Toomyvara Water Supply Scheme

Groundwater Source Protection Zones

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January 2002

1. Introduction

The objectives of this report are:

- To delineate source protection zones for the Toomyvara Water Supply Scheme spring 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 situated in the townland of Castlequarter approximately 700 m southwest of the centre of Toomyvara, between the roads to Newport/Limerick and to Nenagh.

The source comprises a line of four springs in a very boggy low-lying area. The springs are all piped into one sump and they overflow individually into a culvert that flows to a v-notch weir. A ditch drains the site next to the pump house, and a stream rises just to the east of the springs and runs downhill from them. The whole site appears well fenced off although, on a visit in November 2001, a cow had obviously been in the enclosure.

The water is chlorinated.

3. Summary of Spring Details

GSI no.	1717SEW164
Grid ref. (1:25,000)	19689 17736
Townland	Castlequarter
Owner	North Tipperary County Council
Well type	Springs (four) fed into chamber
Elevation (top of housing)	*c.* 108 m OD
Depth-to-rock	~4.5 m
Static water level	~108 m OD (at surface)
Hours pumped per day	8 – 9
Pumping rate	435 - 386 m^3/d (3988 - 3544 gal/hr)
Daily Abstraction	145 m^3/d (31,900 gal/d)
Flow to springs	Average summer and winter flows 300 m^3/d and 1650 m^3/d, respectively (measured using V-notch weir (pumps off) July and December 2000). Average flow July 2000 – July 2001 was about 750 m^3/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 Finch & Gardiner (1993). Basic source details were obtained from GSI records and County Council personnel; such details include elevation, abstraction rate, pumping duration details and weir overflow records.

Site visits and fieldwork

The second stage of the 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 in the area. Water samples taken were analysed by the State Laboratory. Five auger holes were bored to ascertain the depth to bedrock in the area. At the request of GSI, the V-notch weir was monitored daily by Tony Moroney, Toomyvara Caretaker.

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

The source lies within the catchment of the westward-flowing Ballintotty River, which lies immediately to the north of the site. Overflow from the springs and an adjacent drainage ditch feed into the river. The four springs emerge in a northeast – southwest line at the same elevation within the river valley.

Uphill, to the south of the springs and pump house, is an area of very boggy ground; marsh grass also grows to the east of the springs, indicating that the water table is very close to the surface in the vicinity of the springs. The ground is better-drained in the crop field to the west of the spring.

The ground rises steeply from an elevation of approximately 108 m OD at the source, to 156 m OD about 700 m away to the southeast. Around 1.5 km further south is the first of the peaks of the Knockanora Hills formed by the Silurian-age Hollyford Formation (see Table 1).

The subsoils in the vicinity of the source and the surrounding area are limestone glacial tills, some with sandstone and shale fragments, and alluvium.

6. Geology

6.1 Bedrock Geology

The bedrock geology of the area comprises sediments of late Silurian and Upper Devonian ages (*c.* 400 and 350 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 the Toomyvara WSS spring

Rock Formation	Rock Material	Thickness	Occurrence
Cadamstown Formation (CW)	Sandstone: medium-coarse grained, pale, often creamy coloured sandstone with siltstones and mudstones.	c. 70-110m	Underlies the source; unconformably overlies the Hollyford Formation.
Hollyford Formation (HF)	Sandstone and mudstone: layered mudstones and siltstones interbedded with numerous thin, fine sandstones. Thicker-bedded and usually coarser sandstone beds occur randomly.	>1000 m	Forms the hills to the southeast and south of the source.

6.1.1 Geological Structure

The spring issues from the Cadamstown Formation on the east limb of a NE-SW trending fold. Approximately 260 m to the south of the source, more or less in line with the Limerick road, is a major NE-SW trending fault that juxtaposes the upthrown Hollyford Formation to the south of the fault against the Cadamstown Formation in the north. Bedding dips recorded locally in the Hollyford Formation are gentle (5-15^{o}) and to the northwest.

6.2 Subsoils (Quaternary) Geology

The subsoils in the area are comprised of both glacial and alluvial (river) deposits. The spring itself occurs very close to the boundary between the till and alluvium. The till composition is influenced to varying degrees by both the dominant lithology in Tipperary (limestone) and the underlying sandstone bedrock. The characteristics of each category are described briefly below.

6.2.1 Alluvium

The river deposits occupy the lowest-lying boggy areas to the north and east of the spring, and along the line of the Ballintotty River for a mile to the west. Silt and clay dominate the upper parts of the saturated (gley) topsoils, which are poorly drained. However, the alluvium grades down into coarser sands and limestone gravels with <25% silt and clay.

6.2.2 Limestone Tills

Most of the area around the Toomyvara source are underlain by tills. Teagasc (1993) assign the soils overlying these tills to the 'Elton' and 'Patrickswell' soil series. The tills are described as limestone-dominated but, in the case of the Elton Series, with significant amounts of sandstone and shale material. As far as determined by Teagasc (down to about 1 m below surface) the subsoils comprise around 50% fines and 15-17% clay. In spite of the apparently high fines and clay contents, the overlying topsoils are generally well drained and consequently the tills are classed as moderately permeable.

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 five auger holes are shown on Figure 2, and the logs are summarised in Figure 3. Depths to bedrock ranged from 3.2 to 5.5 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 spring were obtained from Council personnel, and collected by the GSI as part of this study.

  Toomyvara WSS Caretaker, Tony Moroney, recorded daily spring overflow measurements during 2000 and 2001 (Figure 4).

- Hydrochemistry/water quality

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

The hydrochemical data are summarised fully in the separate report "An assessment of the quality of public, group scheme and private groundwater supplies in North County 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 1077 mm/yr. Potential Evaporation (PE) is estimated from Met Éireann's national contoured map as 505 mm/yr. Actual evapotranspiration (AE), estimated by taking 90% of the potential figure to allow for soil moisture deficits, is 455 mm/yr. Using these figures, the potential recharge (R–AE) is 622 mm. Runoff is assumed to be 50% of available recharge, i.e. 311 mm. This assumption, from Wright *et al.* (1983), is an empirical standard used in GSI for moderately permeable subsoils of the sandy till type which dominate the area uphill of the site. These calculations are summarised below:

Average rainfall (R)	1077 mm/yr
Estimated P.E.	505 mm/yr
Estimated A.E. (90% P.E.)	455 mm/yr
Potential recharge (R–AE)	622 mm/yr
Surface Runoff	311 mm/yr
Recharge	311 mm/yr

7.3 Groundwater levels

The water level at the site is approximately 108 m OD. The water table is at or very close to ground level in the vicinity of the Ballintotty river and the surrounding boggy areas. A slightly marshy area at an elevation of about 150 m OD may reflect the proximity of the water table to the ground surface uphill (south-southeast) of the site. Water level data from wells were not obtained, since there were no accessible wells in the catchment area.

7.4 Groundwater Flow Directions and Gradients

The water table in the area is assumed to broadly reflect topography with groundwater flowing toward and discharging to the springs and to the Ballintotty River. The natural hydraulic gradient is estimated to be, on average, about 2% or 0.02.

7.5 Hydrochemistry and Water Quality

Field measurements recorded an electrical conductivity of 287 μS/cm and a temperature of 10.4°C in December 1999. 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.
- Electrical conductivity ranges between low and normal (relative to average values for the Irish Midlands), indicating that total dissolved solids (TDS) in the water range between low and average.
- The groundwater is 'hard' (total hardness 255 mg/l as $CaCO_3$).
- Nitrate concentrations range widely from 8.4 to 28.8 mg/l, with an average of 22.6 mg/l (14 samples) over the period March 1991 to October 2000. The GSI threshold of 25 mg/l was exceeded five times in the sampling period. The results are representative of general nitrate contamination by both diffuse (spreading of inorganic fertiliser and slurry) and point sources (septic tank systems and farmyards) in this area of relatively intensive farming. There is no trend apparent in the data.
- A single chloride measurement records a concentration of 17.6 mg/l. Chloride is a constituent of organic wastes and (away from coastal areas) levels higher than 25 mg/l may indicate contamination, while concentrations higher than 30 mg/l usually indicate significant contamination. As far as is measured, the chloride level does not give cause for alarm. However, contamination by faecal bacteria is evidenced (see below).
- Bacteriological sampling indicates faecal contamination of the source on seven occasions (out of 13) in the period October 1990 to August 2000. Six of the contaminated samples were treated, with the remaining one indeterminate, indicating that the chlorination process at the source has sometimes been inadequate. There is a marked improvement in the bacteriological quality of the source since late 1994, with only one sample (in November 1996) testing positive since then.
- One potassium:sodium (K:Na) ratio of 0.22 can be calculated from the available data, from August 2000. The K:Na ratio of >0.4 may indicate contamination (along with other parameters). To provide sufficient data to assess the source, it should be measured routinely in the future.
- Iron concentrations exceeded the EU Drinking Water Directive maximum admissible concentration (MAC) of 0.2 mg/l once in eight samples (in June 1995). On the remaining times the source was tested for iron levels, concentrations were below the method detection limit (MDL) of 0.05 mg/l.

Iron is not detrimental to health but can encourage clogging of screens and pipes by bacteria and is aesthetically undesirable.

7.6 Aquifer Parameters

The source at Toomyvara is a spring. Therefore, in the absence of any relevant measurements on site (e.g. from pumping test data), the aquifer parameters are estimated from analogous situations elsewhere. For the Cadamstown Formation, aquifer parameters were tuned to the specific location by using analytical flow equations (Thiem, 1906 in Driscoll, 1986, see Appendix 2) calibrated with water level and flow data. The values are given in Table 2.

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

Parameter	**Data source**	**Cadamstown (CW) parameter values**
Permeability *	• estimated from parameter fitting to analytical equation, coupled with regional experience	4.3 m/d
Porosity		0.03
Hydraulic gradient	• estimated from topography, surface hydraulic features and spring overflow	17/100 (17%) (near spring) 2/100 (2%) (near fault)
Parameter	**Data source**	**Hollyford Formation (HF) parameter values**
Permeability	• estimated from regional experience	0.5 m/d
Porosity		0.02
Hydraulic gradient	• estimated from topography and surface hydraulic features	4/100 (4%)

* at spring, assumed flowing interval is 14 m

7.7 Aquifer Category

The Cadamstown Formation (CW), in which the spring occurs, is classified as a Regionally Important fractured bedrock aquifer (**Rf**). The Hollyford Formation (HF), which supplies part of the water to the spring, is characterised in North Tipperary as '**Pl**' (Bedrock that is generally unproductive except for local zones).

7.8 Conceptual Model

- The Toomyvara springs are located in a local topographic low – near to the centre of the Ballintotty River valley – on the boundary between the glacial till subsoils that cover the hills to the south (topographic relief up to 50 m) and the river deposits.
- Spring flow varies seasonally, between around 400 and 1650 m^3/d in summer and winter respectively.
- The permeability of the Cadamstown and Hollyford Formation aquifers depends on the development of faults, fissures and fractures.
- These sandstone and layered sandstone-mudstone rock units are largely overlain by moderately permeable limestone till with gravel. The groundwater can, therefore, be considered as unconfined or semi-confined.
- The water table is assumed to reflect the topography of the area, with hills acting as recharge mounds and groundwater flowing from these high points to the discharge points (springs and river).

- The average groundwater gradient is approximately 4% south of the fault that runs parallel to the Toomyvara-Limerick road, in the Hollyford Formation (**Pl**). This is in contrast to the higher permeability of the Cadamstown Formation north of the fault in which the spring occurs. Away from the spring, the estimated hydraulic gradient in the Cadamstown Formation is about 2%.

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 springs.

8.2 Outer Protection Area

The Outer Protection Area (SO) is bounded by the zone of contribution (ZOC), which is delineated as the area required to support average spring flow from long-term recharge. The ZOC is controlled primarily by (a) the spring flow (b) 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 spring flow rate.

The average springflow in the period July 2000 – July 2001 was 760 m^3/d (measured with pump off). Taking the recharge to be 311 mm (Section 7.2), the recharge area contributing to the total spring flow is 0.89 km^2 (89 ha). This compares with an area of 0.87 km^2 (87 ha) estimated from the topography. It is therefore inferred that the topographic catchment is close to the actual ZOC.

The inferred ZOC is approximately 2.2 km long and generally 300-700 metres wide, and is elongated in a southerly direction from the spring. The boundaries of the ZOC are illustrated in Figure 6 and are delineated as follows:

Northern Boundary: defined by the spring point location and altitude.

Eastern Boundary: following topography, it runs south-southeast for about 650 m to a local hill top at 156 m OD, then 1.7 km due south to the first of the peaks of the Knockanora Hills.

Western Boundary: north of the Dolla/Newport road, defined by local topographic focussing. North of Garrane Farm, it is roughly parallel to the eastern boundary, likewise crossing topographic contours at right angles.

Southern Boundary: where the ZOC 'originates', at the first of the peaks of the Knockanora Hills.

These boundaries are based largely on 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. It is delineated to protect from potentially contaminating activities that may have an immediate influence on water quality at the source, in particular from microbial contamination. The 100-day ToT shown in Figure 6 was estimated separately either side of the fault and then combined:

a) The 100-day travel time distance in the Cadamstown Formation (CW) is estimated as 365 m, by using the Thiem equation (Thiem, 1906 in Driscoll, 1986) for unconfined steady state flow. The parameters used to compute the 100 day ToT are included in Appendix 2.

b) Because the up-gradient extent of the Cadamstown Formation is only 260 m, the SI extends into the lower-permeability Hollyford Formation (HF). The time to travel 260 m from the centre of the fault to the spring is about 50 days. The time to travel 370 m (from the fault at the edge of the ZOC, to the spring) is about 100 days. Therefore, the remaining maximum 50 days travel in the Hollyford Formation are calculated as follows:

   Taking the permeability as 0.5 m/d, Effective Porosity as 0.02, and Hydraulic Gradient as 0.04, the groundwater flow velocity is estimated as 1 m/day (0.5 x 0.04/0.02), so the 50-day travel time distance is approximately 50 metres. This figure is a maximum distance.

The total distance travelled over 100 days is 260 m + 50 m = 310 m (directly upgradient, within both CW and HF). At the edge of the ZOC, the total distance travelled over 100 days is about 365 m (all within CW).

The Inner Protection Area covers about 0.135 km^2 (13.5 ha), approximately 16 % of the ZOC.

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 3 m from the surface are rated 'Extreme' vulnerability. Where subsoils are more than 3 m thick, aquifer vulnerability ranges between 'Low' and 'High', depending upon the subsoil permeability.

The groundwater vulnerability in the area is considered to be 'Low-High' for much of the area, and Extreme in limited parts. Groundwater vulnerability in the area around and uphill of Toomyvara WSS is shown in Figure 6.

10. Groundwater Protection Zones

The groundwater source 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. As this is an Interim Groundwater Protection Scheme, in which only the extremely vulnerable areas are delineated, there are 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. All four source protection zones (Table 3) are present around the Toomyvara source, as in Figure 6.

Table 3: 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 (crop growing) is the principal activity in the area. Hazards include farmyards, septic tank systems, application of fertilisers (organic and inorganic) and pesticides, and possible spillages into the Ballintotty River or along the major roads that pass either side of the source. No detailed assessment of hazards was carried out as part of this study.

12. Conclusions and Recommendations

- The spring emerges from a "regionally important fractured sandstone bedrock aquifer" (**Rf**). Part of the spring flow is derived from a "bedrock aquifer that is generally unproductive except for local zones" (**Pl**).
- The area around the supply has both 'High-Low' and 'Extreme' 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 daily V-notch weir monitoring undertaken by the Caretaker is extremely useful in constraining spring throughput, and should be continued.
- 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 roads and in the streams in the area, especially along the Limerick/Newport road, and at Phillabeen Bridge, which carries the road to Nenagh across the Ballintotty River.

13. References

Archer, J.B, Sleeman, A.G., & Smith, D.C. (1996) *A Geological Description of Tipperary and Adjoining Parts of Laois, Kilkenny, Offaly, Clare, and Limerick, to Accompany the Bedrock Geology 1:100000 scale Map Series, Sheet 18, Tipperary.* Geological Survey of Ireland.

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Wright, G.R. *et al.* (1983) *Groundwater Resources of the Republic of Ireland* .

Figure 1: Bedrock geology in the Toomyvara area (based on *Archer et al.,* 1996).

Fig 2 – site map

Fig 3 – driller logs

Fig 4 – spring flow

Fig 5 – chemistry

Fig 6 - ZOC and TOT map

Fig 7 - vulnerability map

Fig 8 — source PZs

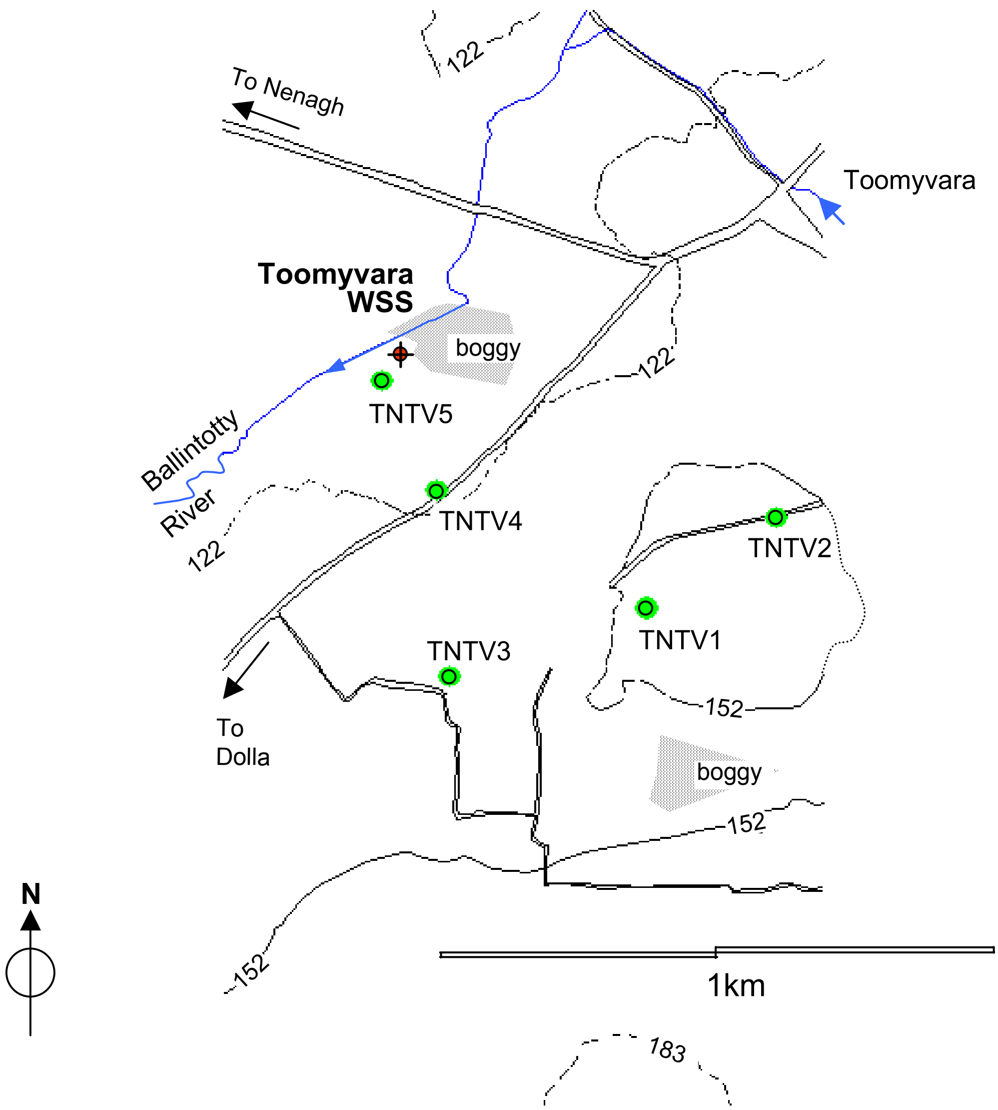
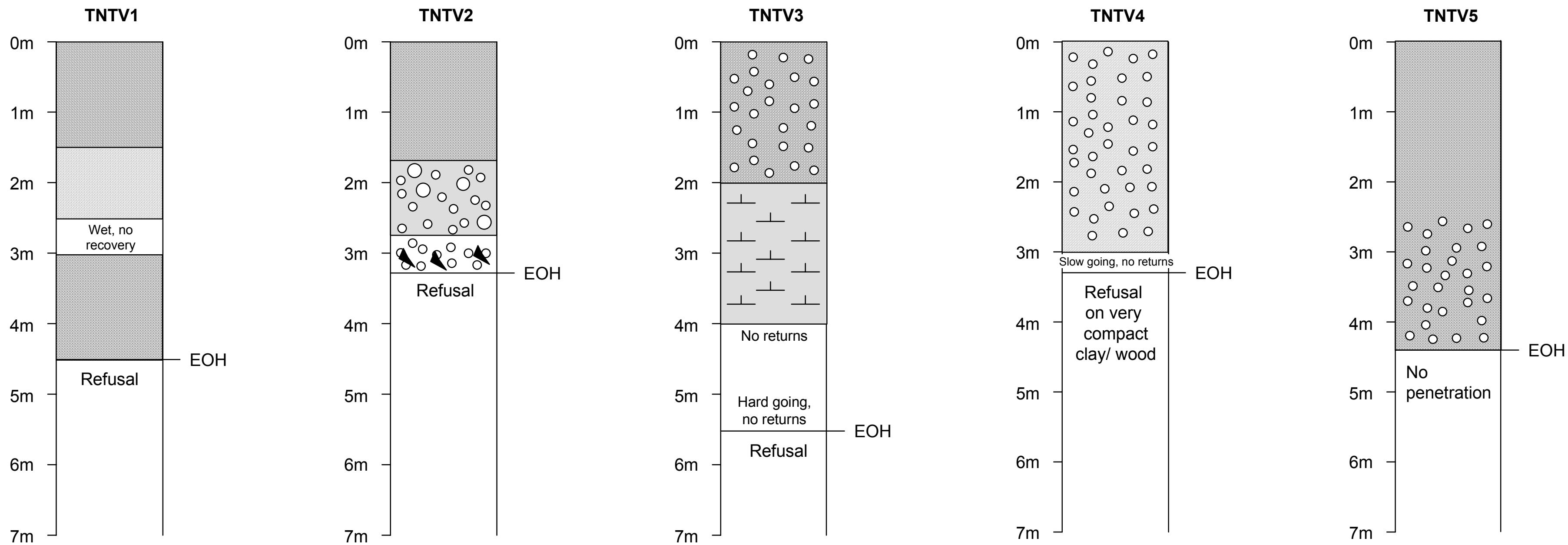


Figure 2: Location map of Toomyvara WSS spring.
(Showing auger holes drilled by GSI to determine depth to bedrock in the vicinity (TNTV1 to TNTV5) and other hydrogeological features discussed in the text).



TNTV1

1.0m	Wet Sandy CLAY
1.5m	Fine SAND
2.5m	Wet NO RECOVERY
	Sandy CLAY
4.0m	Hard going
4.5m	Refusal

TNTV2

1.0m	Sandy CLAY till
1.8m	CLAY with pebbles
2.8m	GRAVEL
3.1m	Gravel and angular frags
3.25m	REFUSAL

TNTV3

1.0m	Sandy Clay GRAVEL
2.0m	SILT/CLAY
3.0m	SILT/CLAY
4.0m	No Returns
5.0m	Hard going NO RETURNS
5.5m	Refusal

TNTV4

1.0m	Sandy GRAVEL
2.0m	Sandy GRAVEL
3.0m	Slow Going NO RETURNS
3.2m	REFUSAL on very Compact CLAY/ Decomposed Branch

TNTV5

1.0m	Damp Sandy CLAY
1.8m	Easy going Wet material
2.0m	Clayey SAND/Sandy CLAY
2.5m	Stoney Sandy CLAY
3.0m	Stoney Sandy CLAY
4.0m	Stoney Sandy CLAY
4.3	EOH. Easy torque but no penetration

Figure 3: Summary logs and lithological descriptions of auger holes drilled to assess depth to bedrock near the Toomyvara spring. (See Figure 2 for locations of the auger holes).

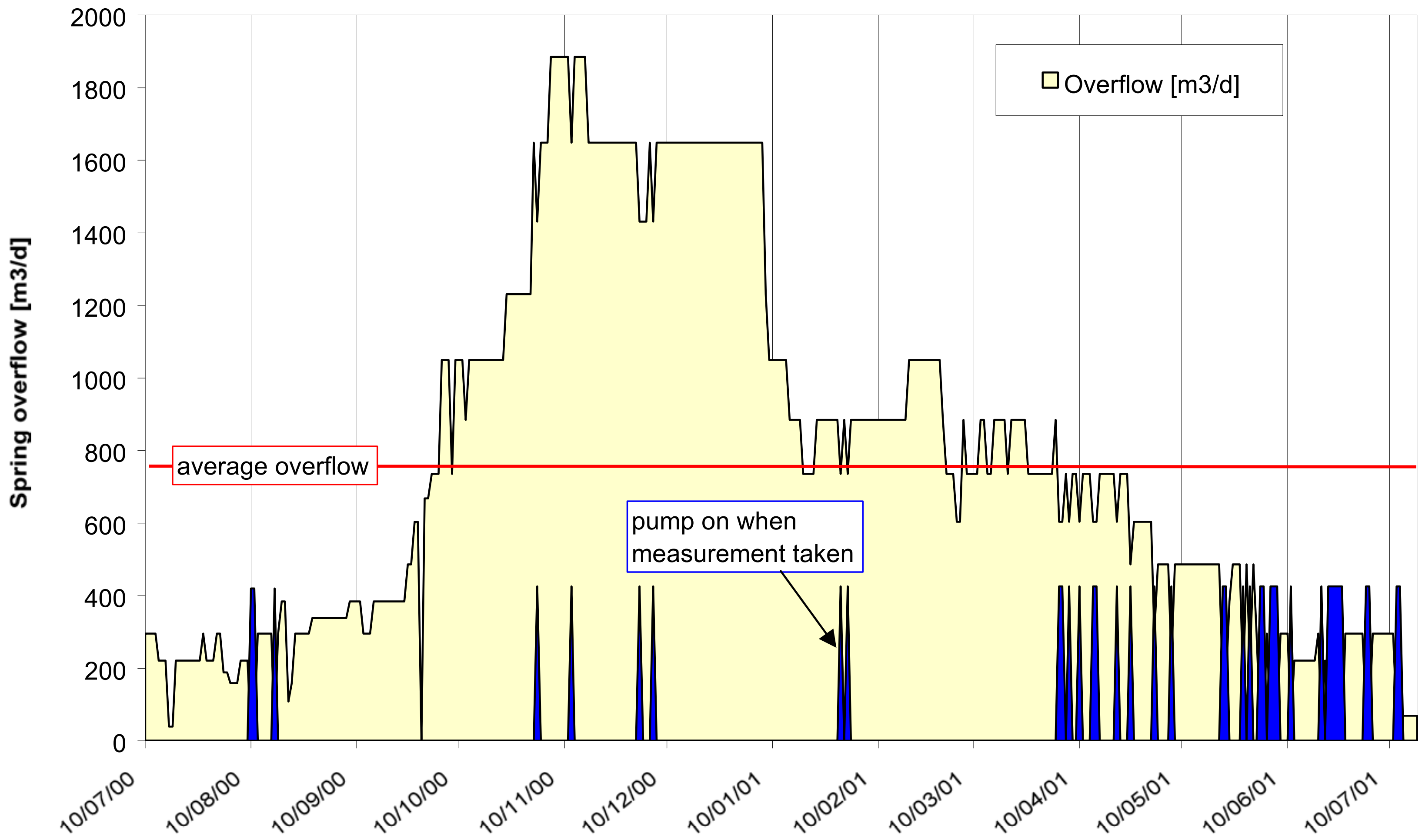


Figure 4: Spring overflow, July 2000 to July 2001 (90° V-notch weir).
Flow measurements taken when the pump was on are indicated by blue 'spikes'. The seasonal overflow varies between 40 m^3/d and 1885 m^3/d (with pumps off). "Representative" (for the measurement period) summer and winter overflows are about 300 m^3/d and 1650 m^3/d, respectively.

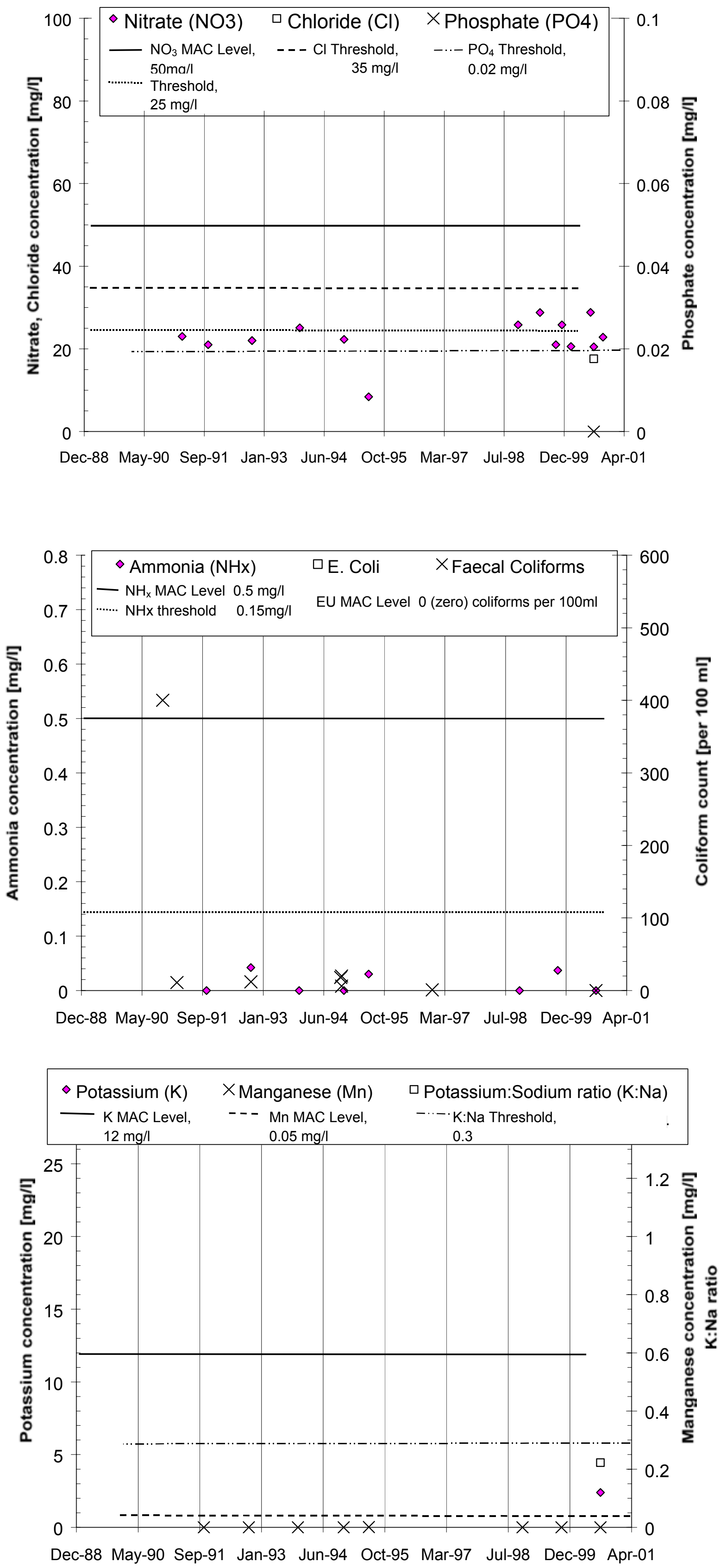


Figure 5: Key indicators of agricultural and domestic groundwater contamination at Toomyvara WSS

Appendix 1: Laboratory Analyses of Groundwater at Toomyvara WSS

Parameter	Results of Laboratory Analyses																															
Laboratory	North Tipperary Co.Co.							Reg WL	North Tipperary Co.Co																				DWR		State Lab	DWR
Sample treatment	NS	NS?	NS?	NS?	NS	NS	NS?		NS?	NS?	NS	NS?	-	NS	-	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	NS	NS	NS			S	
Date	06/03/90	31/07/90	17/10/90	24/10/90	06/11/90	19/02/91	08/03/91	19/03/91	22/10/91	21/11/91	09/06/92	06/10/92	21/10/92	22/10/92	23/11/93	24/11/93	02/11/94	02/11/94	09/11/94	09/11/94	16/11/94	16/11/94	28/11/94	20/06/95	26/11/96	19/05/98	17/11/98	28/09/99	01/02/00	13/07/00	09/08/00	24/10/00
EC (µS/cm)									542				566		611								596	391			598	589			513	
pH (lab.)									7.8				7.7		7.5								7.4	8.6			7.1	7.3				
Total Hardness (mg/l $CaCO_3$)																															255	
Total Alkalinity (mg/l $CaCO_3$)																															242	
Calcium (mg/l)																															92.6	
Magnesium (mg/l)																															5.7	
Chloride (mg/l)																															17.6	
Sulphate (mg/l)																															11.1	
Sodium (mg/l)																															10.8	
Potassium (mg/l)																															2.4	
K:Na																															0.2	
Nitrate (mg/l NO_3)								23	21				22		*25.1*								22.3	8.4			25.8	21	20.6	*28.4*	20.5	22.9
Iron (mg/l)									<MDL				<MDL		<MDL								<MDL	**0.27**			<MDL	<MDL			<MDL	
Manganese (mg/l)									<MDL				<MDL		<MDL								<MDL	0.02			<MDL	<MDL			<MDL	
E/F coli per 100 ml.				**400**		**11**				0				**12**			**18**		**20**	**6**			0		**1**	0	0	0			0	
Total coli /100ml	0	0	1600		0		0		0	2	0	0				0		0		6	0	18	0			0	0	0			0	
Total Ammonia (mg/l NHx)									<MDL				0.042		<MDL								<MDL	0.03			<MDL	0.037			<MDL	
Comments	Probably substantially contaminated																									Parameters less than MACs but should have on-going monitoring						

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

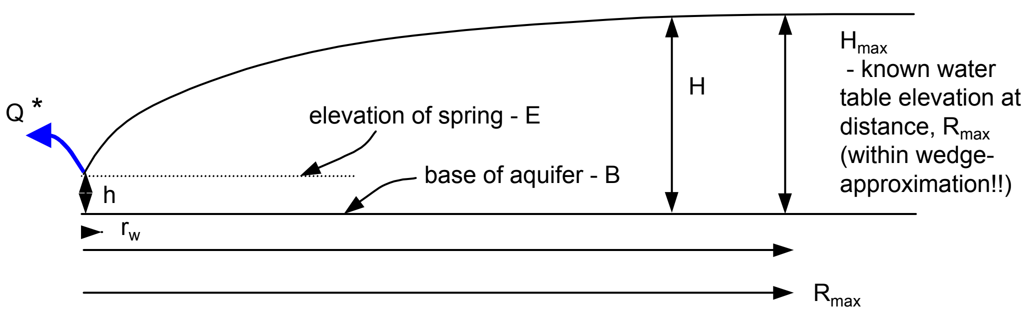
Appendix 2: Calculation of 100 day Time-of-Travel (TOT) to a spring by using the Thiem equation and approximating the zone of contribution (ZOC) to the spring by a wedge

The Thiem equation for unconfined flow is:

$$Q = \frac{1.366\, K\, (H^2 - h^2)}{\log_{10} (R/r_w)} \qquad \text{solving for H:} \qquad H = \sqrt{\frac{Q \, . \, \log_{10} (R/r_w)}{1.366 \, . \, K} - h^2}$$

This equation is for radial flow to a well (i.e. flow from all sides around a cylinder), so the flow Q has to be multiplied by a factor to account for the wedge-like shape of a ZOC to a spring. This gives Q*.

In cross section, the water table has the following shape and the system is defined by these parameters:



Model parameters and predicted water table elevation at Toomyvara WSS

$Q^* = 2443\ m^3/d$ (760 m3/d x 112°/360°)

K = 4.3 m/d, effective porosity = 0.03

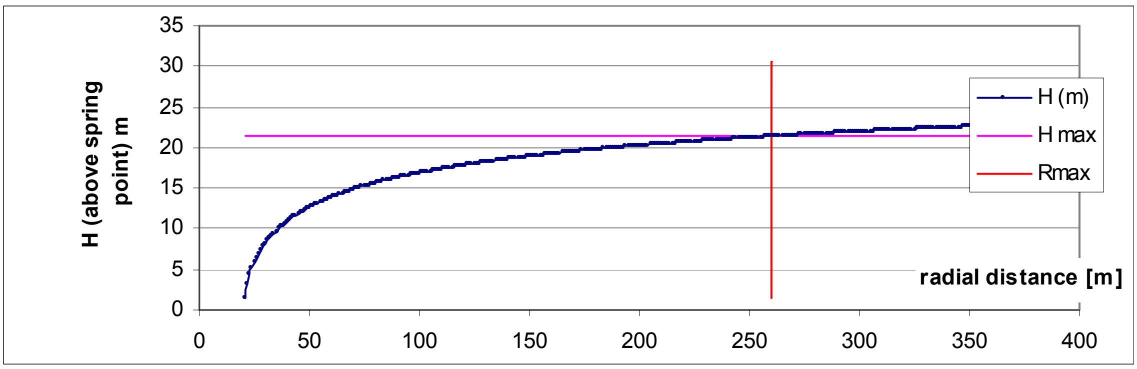
$r_w = 7$ m

$R_{max} = 260$ m; $H_{max} = 115.5$ m (~1 m below rock surface elevation at E-W fault south of spring)

E = 108 m (the elevation of the spring);

B = 94 m (the base of the effectively flowing aquifer at the spring)

s



The 100 day ToT is estimated by computing travel times at incremental distances away from the spring by using the local groundwater gradient (i*) in the equation:

Pore or fracture velocity (m/d) = K.i*/ effective porosity

100 day ToT = Pore or fracture velocity (m/d) x 100 days