughly rectangular in shape and its boundaries, illustrated in Figure 1, are delineated as follows:

Northern Boundary: runs west-southwest from the summit of College Hill, for about 1 km.

Western Boundary: runs roughly north-south along a barely perceptible topographic high.

Southern Boundary: runs roughly east-west close to the southern boundary of Adamstown townland.

Eastern Boundary: more or less bisects the townlands of Butlers Lodge (in the south) and Kiltilliha, before climbing the southern slopes of College Hill.

These boundaries are based essentially on the topography, our current understanding of groundwater conditions in the area and on the available data.

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 (Figure 1).

The 100-day ToT is estimated separately to the north and south of the boreholes, because of evidence of different hydraulic gradients:

North: Taking the Permeability as 10 m/d, Hydraulic Gradient as 0.02, and Effective Porosity as 0.02, the groundwater flow velocity is estimated as 10 m/day (10 x 0.02/0.02), so the 100-day travel time distance is approximately 1000 metres. This takes in the entirety of the ZOC north of the boreholes.

South: Taking the Permeability as 10 m/d, Hydraulic Gradient as 0.01, and Effective Porosity as 0.02, the groundwater flow velocity is estimated as 5 m/day (10 x 0.01/0.02), so the 100-day travel time distance is approximately 500 metres.

Overall, approximately 40% 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 document (DoELG/EPA/GSI, 1999).

Areas of rock outcrop and where rock is less than 3m 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'.

The groundwater vulnerability in the area is considered to be 'Extreme' for much of the area to the north east of the site, and 'High to Low' in other parts. Vulnerability of groundwater in the vicinity of Templemore WSS is shown in Figure 6.

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 4). 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 four groundwater protection zones present around the Templemore WSS source (see Figure 7), as shown in Table 4.

Table 4: Matrix of Source Protection Zones

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

11. Land Use and Potential Pollution Sources

Agriculture, predominantly cattle farming, 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 road that passes by the site. No detailed assessment of hazards was carried out as part of this study.

12. Conclusions and Recommendations

- The boreholes at Templemore extract water from a limestone 'bedrock aquifer which is moderately productive only in local zones' **(Ll)**.
- There is substantial evidence that the boreholes are currently exceeding their sustainable yield in late summer/autumn, and have been doing so in recent years.
- The area around the supply has 'extreme' to 'high-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.

- Chemical and bacteriological analyses of raw water (rather than treated water) should be carried out on a regular basis (every 3 - 6 months).
- Guidelines should be drawn up for dealing with spillages along the Roscrea road beside the site.
- Guidelines should be drawn up for coping with low pumping water levels in the boreholes. A more detailed source report using additional borehole flow data (not available for this report) and long-term recharge data could help to constrain better the sustainable yield from the aquifer for given rainfall patterns.

13. References

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

Fig 2 – site map,

Fig 3 – driller logs

Fig 4 – water levels at site

Fig 5 – chemistry

Fig 6 – ZOC, TOT

Fig 7 - vulnerability map

Fig 8 – source protection Zone

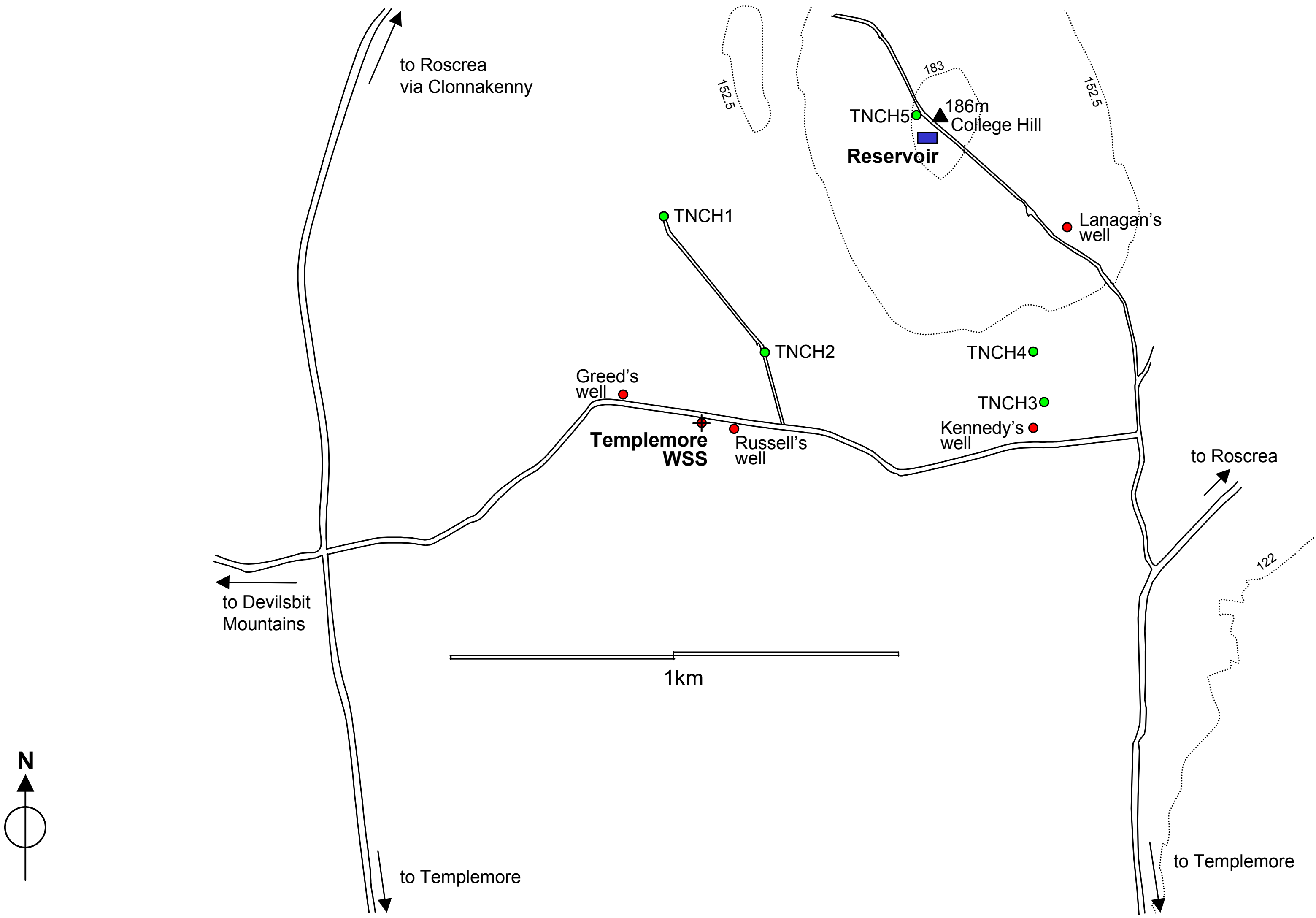
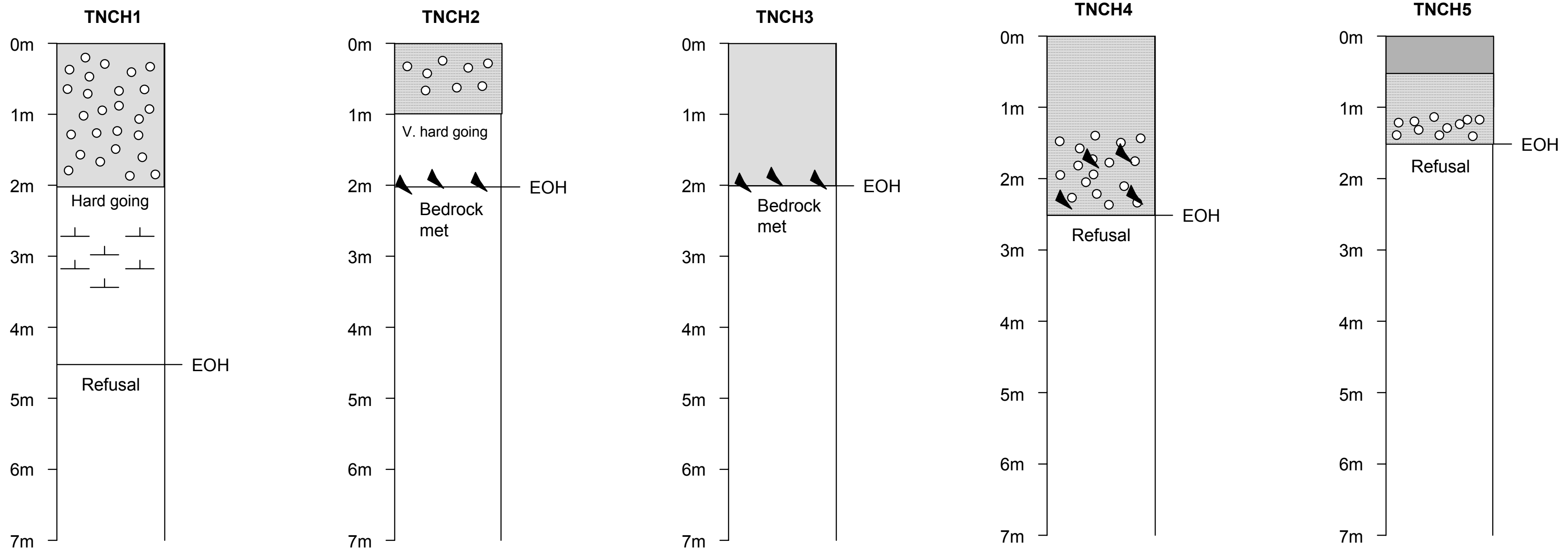


Figure 2: Location map of Templemore WSS production boreholes.
Showing auger holes drilled by GSI to determine depth to bedrock in the vicinity (TNCH1 to TNCH5) and private boreholes discussed in the text.



TNCH1 -

1.0m	Soft CLAY with gravel
2.0m	Soft CLAY with gravel
2.5m	Hard Going
3.0m	Silt Slurry No Proper Recovery
4.0m	No Recovery
4.5m	Refusal on Weathered Shale ?

TNCH2 -

1.0m	Sandy CLAY
1.1m	v. Hard going
2.0m	Fresh Stone Returns (lsts/Shale)

TNCH3 -

1.0m	CLAY
2.0m	Limestone

TNCH4 -

1.0m	Sandy CLAY
1.5m	Stoney CLAY
2.0m	Stoney CLAY
2.5m	Refusal on Lst

TNCH5 -

0.2m	V.Stiff CLAY
1.0m	Sandy CLAY
1.5m	Sandy CLAY gravel REFUSAL

Figure 3: Summary logs and lithological descriptions of auger holes bored to assess depth to bedrock in the vicinity of Templemore WSS boreholes. See Figure 2 for the locations of the auger holes.

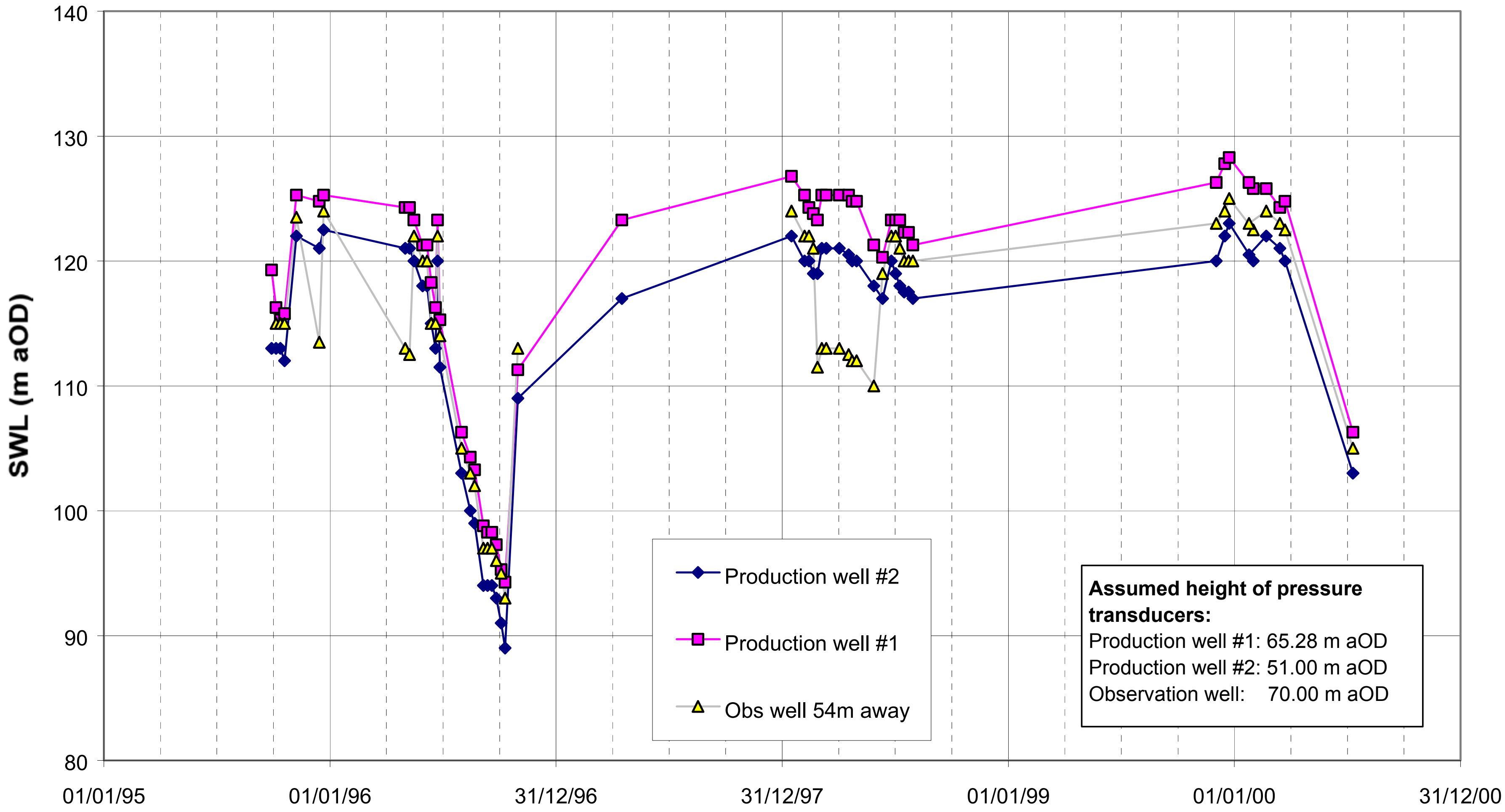


Figure 4: Approximate water levels in the production wells and an observation borehole at Templemore WSS from September 1995 to July 2000. The water levels are measured by down-hole pressure transducers; the heights of the pressure transducers in the pumping wells are from MCOS (1994) plans, and the position of the pressure transducer in the observation well is inferred. Water level data were taken from the continuous-measurement discs.

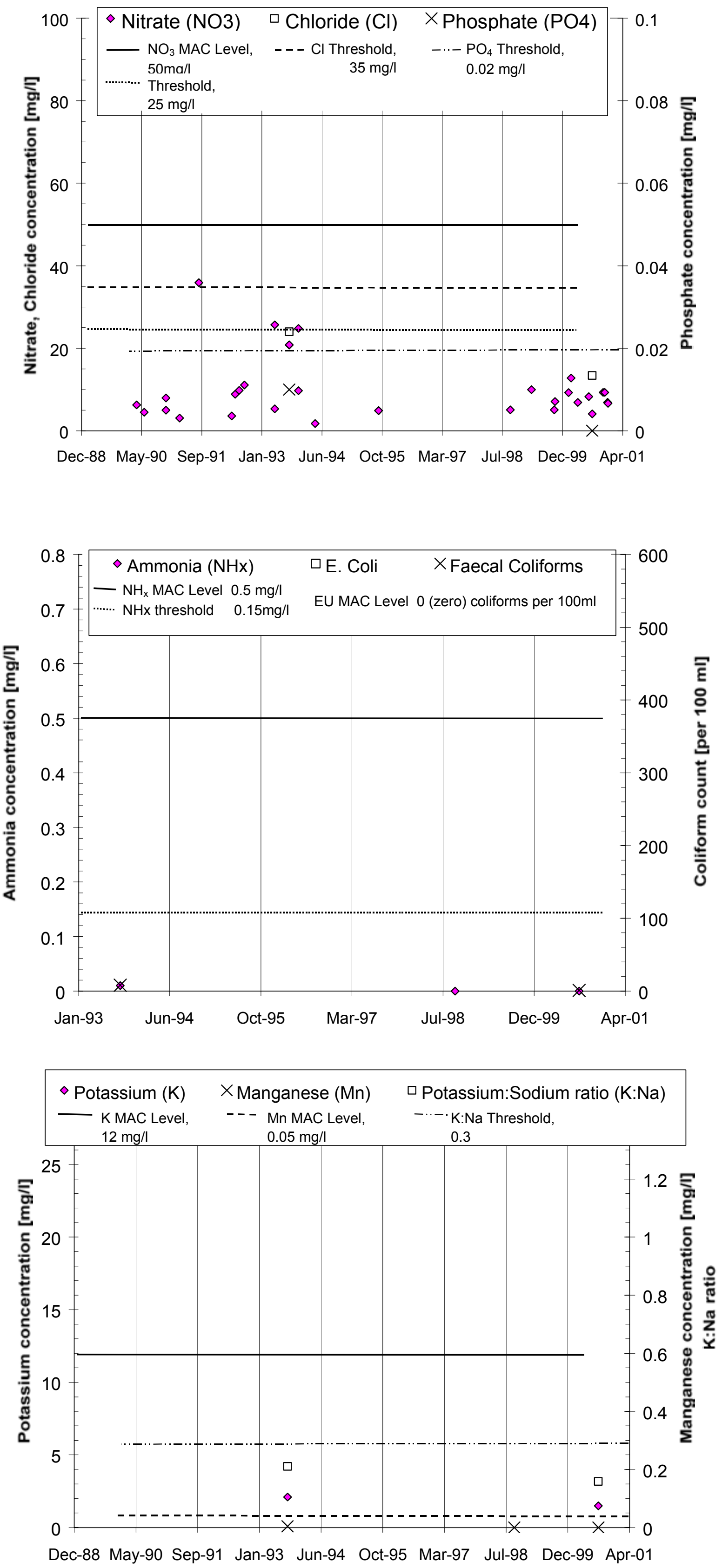


Figure 5: Key indicators of agricultural and domestic groundwater contamination at Templemore WSS

Appendix 1: Laboratory Analyses of Groundwater at Templemore WSS

Parameter	**Results of Laboratory Analyses**																											
Laboratory	DWR									Reg. WL	DWR			North Tipperary Co. Co.						DWR				State Lab	DWR			
Sample treatment										NS				NS	NS ?	-								S				
Date	27/03/90	28/05/90	26/11/90	19/03/91	26/05/92	23/06/92	27/07/92	08/09/92	18/05/93	16/09/93	01/12/93	19/04/94	28/09/95	23/03/98	18/08/98	28/09/98	23/03/99	28/09/99	05/10/99	25/01/00	15/02/00	11/04/00	11/07/00	09/08/00	07/11/00	21/11/00	14/12/00	18/12/00
EC (μS/cm)										797						873								691				
pH (lab.)										7.3						7.4												
Total Hardness (mg/l $CaCO_3$)										459														378				
Total Alkalinity (mg/l $CaCO_3$)										375														350				
Calcium (mg/l)										162														126				
Magnesium (mg/l)										13														14.9				
Chloride (mg/l)										24														13.4				
Sulphate (mg/l)										18														55.2				
Sodium (mg/l)										10														9.4				
Potassium (mg/l)										2.1														1.5				
K:Na										0.21														0.16				
Nitrate (mg/l NO_3)	6.3	4.5	8.0	3.1	3.6	8.9	9.8	11.1	25.7	20.8	24.8	1.8	4.9			5.1	10.0	5.1	7.1	9.2	12.8	6.9	8.3	4.1	9.3	9.3	6.9	6.7
Iron (mg/l)										0.016						<MDL								0.008				
Manganese (mg/l)										0.004						<MDL								<MDL				
E/F coli per 100 ml.										**8**														**1**				
Total Coli /100ml										12				1	0	0								3				
Total Ammonia (mg/l NHx)										0.01						<MDL								<MDL				
Comments	Polluted with coliforms of faecal origin. Otherwise, water quality good. Regular monitoring should be undertaken, together with attempts to trace the source of the faecal contamination and good quality control on supply chlorination.																											

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