Borrisoleigh Water Supply Scheme

Groundwater Source Protection Zones

Prepared by:

Natalya Hunter Williams, Kevin Motherway & Geoff Wright
Geological Survey of Ireland

In collaboration with:

North Tipperary County Council

January 2002

1. Introduction

The objectives of this report are:

- To delineate source protection zones for the Borrisoleigh Water Supply Scheme borehole 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 approximately 2.5 km southeast of Borrisoleigh and 370 m southeast of Rathmoy Bridge, in the townland of Fishmoyne. There are two production boreholes, five metres apart, which used to be pumped on alternate days but are now pumped simultaneously, one well supplying Borrisoleigh and the area to the northwest, and the other well supplying areas to the southeast. The boreholes are immediately beside the road and are very vulnerable to pollution from roadside runoff or spillages, although no serious incident has yet been recorded. However, there is a record of a car crashing through the wall around the site.

The water is chlorinated.

3. Summary of Well Details

GSI no.	2015NWW188 – Production well #2	2015NWW187 – Production well #1
Grid ref. (1:25,000)	20510 16542	20509 16543
Townland	Fishmoyne	Fishmoyne
Owner	North Tipperary County Council	North Tipperary County Council
Well type	Borehole	Borehole
Elevation (top of casing)	91.95 m O.D.	91.43 m O.D.
Depth and screening	42 m deep, screened 19-42 mbgl	40.5 m
Diameter	drilled at 450 mm (18”), cased at 300 mm (12”)	450 mm (18”)
Depth-to-rock	12 m	12 m
Static water level	89.47 m OD (November 2001; 3.03 m.b. box level)	89.28 m OD (November 1999); 89.43 m OD (November 2001; 2.98 m.b. box level).
Drawdown	0.445 m (well #2 pumping at 384m^3/d; well #1 pumping at 648 m^3/d)	0.625 m (well #1 pumping at 648m^3/d; well #2 pumping at 384m^3/d)
Daily Abstraction	384 m^3/d (pumping on demand)	648 m^3/d (pumping on demand)
Pumping test summary	(i) Abstraction rate: 6758 m^3/d (constant rate test, 1991)	(i) Abstraction rate: 1300-1070 m^3/d (‘constant’ rate test, 2001)
	(ii) Specific capacity 500 m^3/d/m (after 168 hours pumping)	(ii) Specific capacity 1030 m^3/d/m (after 15 minutes pumping)
	(iii) Transmissivity: 611 m^2/d (Logan approximation)	(iii) Transmissivity: 1071 m^2/d (Jacob analysis of recovery curve); 1216 m^2/d (Logan approximation)

4. Methodology

Desk study

Bedrock geology information was compiled from the GSI Geology Sheet No. 18 (Archer *et al.*, 1996) and subsoils were compiled from Finch and Gardiner (1993). Basic public supply well details were obtained from GSI records and County Council personnel; such details include borehole depth, elevation, abstraction rate, pumping test details and geophysical surveys.

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 the current pollutant loading. Water samples taken were analysed by the State Laboratory. Four 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 Hydrology

Borrisoleigh WSS source lies about 100 m east of the Fishmoyne River, which runs south to become the Cromoge River, then the Clodiagh, and eventually the Suir. To the northeast, the ground rises from approximately 91.5 m to height of about 115 m, where a ridge runs parallel to the river.

The sources are located in an area of undulating pasture, on a river meadow. The boreholes are a few metres from and down-slope of the main Borrisoleigh–Thurles road.

A small stream originates from a seep approximately 300 m north east of the boreholes and is routed downhill and under the main road in a dug ditch and through pipes. After the construction of the boreholes, the piped section was extended and the stream now drains to a point west (downhill) of the boreholes. On one occasion, the stream became blocked before entering the pipe under the road, and flooded. The source overseer and caretaker noted that flood waters entering the site soaked away to the subsurface within 0.5 m of production borehole # 1.

The soils and subsoils are river-deposits in the vicinity of the source, and limestone glacial tills over the zone of contribution of the source.

6. Geology

6.1 Bedrock Geology

The bedrock geology of the area comprises limestone sediments of Lower Carboniferous age (c. 330 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 Borrisoleigh WSS

Rock Formation	Rock Material	Thickness	Occurrence
Ballysteen Formation (BA)	Muddy limestones*:* blue-grey to mid-grey well-bedded, ca. 0.5m thick beds.	~200 m	Underlies the source and for several kms in the surrounding area. Outcrops in several places nearby either side of the Fishmoyne River.

6.1.1 Geological Structure

The borehole is sited in the Ballysteen Formation in a major NE-SW trending synclinal fold. Bedding dips in the immediate vicinity are very low (5^o) and generally to the southeast and east. Approximately 1250 m to the west of the source is a major NW-SE trending fault (i.e. cross-cutting the fold). Other, less extensive, faults with a similar orientation occur in the area, including one whose extension from the fault tip 800 m to the northwest would pass very closely by the boreholes.

6.2 Subsoils (Quaternary) Geology

The subsoils in the vicinity of the source and its zone of contribution are comprised of glacial deposits. The boreholes are sited close to the boundary between till and colluvium (material deposited by gravity at the foot of a slope). The soil compositions are influenced by both the dominant lithology in Tipperary (limestone) and the sandstone bedrock exposed in the Knockanora and Knockacreggan mountains to the north west and west of Borrisoleigh, respectively. The characteristics of each category are described briefly below.

6.2.1 Limestone with some Sandstone and Shale Till

Teagasc (1993) assign the soils in this area to the 'Elton' Series. This soil type covers almost 10% of Tipperary North Riding and, in the zone of contribution to the source, occurs in uphill parts. It is a gravelly loam ranging in colour from dark to pale brown, and comprises 45% sand-grade grains and 35% silt, with the remaining fraction clay grade. It contains sandstone and shale fragments in addition to limestone gravel. The parent till type is moderately permeable.

6.2.2 Colluvium

These soil deposits occupy the area between the boreholes and the river and for a distance of 350 m north and south along the line of the Fishmoyne River. Coarse and fine sand account for 30-35% of the deposit, with the remainder comprising 40-45% silt and 20-25% clay. The soil becomes more gravelly downwards, to the base of the soil horizon at around 100 cm. Drilling records from Dunne's Drillers describe 'clay, sand and gravel' as comprising the subsoil cover. Anecdotal evidence from County Council personnel who observed the upgrading of the Borrisoleigh-Thurles road describes the subsoil as gravelly.

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 four auger holes are shown on Figure 2, and the logs are summarised in Figure 3. Depths to bedrock range from 2.8 to 4.8 m.

7. Hydrogeology

7.1 Data availability

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

- Hydrochemistry/water quality

  GSI targeted sampling (August 2000)
  EPA (March 1997 and in prep.)
  County Council analyses of Public supplies (1989 – 2000)
  EC STRIDE Sub-programme Measure 1 (September 1993)

- Hydrogeology

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

Data such as flows, and water levels in the boreholes and Fishmoyne River were gained from Co. Co. personnel, 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 Tipperary County".

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 1177 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 722 mm. Runoff is assumed to be 70% of available recharge, i.e. 361 mm. This assumption, from Wright *et al.* (1983), is an empirical standard used in GSI for moderately permeable subsoils of the sandy till type that dominate the area uphill of the site. These calculations are summarised below:

Average rainfall (R)	1177 mm/yr
Estimated P.E.	505 mm/yr
Estimated A.E. (90% P.E.)	455 mm/yr
Potential recharge (R–AE)	722 mm/yr
Surface Runoff	217 mm/yr
Recharge	505 mm/yr

7.3 Groundwater levels

Water level data were obtained during well surveys carried out in November 1999 and 2001. A seep in the hillside about 300 m to the northeast of the source described by Co. Co. personnel is determined from the map as having an elevation of approximately 108 m aOD.

In November 1999, the water levels at the site were 89.28 m aOD in production borehole #1, and 81.87 m aOD in the old production borehole 1.3 km southeast down the road to Thurles.

In November 2001, water levels were: Production borehole #1 - 89.28 m aOD; Production borehole #2 - 89.43 m aOD; river surface – 88.75 m aOD.

7.4 Groundwater Flow Directions and Gradients

The water table in the area is assumed broadly to reflect topography, with groundwater flowing toward and discharging into the Fishmoyne River. The average topographic gradient east of the boreholes is about 3.74%, and between the boreholes and the river is about 0.5%. The average natural hydraulic gradient is estimated to be 2/100 (2%) east of the boreholes, and 4/1000 (0.4%) between the boreholes and the river.

7.5 Hydrochemistry and Water Quality

Field measurements indicated a groundwater electrical conductivity of 606 μS/cm and a temperature of 11.5°C. Results of laboratory analyses of water samples are presented in Appendix 1. Data that reflect water quality are shown graphically in Figure 4. The following key points are identified from the data:

- The groundwater samples have a calcium-bicarbonate ($CaCO_3$ - HCO_3) hydrochemical signature.
- The groundwater is 'hard' (255 mg/l $CaCO_3$).
- Nitrate concentrations range widely from 4.7-27.6 mg/l, with an average concentration of 16.6 mg/l (36 samples) over the period August 1989 to November 2000. The GSI threshold of 25 mg/l was exceeded once in the sampling period. These results do not include the concentration of 48.7 mg/l measured on 11/04/00, which may be anomalous. As far as is measured, nitrate levels do not give

cause for alarm and indicate that loadings from fertiliser application are not too high. There is a slight downwards trend apparent in the data.

- Two chloride measurements record concentrations of 22 and 17.6 mg/l. Chloride is a constituent of organic wastes and levels higher than 25 mg/l may indicate contamination, and away from coastal areas, 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 two occasions (out of three) in the period June 1994 to August 2000. One of the contaminated samples was treated, with the remaining one indeterminate, indicating that the chlorination process at the source is, or has been, inadequate. There is a marked improvement in the bacteriological quality of the source since 1998, with none of five 'total coliform' samples testing positive.
- Two potassium:sodium (K:Na) ratios can be calculated from the available data, and are 0.17 and 0.31. The K:Na ratio is used to help indicate (along with other parameters) if water has been contaminated and may indicate contamination if the ratio is >0.4. To provide sufficient data to assess the source, it should be measured routinely in the future.
- Iron concentrations attained the EU Drinking Water Directive maximum admissible concentration (MAC) of 0.2 mg/l once in 13 samples (in February 1994). 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.

7.6 Aquifer Parameters

Various sources of data are used to estimate the aquifer parameters of the Ballysteen Formation in the vicinity of Rathmoy Bridge.

- An extended (7 day) constant rate pumping test of Production well #2 by Dunne's Drillers in 1991
- A short (420 minutes) pumping test conducted by K.T. Cullen on a trial well in 1986
- A short (100 minutes) pumping test conducted by the GSI on Production well # 1 in November 2001

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 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.

As can be seen from the values listed in Table 2, estimated permeabilities vary by up to a factor of three, ranging between 12.45 and 46.57 m/d. There are various reasons for the observed differences:

- Borehole and pump test factors

  Drawdown 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 pump test durations are different.

  Well construction impacts upon drawdown at any given pumping rate. The tests were conducted in different boreholes with different constructions and well efficiencies.

- Aquifer factors

  Well depth and placement in fractured aquifers control the interception of water-yielding fractures. For example, the 28 m deep trial well tested by K.T. Cullen had recorded inflows at about 13, 15 and 25 m. This compares with the inflows at 17, 22 and 38 m in Production borehole # 2.

There is a thickness (*c.* 10 m) of saturated gravel, and clayey sand over parts of the aquifer. Water will flow from the gravel to the limestone bedrock aquifer, in response to the pressure gradient when the wells are pumped. This 'extra' water entering the aquifer will cause the drawdowns in the wells to be less than they would otherwise, especially at short to intermediate times.

For the reasons outlined above, a permeability of 30 m/d, estimated from the long-term test in a production borehole, is assigned to the Ballysteen Formation aquifer.

Table 2: Estimated aquifer parameters for the rock units at Rathmoy Bridge, Borrisoleigh WSS

Parameter	**Data source**	**Ballysteen Formation parameter values**
Permeability	7 day constant rate pumping test Production well # 2 (Dunne's) • Logan approximation)	26.57 m/d
	420 minutes pumping test (KT Cullen) • Logan approximation, 180 mins • Logan approximation, 350 mins • Jacob analysis of pumping data, 30-150 mins	25.27 m/d 15.91 m/d 12.45 m/d
	100 minutes pumping test Production well # 1 (GSI) • Jacob analysis of recovery • Logan approximation	46.57 m/d 43.35 m/d
Porosity	420 minutes pumping test (KT Cullen)	0.002 (confined) 0.02 (unconfined)
Hydraulic gradient		2% east of production boreholes, 0.4% between wells and river.

7.7 Aquifer Category

Overall in North 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 Rathmoy Bridge (and at Templemore) that the yields are excellent in this location.

As previously mentioned (section 6.1.1), the boreholes are in line with a NW-SE trending fault whose termination is mapped 800 m to the northwest. Evidence for the fault extension to the vicinity of Rathmoy Bridge comes from the steep increase in hill slope to the east of the river Fishmoyne River valley, and is also indicated by high yields of the boreholes. The apparent longevity of the drainage pattern in this area may also have contributed to enhancement of fracture apertures and flow conduits in the limestone beneath the river valley.

Resistivity surveys by K.T. Cullen (1986) show that there is an elongated zone over 1.8 km long of lower resistivity that is parallel but offset slightly to the east of the Fishmoyne River. 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 zone location suggests that the low resistivity zone is related to the former location of the Fishmoyne river and its deposits, and to the high water table in this area.

7.8 Conceptual Model

- The Borrisoleigh source is fed from the Ballysteen Formation which is a 'bedrock aquifer which is moderately productive only in local zones' **(Ll)**.
- The permeability in this aquifer depends on the development of faults, fissures and fractures and bedding plane separation. There may be a limited degree of karstification.
- In general, there are few drains and surface streams apart from the Fishmoyne River, indicating the free draining nature of the subsoils and the relatively high permeabilities of the bedrock. The streams draining the field on the opposite side of the Borrisoleigh-Thurles road to the boreholes reflect the water table elevation.
- The rock unit is largely overlain by moderately permeable till and highly permeable sand & gravel. At the altitude of the boreholes, the water table lies within the gravelly (-sandy-clayey) subsoils. Towards the east in the higher ground, the water table is probably within the limestone bedrock. Therefore, the groundwater can be considered unconfined over much of its extent, and possibly partially confined near to the river.
- The shapes of the pumping test drawdown curves indicate that the high-storage gravels and sands overlying parts of the aquifer contribute to the groundwater abstracted by the boreholes.
- The groundwater flow in the area broadly reflects topography, flowing from east to west towards, and probably discharging into, the Fishmoyne River.
- Electrical conductivity measurements in early months of the year appear to be lower than later months indicating dilution of the groundwater by rapid rainfall recharge, although there are insufficient measurements to confirm this absolutely. The variability of groundwater nitrate concentrations also indicates a relatively rapid component of recharge to the aquifer.
- Water level measurements indicate flow from the vicinity of the boreholes towards the river. Even during pumping, the hydraulic gradient was still directed towards the river when measured in November 2001. There is no hydrochemical evidence to indicate that water is drawn from the river by the boreholes under the current pumping schedule.

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) includes the complete catchment area to the source, i.e. the zone of contribution (ZOC), and it 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 site is 1032 m^3/d. This figure is increased by about 50% to 1550 m^3/d for the following reasons:

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

Taking the recharge to be 505 mm/y as indicated in Section 7.2, the area required to supply a pumping rate of 1550 m^3/d is calculated to be 1.12 km^2 (112 ha). This figure compares with a topographically-determined area of 1.20 km^2.

The inferred ZOC is roughly oval in shape. The boundaries of the ZOC are illustrated in Figure 1 and are delineated as follows:

Northern Boundary: runs west-southwest along a small ridge jutting into the Fishmoyne River valley.

Eastern Boundary: lies 250 m east of the Kilfithmone road and parallel to it, demarcated by the top of the ridge that runs parallel to the river valley.

Southern Boundary: runs southwest–northeast along the road branching uphill off the Borrisoleigh-Thurles road.

Western Boundary: parallel to the general south-southeast flow direction of the Fishmoyne River; the ZOC does not intersect the river.

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, 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).

Because of evidence of different hydraulic gradients, the 100-day ToT is estimated separately to the west and east of the boreholes:

East: Taking the permeability as 30 m/d, Effective Porosity as 0.02, and Hydraulic Gradient as 0.02, the groundwater flow velocity is estimated as 30 m/day (30 x 0.02/0.02), so the 100-day travel time distance is approximately 3000 metres. This takes in the entirety of the ZOC east of the boreholes.

West: Taking the permeability as 30 m/d, Effective Porosity as 0.02, and Hydraulic Gradient as 0.004, the groundwater flow velocity is estimated as 6 m/day (30 x 0.004/0.02), so the 100-day travel time distance is approximately 600 metres. Again, this takes in the entirety of the ZOC in the region between the boreholes and the river.

The entire 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 (DELG/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 High-Low for much of the area, and Extreme in restricted parts. Vulnerability of groundwater in the vicinity of Borrisoleigh 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 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. Not all of the hydrogeological settings represented by the zones may be present around each local authority source. There are four groundwater protection zones present around the Borrisoleigh WSS source (see Figure 7), as shown in Table 3. As discussed in section 8.3, the Inner Protection Zone encompasses the entirety of the ZOC (Outer Protection Zone).

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 is the principal activity in the area. Other hazards include farmyards, septic tank systems, application of fertilisers (organic and inorganic) and pesticides. Possible spillages along the road pose a particular hazard, as the boreholes are so close to the road, and the subsoil so permeable directly adjacent to the boreholes. Although the stream that flows immediately south of the pump house was piped through a culvert beneath the Borrisoleigh-Thurles road, it is not lined all the way to the Fishmoyne River. Pollution potentially carried by the stream could soak into the aquifer very close to the point of abstraction. No detailed assessment of hazards was carried out as part of this study.

12. Conclusions and Recommendations

- The borehole at Borrisoleigh abstracts water from a limestone 'bedrock aquifer which is moderately productive only in local zones' **(Ll)**.
- The area around the supply generally has 'high-low' vulnerability to contamination, with 'extreme' vulnerability in restricted areas.
- 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 Borrisoleigh–Thurles road. Construction of a well-lined drain between the road and the WSS site could be considered to act as a 'firebreak' against potential pollution from petroleum products/other hazardous wastes spilt on the road.

- The potential pollution of the aquifer by the stream that flows over the aquifer into the Fishmoyne River should be considered, and guidelines drawn up for dealing with up-stream contamination incidents (both acute events from spills and longer-term issues from, e.g., nitrate- or faecal bacteria-rich run-off).

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.

Cooper, H.H. Jr & Jacob, C.E. (1946) A generalised graphical method for evaluating formation constants and summarizing well field history. *Trans. American Geophysical Union,* **27**, No. 4.

Cullen, K.T. (1986) *Preliminary hydrogeological report on the Templemore area, Co. Tipperary*. March 1986, K.T. Cullen and Co. Ltd.

Daly, E.P. (1992) *Groundwater Resources of the Nore River Basin. Interim Report.* Geological Survey of Ireland unpublished report.

DELG/EPA/GSI (1999) *Groundwater Protection Schemes*. Department of Environment & Local Government, Environmental Protection Agency & Geological Survey of Ireland, joint publication.

Finch, T.F. & Gardiner, M.J. (1993) *Soils of Tipperary North Riding*. Soil Survey Bulletin No. 42, National Soil Survey of Ireland, Teagasc, Dublin.

Logan, J. (1964) Estimating transmissibility from routine production tests of water wells. *Ground Water*, **2**, No. 1, 35-37.

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

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

Fig 2 – site map

Fig 3 – driller logs

Fig 4 - chemistry

Fig 5 - EC

Fig 6 - ZOC and TOT map

Fig 7 – vulnerability map

Fig 8 – source PZ

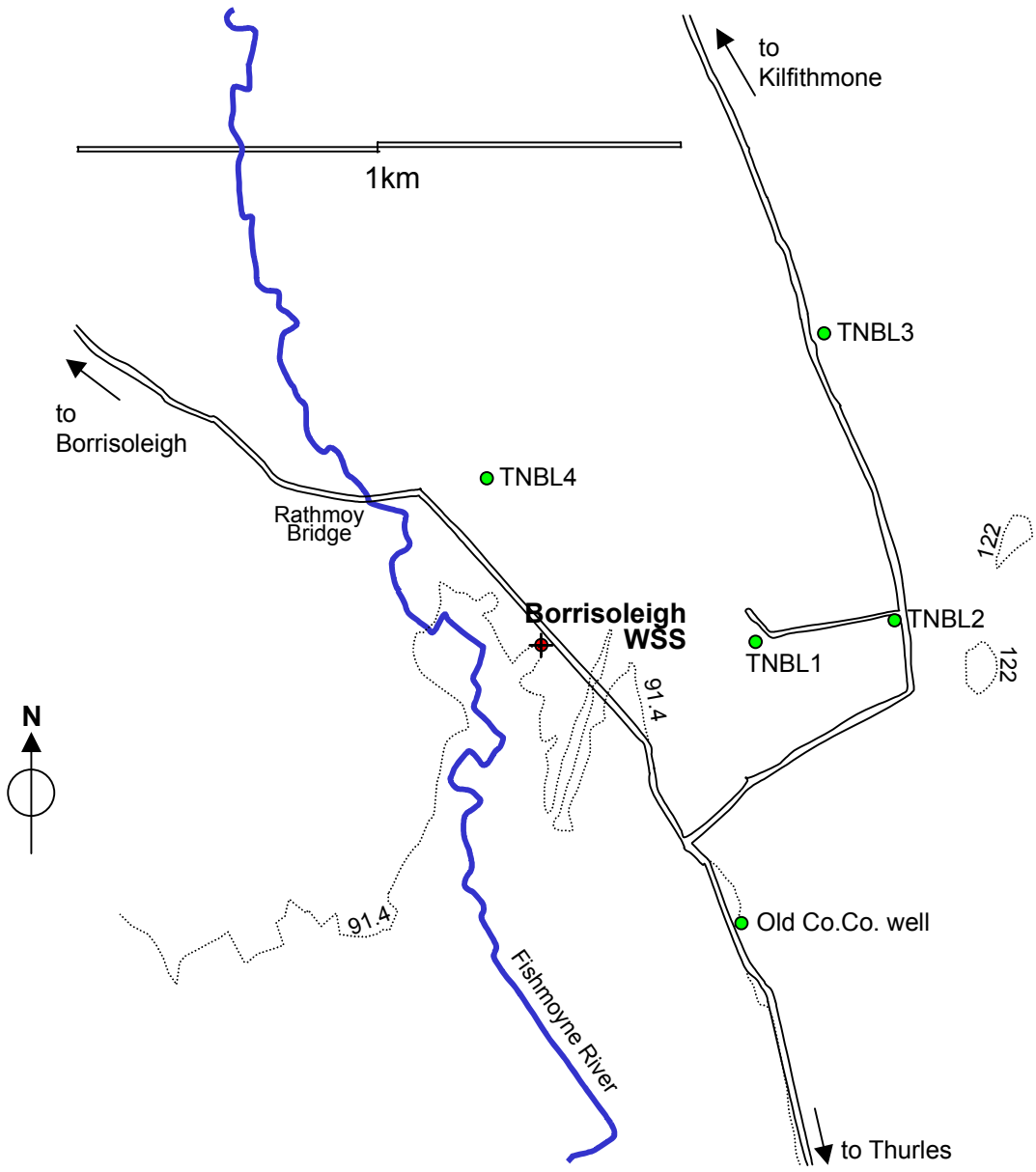
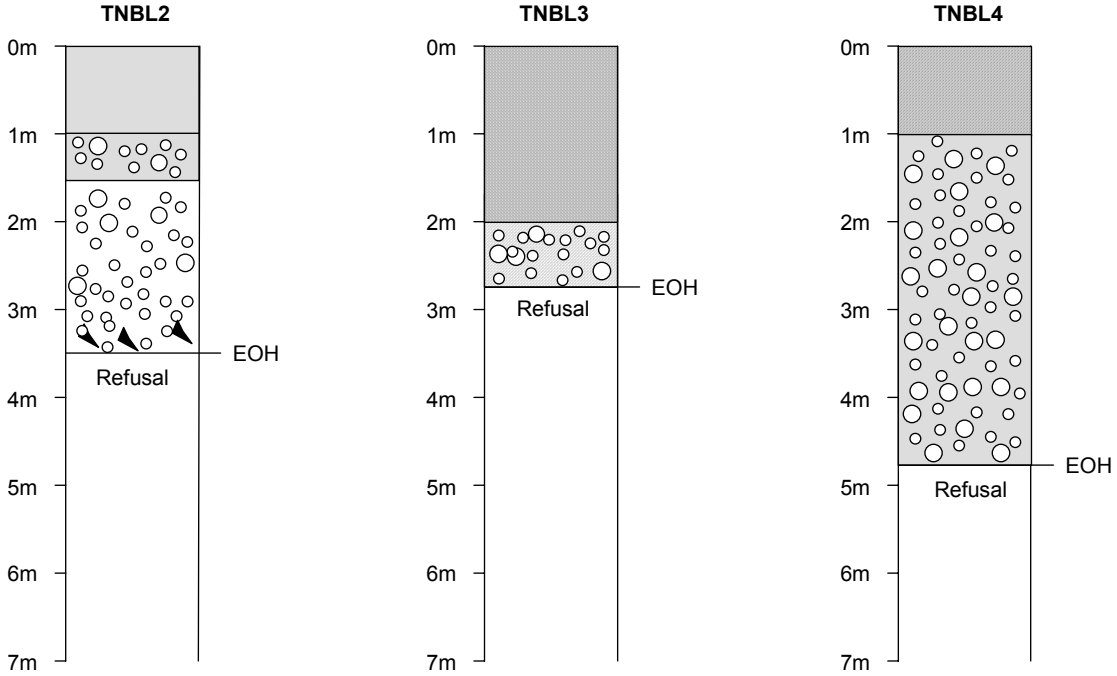


Figure 2: Location map of Borrisoleigh WSS production boreholes, auger holes drilled by GSI to determine depth to bedrock in the vicinity (TNBL1 to TNBL4) and other boreholes discussed in the text.



TNBL2	
1.0m	CLAY
1.5m	Gravelly CLAY
2.8m	Gravel/Lsts Frags
3.3m	Fresh Lsts Rock
3.5m	REFUSAL

TNBL3	
1.0m	Sandy CLAY
2.0m	Sandy CLAY
2.5m	Gravelly Sandy CLAY (rougher)
2.8m	Fresh Lsts REFUSAL

TNBL4	
1.0m	Sandy CLAY
2.0m	Gravelly (50-100mm)CLAY
3.0m	Gravelly (50-100mm)CLAY
4.0m	Gravelly (50-100mm)CLAY
4.8m	REFUSAL on Rock

Figure 3: Summary driller's logs and lithological descriptions of augerholes drilled to assess depth to bedrock in the vicinity of Borrisoleigh WSS boreholes. See Figure 2 for the locations of the augered holes. **TNBL1** reached bedrock at a depth of 3 m.

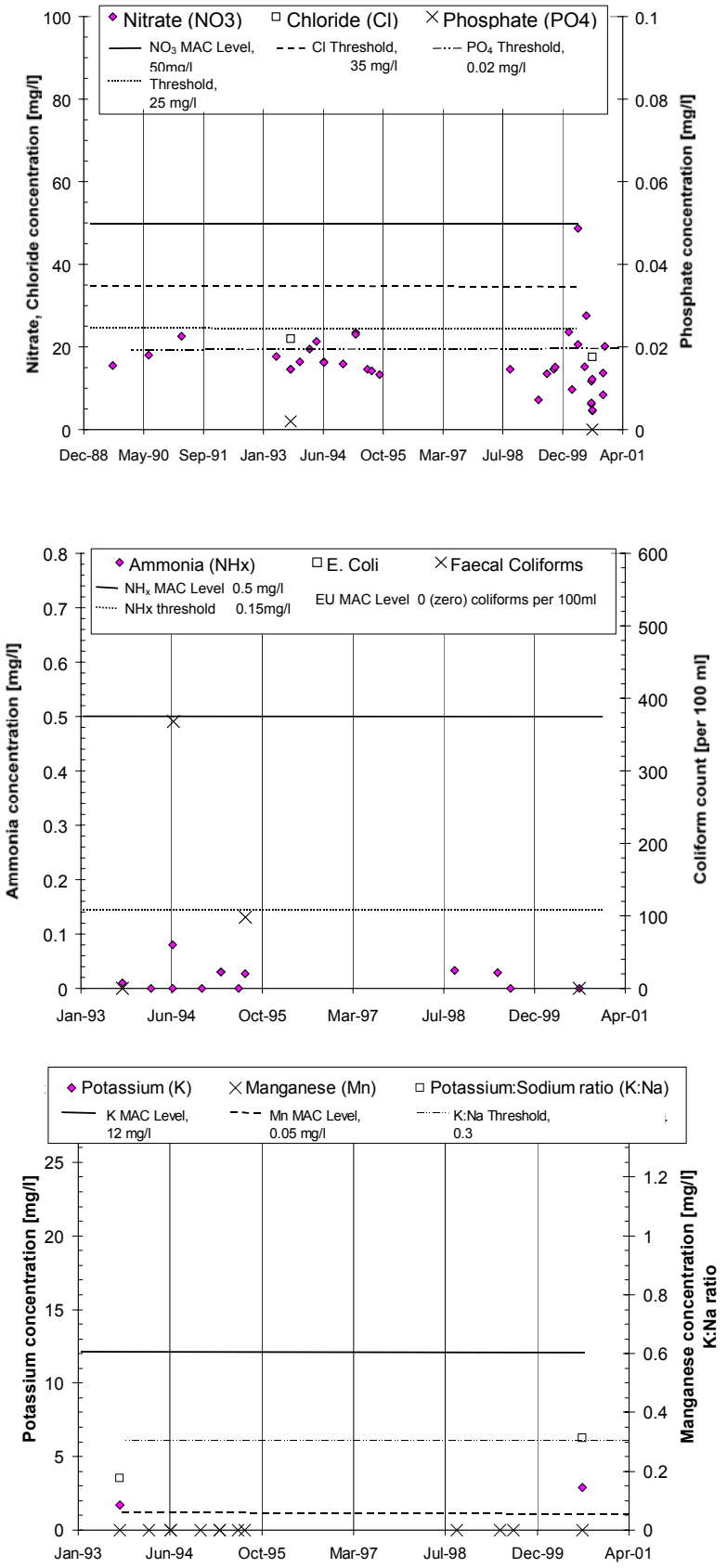


Figure 4: Key indicators of agricultural and domestic groundwater contamination at Borrisoleigh WSS

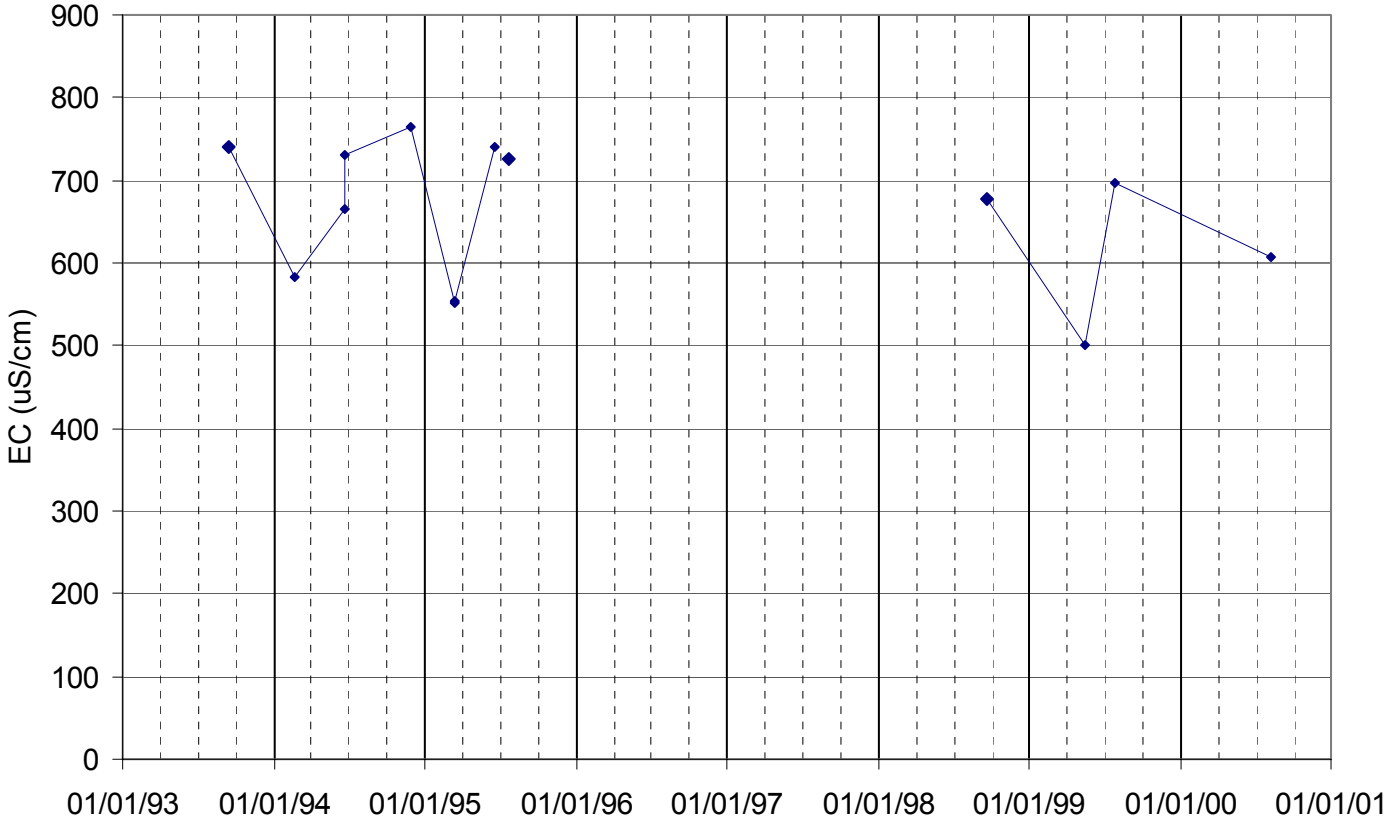
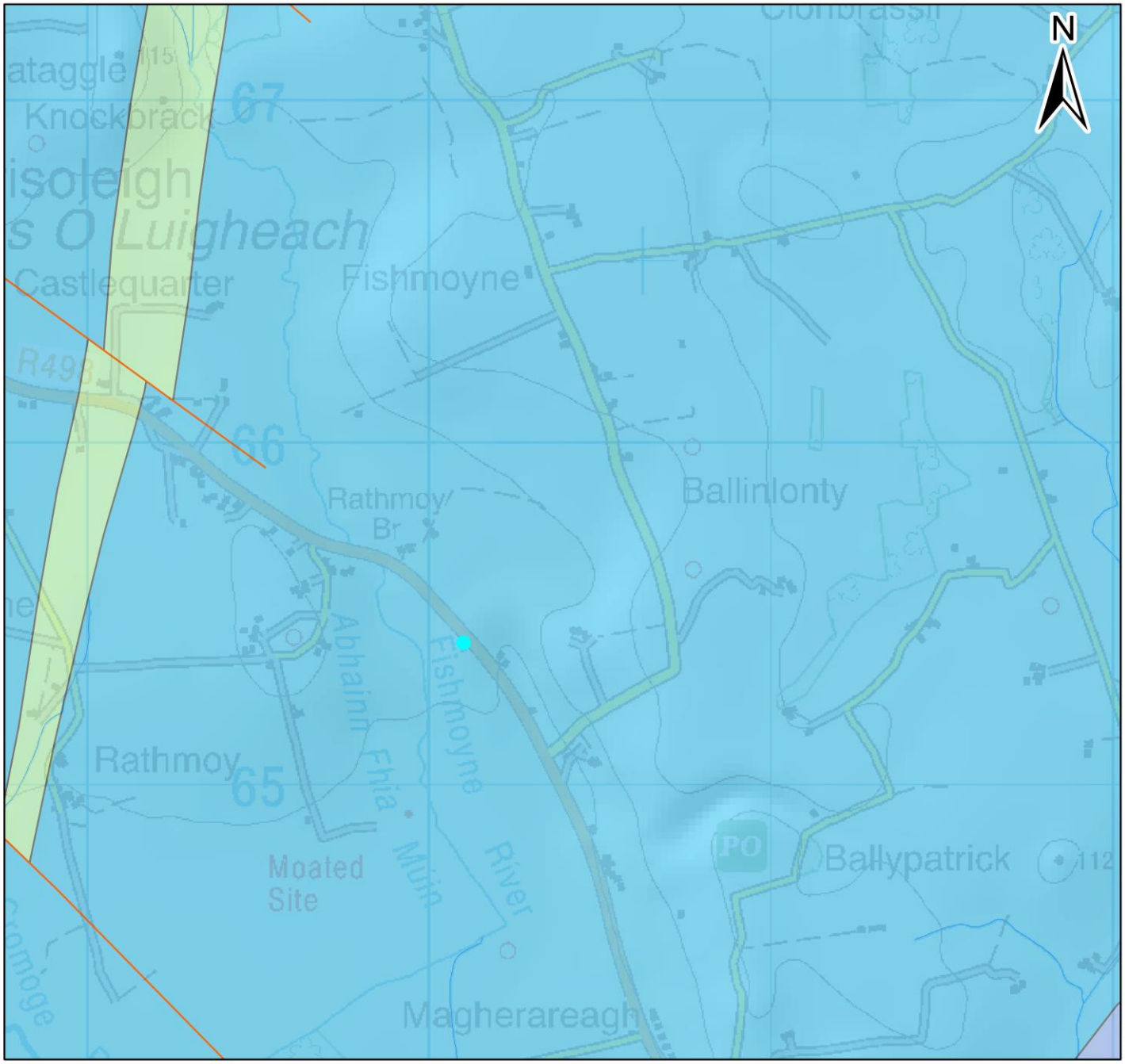


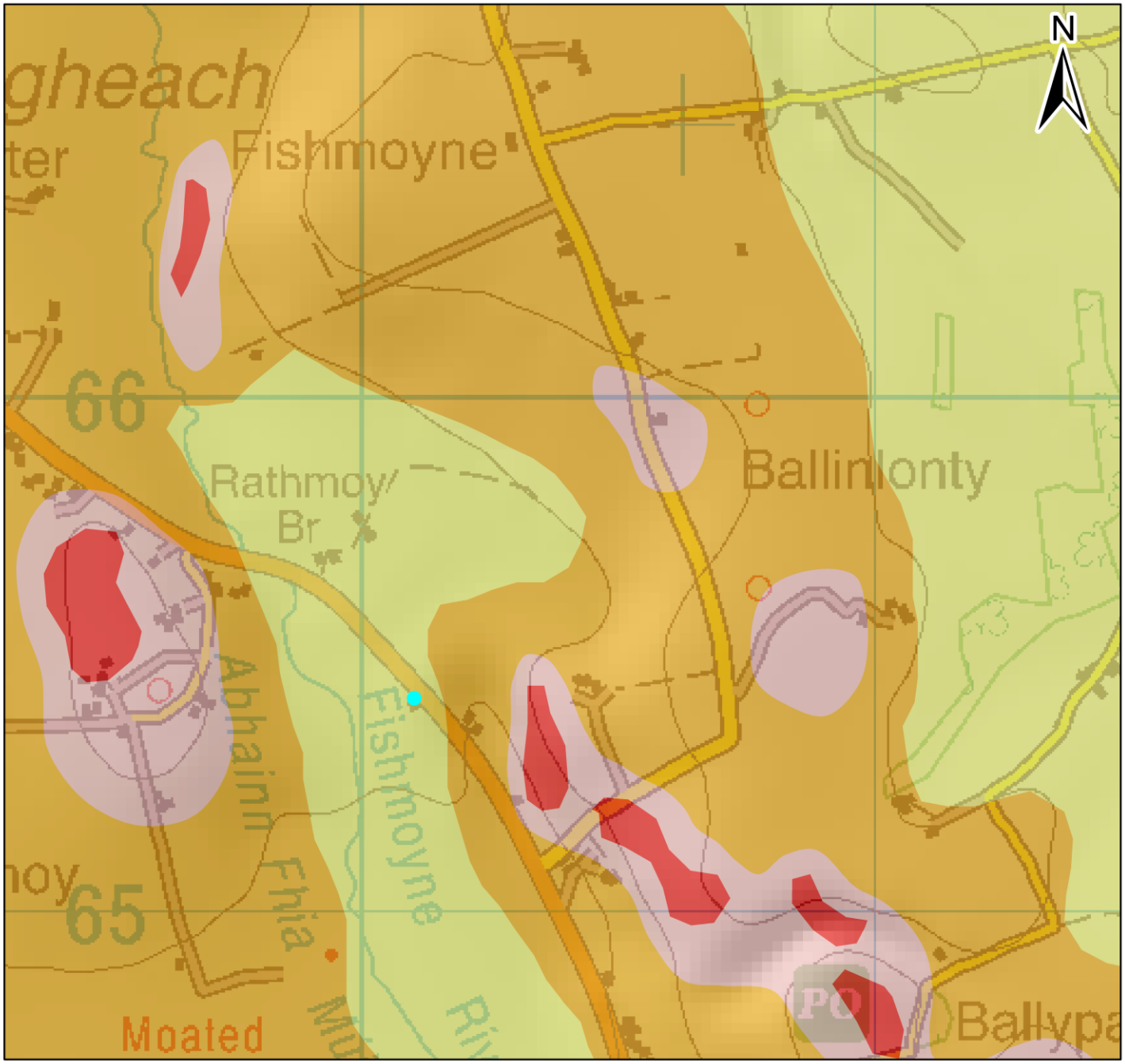
Figure 5: Variation in groundwater Electrical Conductivity (EC, μS/cm) measured at Borrisoleigh WSS in the period September 1993 to August 2000. The data indicate that EC decreases by about 150 μS/cm during the winter recharge months relative to the summer, non-recharge, months.

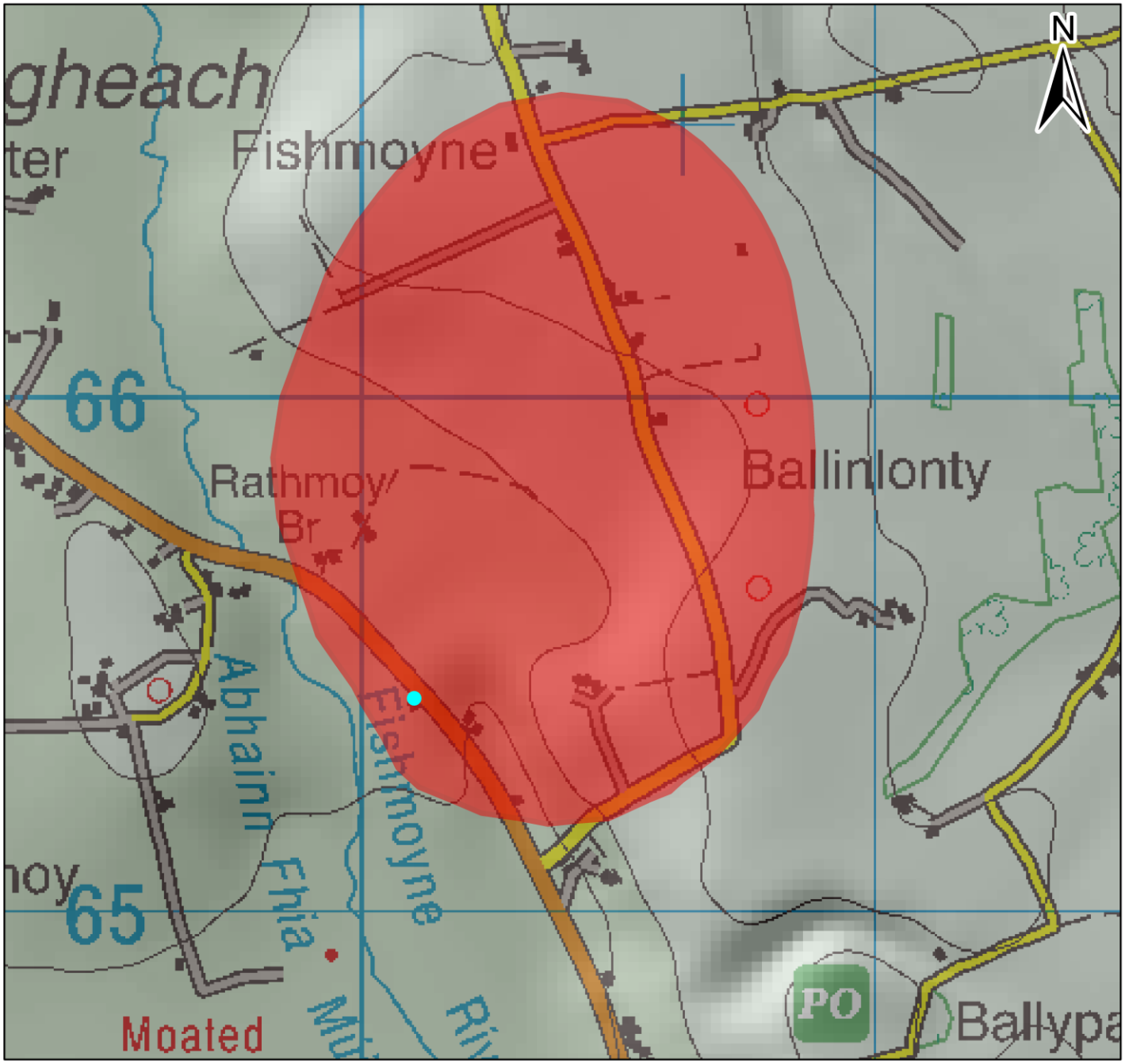
Appendix 1: Laboratory Analyses of Groundwater at Borrisoleigh WSS

Parameter	Results of Laboratory Analyses																															
Laboratory	DWR				Reg WL	Tipperary NR Co. Co.																			DWR					State Lab	DWR	
Sample treatment	-	-	-	-	S	-	-	-	NS	-	-	-	-	-	NS?	S	NS	NS	NS	-	-	NS	-	-	-	-	-	-	S	-		
Date	22/08/89	18/06/90	19/03/91	18/05/93	16/09/93	21/02/94	20/06/94	20/06/94	24/06/94	28/11/94	13/03/95	13/03/95	19/06/95	25/07/95	26/07/95	26/07/95	22/09/98	20/04/99	30/04/99	17/05/99	27/07/99	30/07/99	22/09/99	05/10/99	25/01/00	11/04/00	20/06/00	01/08/00	09/08/00	10/08/00	07/11/00	21/11/00
EC (µS/cm)					740	584	666	730		764	551	554	741	727			677			501	697								607			
pH (lab.)					7.8	7.6	7.3	7.3		7.2	7.7	7.7	7.1	7.1			7.2			7.7	7.5											
Total Hardness (mg/l $CaCO_3$)					430																								321			
Total Alkalinity (mg/l $CaCO_3$)					373																								322			
Calcium (mg/l)					122																								99.6			
Magnesium (mg/l)					30																								17.5			
Chloride (mg/l)					22																								17.6			
Sulphate (mg/l)					7																								11.7			
Sodium (mg/l)					9.6																								9.3			
Potassium (mg/l)					1.7																								2.9			
K:Na					0.2																								0.3			
Nitrate (mg/l NO_3)	15.5	18.0	22.6	17.7	14.6	19.5	16.4	16.2		15.9	23.5	23.0	14.6	14.2			14.6			7.2	13.5		14.6	15.1	23.6	20.6	27.6	11.7	12.2	4.7	13.7	20.2
Iron (mg/l)					0.04	**0.2**	<MDL	<MDL		<MDL	0.03	0.02	0.05	<MDL			<MDL			<MDL	0.08								<MDL			
Manganese (mg/l)					0.007	<MDL	<MDL	<MDL		<MDL	<MDL	<MDL	<MDL	<MDL			<MDL			<MDL	<MDL								<MDL			
E/F coli per 100 ml.					0				**368**						**98**														0			
Total Coli /100ml					15				368						124	0	0	10	0			0							0			
Total Ammonia (mg/l NHx)					0.01	<MDL	<MDL	0.08		<MDL	0.03	0.03	<MDL	0.03			0.03			0.03	<MDL								<MDL			
Comments	Polluted with coliforms of faecal origin																	Generally good quality water but should have on-going monitoring of faecal bacteria and nitrate especially.														

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


N
Legend
Borehole
Rivers
Structural Features
Geological Fault
Geological Unit
Waulsortian Limestone Formation
Ballysteen Formation
Lisduff Oolite Member
Fishmoyne
Ballinlonty
Rathmoy Br
Rathmoy
Moated Site
Ballypatrick
Magherareagh
0
0.25
0.5
1 Km


N
Legend
Borehole
Rivers
Vulnerability
X- Extreme (rock close/karst)
E- Extreme
H- High
M- Moderate
L- Low
Fishmoyne
Rathmoy/
Br
Ballinlonty
Abhainn Fhia
Fishmoyne
Moated
PO
66
65
0
0.125
0.25
0.5 Km



Legend

- Borehole
- Rivers

Source Protection Area

- SI- Inner Source Protection Area
- SO- Outer Source Protection Area

0 0.125 0.25 0.5 Km