Nenagh GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water bodies	Associated terrestrial ecosystem(s)	Area (km^2)
25 - Nenagh/ Lough Derg North Tipperary and Offaly Co. Co.'s	Rivers: Nenagh, Ballyfinboy, Youghal, Ballintotty, Ollatrim, Kilmastulla, Carrigahorrig, Newtown, Dolla, Gortnagowna. Streams: Lorrha, Ardcroney, Ardgregane, Ballyquiveen. Loughs: Derg, Friar's, Ballinagross, Scarragh, Nahinch, Ballycuinlevan, Cornnaling, Annagh, Nagelane, Black, Clareen, Eorna, Coumbeg, Grange, Ania, Claree, Poulawee.	Ballintemple Bog (000882), Lough Nahinch (000936), River Shannon Callows (000216), Lough Derg (000011), Lorrha Bog (001684), Friar's Lough (000933), Arragh More Bog (000640), Kilcarren-Firville Bog (000647), Lough Avan (001995), Scohaboy Bog (000937), Newchapel Turlough (000653), Kilduff, Devilsbit Mountain (000934), Silvermine Mountains (000939), Nenagh River Gorge (001133)	756

Topography	The major part of the groundwater body is roughly rectangular, with the longer axis oriented E-W. There is a spur leading northwards to about 3 km north of Lorrha. Elevation within the GWB ranges from 30 mAOD along the shore of Lough Derg to 489 mAOD in the Silvermine Mountains in the south of the GWB. Overall, elevation decreases westwards and northwards to the centre of the GWB. The topography ranges from mountainous in areas underlain by the resistant sandstones and mudstones of the Devonian Old Red Sandstones and Silurian rocks to flat-lying in areas underlain by impure limestones. Rivers flows are predominantly northwards and westwards, to Lough Derg.	
Geology and Aquifers	Aquifer categories	**Ll:** Locally important aquifer which is moderately productive only in local zones; **Pl:** Poor aquifer which is generally unproductive except for local zones; **Lm:** Locally important aquifer which is generally moderately productive; **Rk^d**: Regionally important karstified aquifer dominated by diffuse flow.
	Main aquifer lithologies	Silurian Metasediments and Volcanics, Devonian Old Red Sandstones, Dinantian Lower Impure Limestones, Dinantian Pure Unbedded Limestones, Dinantian Upper Impure Limestones, Dinantian (early) Sandstones, Shales and Limestones, Dinantian Pure Bedded Limestones, Basalts & other Volcanic Rocks.
	Key structures	The major structures affecting the distribution of rock types and hence aquifer types are large anticlinal and synclinal folds, and major faults. The older and more resistant rocks that form the Silvermine, Arra and Devilsbit Mountains occur within the cores of the anticlines that are found in the south of the GWB. The younger impure and pure limestones are found preserved in the cores of the synclines. The largest structure is the Borrisokane Syncline, towards the north of the GWB. Fold axes trends range from ENE-WSW to NE-SW. There are several major faults with the same orientation as the fold axes crossing the GWB. The most notable are the Silvermines Fault, which links up with the Navan Fault in Co. Meath, and the Knockshigowna Fault, which runs along a sinuous, offset trace from southeast Co. Clare to east of Tullamore in Co. Offaly. Compression during the folding also caused some fracturing and jointing of the rocks. There are a few NW-SE trending faults cross-cutting the main NE-SW structural grain.
	Key properties	In the Silurian rock unit in the Slieve Felim mountains to the south of this GWB, a site investigation undertaken for a proposed landfill found that permeabilities in the top 30 m of rock ranged from 0.00036 to 0.76 m/d. A zone of higher permeability, 150-200 m wide, 12-14 m deep and 2.2 km long was delineated on the site. The transmissivity estimated for this zone was 27-82 m^2/d (Deakin, Daly and Coxon, 1998). At Templederry, in the south of this GWB, early time pumping test data indicate a transmissivity of around 5 m^2/d. A pumping test at Lorrha WS indicates an aquifer permeability of 5 m/d. This value is at the high end of what would be expected for this rock unit group, which typically has transmissivities in the range 2-20 m^2/d. There are no data for the ORS in this area; transmissivities will be low, but better than in the Silurian rocks, especially toward the top of the ORS succession. Within the Dinantian Lower Impure Limestones, transmissivities are likely to be in the range 2-20 m^2/d, with most values at the lower end of the range. Dinantian (early) Sandstones, Shales and Limestones aquifer properties are less good than this. A pumping test in the Dinantian Pure Unbedded Limestones (Waulsortian limestones) at Shinrone in west Co. Offaly indicated a transmissivity of approximately 27 m^2/d. At Tulla in Co. Clare, transmissivity in the same rock unit is estimated as 13 m^2/d. These values are probably at the middle to higher end of the range. Within all rock units, storativities are low. Groundwater gradients in the upland areas may be steep (up to 0.1). In low-lying areas, groundwater gradients on the order of 0.02 to 0.05 may be the norm. *(data sources: Rock Unit Group Aquifer Chapters, GWPS Reports,source reports, see references)*
	Thickness	The Silurian, ORS and Lower Impure Limestone aquifers are more than several hundreds of metres thick. However, the effective flowing thickness of these aquifers is usually ≤15 m, although isolated deeper inflows may occur where faults or significant fractures are intercepted by boreholes. The maximum thickness of Dinantian Sandstones, Shales and Limestones is less than 100 m. Again, groundwater flow is confined to the top 15 m in the main. In the Pure Unbedded Limestones east of Lough Derg, epikarst has been observed that has a thickness of up to 1-2 m. Below this, the thickness of the bedding (around 5-10 m) and/ or faulting controls the inflow intervals.

Overlying Strata	Lithologies	*[Information to be added at a later date]*
	Thickness	The groundwater body is large and with varied topography, hence the subsoil thickness varies widely. From available data, depth to bedrock ranges between 2 and over 60 m. It is particularly thick in the valley north of Silvermine Mountains where gravels have accumulated, and as alluvium along some of the river valleys. In the upland areas in the south of the GWB, subsoil thicknesses tend to be less than 6 m, although DTB can exceed 20 m locally. In the lowland areas in the northern half of the GWB, subsoil thicknesses tend to be less than 10 m. Outcrops occur mainly in the upland areas in the south, along Lough Derg, and over areas underlain by Pure Unbedded Limestones that have hilly topography.
	% area aquifer near surface	*[Information to be added at a later date]*
	Vulnerability	Vulnerability ranges from Extreme in the upland areas and in hilly ground near Lough Derg to "High to Low" in low-lying areas.
Recharge	Main recharge mechanisms	Diffuse recharge will occur via rainfall percolating through the subsoil. The proportion of the effective rainfall that recharges the aquifer is largely determined by the thickness and permeability of the soil and subsoil, and by the slope. In general, due to the generally low permeability of the aquifers within this GWB, a proportion of the recharge will discharge rapidly to surface watercourses via the upper layers of the aquifer, effectively reducing further the available groundwater resource in the aquifer. Where gravelly subsoils cover parts of the GWB, however, these will act as a 'store' of groundwater and somewhat mitigate rapid through-flow. The few swallow holes in the area accept point recharge from surface waters, as do the turloughs in low water table conditions.
	Est. recharge rates	*[Information to be added at a later date]*
Discharge	Springs and large known abstractions (m^3/d)	Toomyvara (145 m^3/d – GSI database; 100 m^3/d – EPA database), Templederry (82 m^3/d – GSI database; 90 m^3/d – EPA database), Lorrha (280 m^3/d – GSI database; 58 m^3/d – EPA database), Silvermines GWS (up to 235 m^3/d – GSI database, may be abstracting from gravel aquifer), Shallee GWS (unknown volume – GSI database), Imokilly Co-Op Creamery (unknown, up to 1000 m^3/d – GSI database), Patrickswell GWS (unknown volume – GSI database), Derryoober GWS (12 m^3/d – GSI database), Ballycommon WS (14 m^3/d – GSI and EPA databases), Nenagh Golf Course (15 m^3/d – GSI database; 60 m^3/d – EPA database), Knigh WS (unknown, up to 327 m^3/d – GSI database), Dromineer WS (53 m^3/d – GSI database; 83 m^3/d – EPA database), Puckaun WS (95 m^3/d – GSI database; 330 m^3/d – EPA database), Terryglass WS (90 m^3/d – GSI database; 65 m^3/d – EPA database), Chicken Farm at Ballyquirk (?2 m^3/d – GSI database), Borrisokane GWS at Lissadonna (380 m^3/d – GSI database), Lorrha GWS (15 m^3/d , still active? – GSI database), Dunkerrin (450 m^3/d, groundwater derived from both bedrock and gravel aquifers – GSI database), Rhone Poulenc at Lisbunny (up to 475 m^3/d – GSI database), Abbeyville (Lisgreen) GWS (55 m^3/d – EPA database), Annaghbeg GWS (5 m^3/d – EPA database), Ballinaclough WS (320 m^3/d – EPA database), Ballyscanlon GWS (unknown volume– EPA database), Carrigahorig GWS (unknown volume – EPA database), Castlecrannagh GWS (17 m^3/d – EPA database), Cloneybrian GWS (10 m^3/d – EPA database), Clonmackillduff GWS (5 m^3/d – EPA database), Cloghjordan WS (Matty's Well) (765 m^3/d – EPA database; 778 m^3/d – GSI database), Elm Hill GWS (unknown volume – EPA database), Gortagarry GWS (45 m^3/d – EPA database), Gorteenahilla GWS (28 m^3/d – EPA database), Killeen GWS (42 m^3/d – EPA database), Kilriffet (Toberanure) (227 m^3/d – EPA database), Lahessaragh GWS (Ballintogher) (24 m^3/d – EPA database), Lisgarode GWS (Lough Duff Spring) (unknown volume – EPA database), Lisheen GWS (5 m^3/d – EPA database), Plunkett Street GWS (Five Alley) (10 m^3/d – EPA database), Rathnaleen GWS (82 m^3/d – EPA database), Rathurles GWS (unknown volume – EPA database), Reyninch/ Drombane GWS (23 m^3/d – EPA database), St Patrick's Well GWS (73 m^3/d – EPA database), Tullahedy WS (20 m^3/d – EPA database), Ballywilliam Creamery (10 m^3/d – EPA database), Buckley's Nurseries (Kilmastulla) (12 m^3/d – EPA database), Duharra Creamery (12 m^3/d – EPA database), Grange Meats (545 m^3/d – EPA database), Magcobar Ltd (4000 m^3/d – EPA database), James Mundsay (14 m^3/d – EPA database), Nenagh Co-Op (454 m^3/d – EPA database), Toomyvara Co-Op (Phillabeen Bridge) (15 m^3/d – EPA database), Tubex Ltd (5 m^3/d – EPA database), Ballinderry GWS (unknown volume – EPA database), Ardcroney WS (unknown volume – EPA database). Birdhill Creamery (8 m^3/d – EPA database; may be abstracting from Birdhill Gravels.), *[More information to be added at a later date]*
	Main discharge mechanisms	Groundwater discharges to surface water in several ways. In the uplands, groundwater emerges at many springs on the hill slopes, and then feeds streams. The locations of faults and juxtaposed rock units may contribute to the locations of spring points in lower areas. Groundwater discharges to the gaining streams and rivers crossing the GWB and also to the three known turloughs during high water table conditions. Moderate to high specific dry weather flows along the River Nenagh of 0.91 to 2.25 $l/s/km^2$ are probably supported by alluvium along the river's course rather than being reflective of the storage capacity of the bedrock aquifer.

	Hydrochemical Signature	Groundwaters from all aquifers within this groundwater body have a calcium-bicarbonate signature. Hardness, alkalinity and electrical conductivities vary between the different rock unit group aquifers, however. There are limited data for this GWB, so data from the adjacent Slievefelim GWB are considered. Groundwaters from the Silurian strata range from slightly hard to hard (90–360 mg/l $CaCO_3$). In association, alkalinities range from 60 to 270 mg/l (as $CaCO_3$) and electrical conductivities from 260–600 µS/cm. pHs are neutral, with lab. pHs in the range 7.12–7.33. The majority of samples are at the upper end of the range. At springs, or other systems where throughput is rapid, groundwaters have limited dissolved solids. In Old Red Sandstone aquifers, groundwaters are similar, but all parameters are elevated compared to the Silurian rocks, i.e., groundwaters are moderately hard to hard. In other areas, alkalinity ranges from approximately 14 to 200 mg/l (as $CaCO_3$) and hardness ranges from approximately 50 to 270 mg/l. Groundwater in the Old Red Sandstone rock units is considered to range from moderately soft to moderately hard water (Kelly and Wright 2000). Groundwater conductivities are relatively low ranging from approximately 150 to 500 µS/cm. A typical range for pH in groundwater from the Old Red Sandstone rock units is 6–7. In the Dinantian (early) Sandstones, Limestones and Shales and the Lower Impure Limestones, groundwaters are Hard to Very Hard (typically ranging between 380–450 mg/l), and high electrical conductivities (650–800 µS/cm) are often observed. Alkalinity is also high, but less than hardness (250-370 mg/l as $CaCO_3$). High iron (Fe) and manganese (Mn) concentrations can occur in groundwater derived from ORS, due to the dissolution of Fe and Mn from the sandstone/shale where reducing conditions occur. It has been demonstrated that at low pumping rates water does not reside long enough in the well for oxidation to occur, thereby resulting in elevated Fe and Mn in small domestic supplies (Applin *et al*, 1989). Within the Impure Limestones, iron and manganese concentrations frequently fluctuate between zero and more than the EU Drinking Water Directive maximum admissible concentrations (MACs). Hydrogen sulphide can often reach unacceptable levels (E.P. Daly, 1982). These components come from the muddy parts of these rock units and reflect both the characteristics of the rock-forming materials and the relatively slow speed of groundwater movement through the fractures in the rock allowing low dissolved oxygen conditions to develop.
Groundwater Flow Paths		These rocks are devoid of intergranular permeability; groundwater flow occurs in fractures and faults. In the main, the rocks are dependent on fracturing and fissuring to enhance their permeability. The pure limestones may have had their transmissivity enhanced further by dissolution of calcium carbonate along fracture and bedding planes. Zones of high permeability can be encountered near fault zones and in areas of intensive fracturing. Permeabilities in the upper few metres are often high although they decrease rapidly with depth. In general, groundwater flow is concentrated in the upper 15 m of the aquifer. Evidence of the relatively low permeabilities is provided by the drainage density and flashy runoff response to rainfall in areas underlain by Silurian and Devonian rocks. Areas underlain by Pure Unbedded Limestones are generally well-drained. This is due to the presence of an epikarstic layer. Examination of data in the GSI well database shows that water levels in Silurian rocks are shallow, usually less than 15 m below surface. Water levels within the ORS unit are generally less than 15 m below ground surface with an average of approximately 12 m although this varies depending on topography. In the low-lying areas underlain by impure limestones, groundwater levels are between 2 and 10 mbgl. Next to the rivers, water levels will be closer to ground level. Water levels in the Upper Impure Limestone aquifer at Ardcroney have a variation of up to 16 m, indicating a low storativity. 4 km to the SW, water levels in the pure bedded aquifer at Castleview vary by up to 8 m. Groundwater flow paths are generally short, with groundwater discharging to small springs, or to the streams and rivers that traverse the aquifer. Flow directions are expected to approximately follow the local surface water catchments. There is no regional flow. Generally speaking, these rocks are unconfined, except where subsoils are thick and of low permeability. There are several gravel aquifers overlying this bedrock GWB. These are along the Silvermine Valley, and within about 10 km of Toomyvara, to the north and to the east.
Groundwater & Surface water interactions		The streams crossing the aquifer are effluent (gaining). Due to the shallow groundwater flow in this aquifer the groundwater and surface waters are closely linked. There are several marshes and wetlands in the area. At Shannon Callows, there is a 'petrifying stream' with associated species-rich calcareous flush, whilst at Lough Avan, there are a number of small lakes. Lough Derg, as well as receiving surface water input, is sustained by groundwater flow. Associated with the Lough are Cladium fens and a petrifying spring. At Arragh More Bog, ground water upwelling at the base of the ridge on the eastern side of the site flushes the area with more mineral rich water. Swallow holes accept point recharge from surface waters, and turloughs act as both groundwater discharge and recharge points.

Conceptual model	• The groundwater body is bounded to the south, east and north by surface water catchments, to the west by Lough Derg, and to the northeast by the contact between the Pure Unbedded and Lower Impure Limestones of this GWB and the Pure Bedded Limestones of the adjacent Lismaline GWB. The terrain ranges between mountainous in areas underlain by Silurian and Devonian rocks to flat-lying or gently undulating in areas underlain by the impure and pure limestones. • The groundwater body is comprised of generally low transmissivity and storativity rocks. The older rock units (i.e., Silurian and Devonian) are likely to have the lowest transmissivities, whereas the Pure Unbedded and Upper Impure (i.e. younger rock units) will have better flow properties. Where gravels, extensive alluvium or very sandy till overlies the bedrock aquifer, this can contribute to the storage. • Flow occurs along fractures, joints and major faults. Within the pure limestones, transmissivity may have been enhanced further by dissolution of calcium carbonate along fracture and bedding planes. Flows in the aquifer are typically concentrated in a thin zone at the top of the rock. An epikarstic layer exists at the top of the Pure Unbedded Limestones, at least in the vicinity of Lough Derg. • Recharge occurs particularly in the upland areas, and where rock outcrops, or subsoils are thin. Much of the potential recharge runs off in the upland areas. Where the water table is close to the surface in upland or lowland areas, potential recharge may be rejected. • Depending upon the local topography, the water table can vary between a few metres up to >10 m below ground surface. Overall, groundwater flow follows topography, flowing generally westwards. Locally, groundwater flows to the surface water bodies. Flow path lengths in the upland areas are short (≤ 300 m). The increased hydraulic gradient, due to the sloping topography, will allow groundwater to flow faster than if it were flowing through a similar rock type in low-lying land. • Groundwater discharges to springs and to the numerous streams and rivers crossing the aquifer, and to Lough Derg. • Due to the shallow groundwater flow in this aquifer the groundwater and surface waters are closely linked. There are several ecosystems in the GWB dependent on groundwater, including mineralised flushes. • In the southwest of the GWB along the Silvermine valley, a locally important (Lg) gravel aquifer overlies the bedrock aquifers. There are also gravel aquifers overlying the bedrock north and east of Toomyvara. • In areas underlain by Pure Unbedded Limestones, there are three turloughs and two swallow holes known; swallow holes accept point recharge from surface waters, and turloughs act as both groundwater discharge and recharge points.
Attachments	Groundwater hydrograph (Figures 1 and 2), Hydrochemical signature (Figure 3).
Instrumentation	Stream gauges:25025*, 25026, 25027*, 25028, 25029*, 25031*, 25038, 25043, 25044*, 25048, 25059, 25077, 25100, 25101, 25102, 25104, 25105*, 25109, 25113, 25120, 25134*, 25141, 25148, 25150, 25154, 25200, 25207, 25212, 25226, 25227, 25228, 25229, 25230, 25231, 25232, 25233, 25234, 25235, 25236, 25239, 25246, 25247, 25248, 25249, 25255, 25256, 25302, 25303, 25304, 25313, 25314, 25322. *(Adjusted dry weather flow calculated for stations marked with *)* EPA Water Level Monitoring boreholes: Ardcroney (TIN141), Castleview (TIN144). EPA Representative Monitoring boreholes: Cloughjordan WS (TIN 27), Ballyscanlon GWS (TIN 12).
Information Sources	Applin, K. R. and N. Zhao (1989) The Kinetics of Fe(II) Oxidation and Well Screen Encrustation. *Ground Water*, Vol 27, No 2. Daly, D., Cronin, C., Coxon, C. and Burns, S-J (1998) *County Offaly Groundwater Protection Scheme.* Geological Survey of Ireland Report to Offaly Co. Co., 54 pp. Hunter Williams, N., Motherway, K. and Wright, G. (2002) *North County Tipperary Groundwater Protection Scheme (draft).* Geological Survey of Ireland Report to North Tipperary Co. Co., 58 pp. Hunter Williams, N., Motherway, K. & Wright, G.R. (2002) *Templederry WS, Groundwater Source Protection Zones*. Geological Survey of Ireland, 18 pp. Hunter Williams, N., Motherway, K. & Wright, G.R. (2002) *Toomyvara WS, Groundwater Source Protection Zones*. Geological Survey of Ireland, 17 pp. Kelly, C. *Shinrone Public Supply-Groundwater Source Protection Zones*. Geological Survey of Ireland Report to Clare Co. Co., in preparation. Kelly, D. and Wright, G. (2000) *An Assessment of Groundwater Quality in County Cork (Southern Division).* Report to Cork County Council (Northern Division). Geological Survey of Ireland. Motherway, K., Hunter Williams, N. & Wright, G.R. (2002) *Lorrha WS, Groundwater Source Protection Zones*. Geological Survey of Ireland, 15 pp. Aquifer chapters: Devonian Old Red Sandstones; Dinantian Lower Impure Limestones; Dinantian Pure Unbedded Limestones; Dinantian Upper Impure Limestones; Silurian Metasediments and Volcanics; Dinantian Pure Bedded Limestones.
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae

Figure 1: Groundwater hydrograph

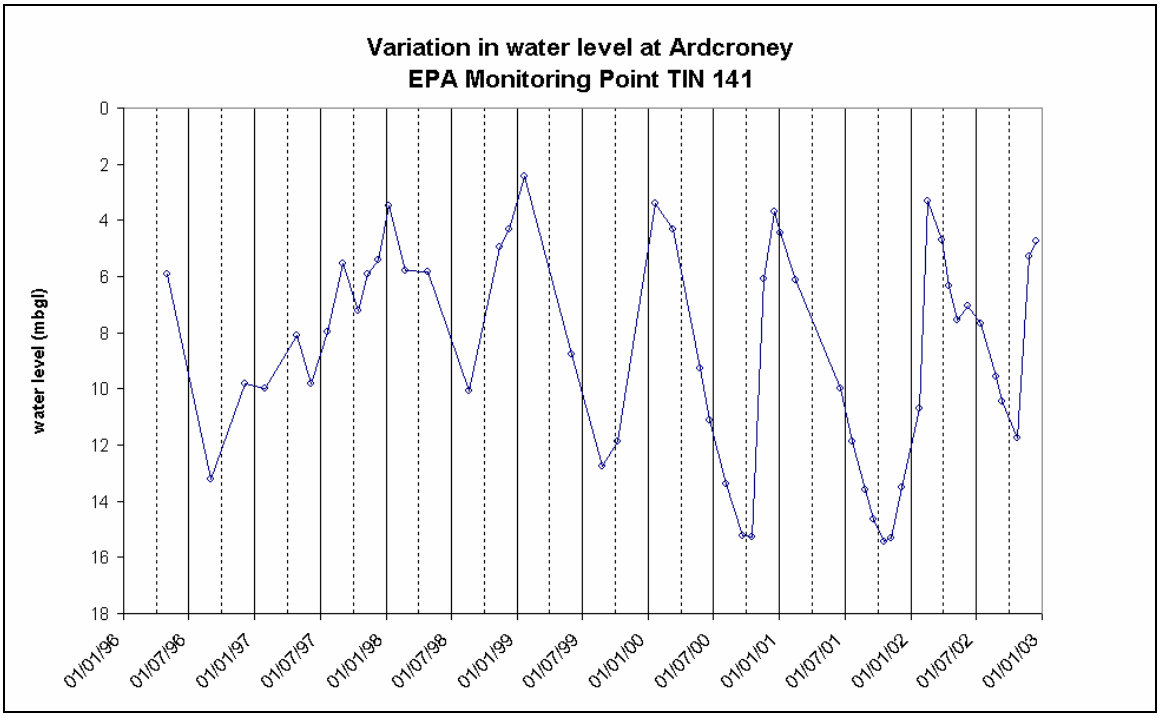


Figure 2: Groundwater hydrograph

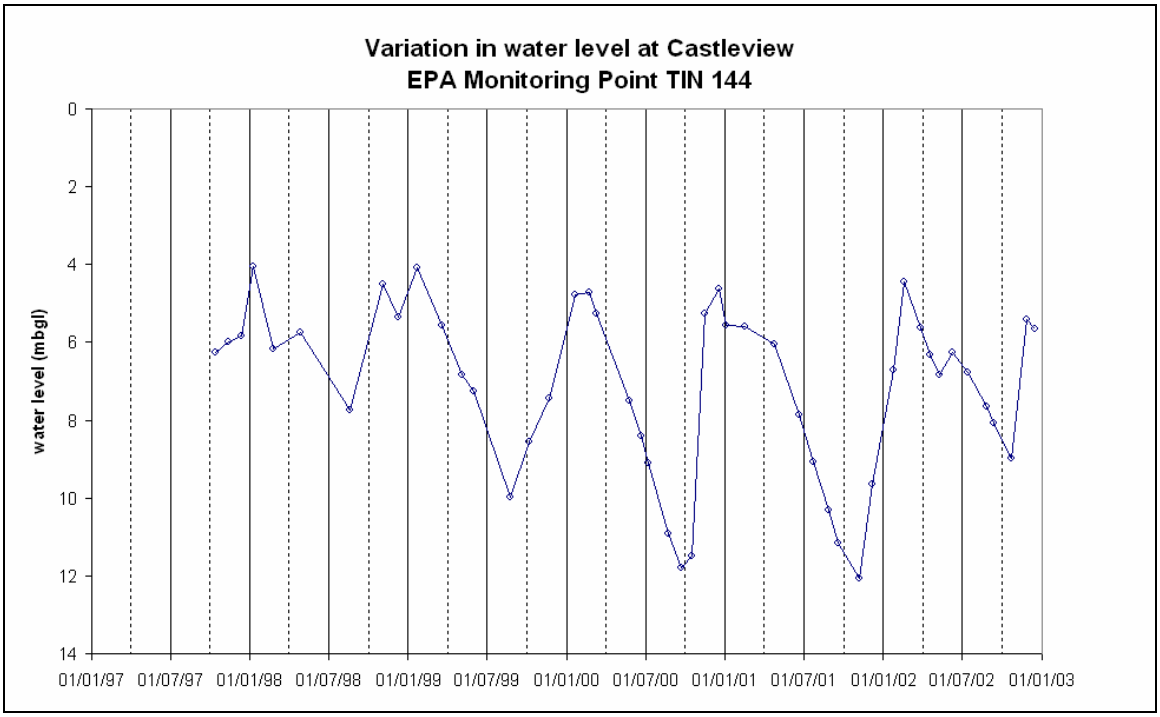
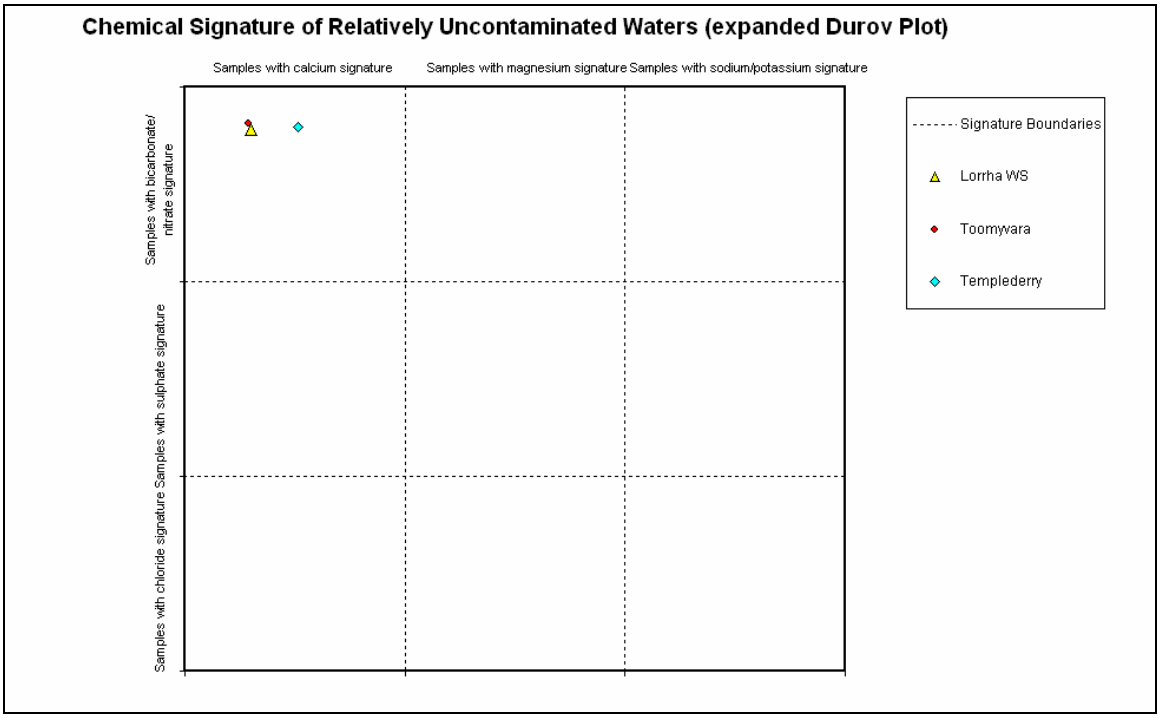
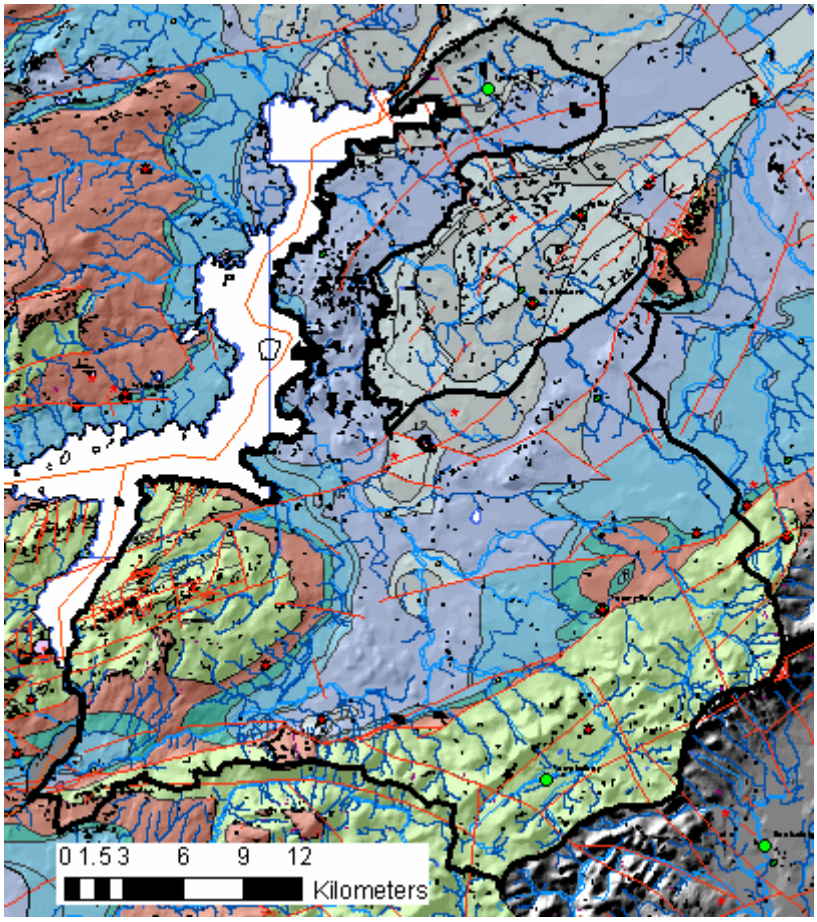


Figure 3: Hydrochemical signature



NB: *Lorrha WS abstracts water from Dinantian Upper Impure Limestones, Toomyvara WS from Devonian Old Red Sandstones, and Templederry WS from Silurian strata.*



Rock units in GWB

Rock unit name and code	Description	Rock unit group
Calp (CD)	Dark-grey to black limestone and shale	Dinantian Upper Impure Limestones
Lucan Formation (LU)	Dark limestone and shale (Calp)	Dinantian Upper Impure Limestones
Slevoir Formation (SV)	Muddy limestone & calcareous shale	Dinantian Upper Impure Limestones
Terryglass Formation	Grey calcarenitic & oolitic limestone	Dinantian Pure Bedded Limestones
Oldcourt Cherty Limestone Formation (OC)	Grey limestone and dark chert	Dinantian Pure Bedded Limestones
Waulsortian Limestones (WA)	Massive unbedded lime-mudstone	Dinantian Pure Unbedded Limestones
Ballysteen Formation (BA)	Fossiliferous dark-grey muddy limestone	Dinantian Lower Impure Limestones
Ballynash Member (BAbn)	Wavy-bedded cherty limestone, thin shale	Dinantian Lower Impure Limestones
Lower Limestone Shale (LLS)	Sandstone, mudstone & thin limestone	Dinantian (early) Sandstones, Shales and Limestones
Old Red Sandstone (undifferentiated) (ORS)	Red conglomerate, sandstone, mudstone	Devonian Old Red Sandstones
Cadamstown Formation (CW)	Pale & red sandstone, grit & claystone	Devonian Old Red Sandstones
Keeper Hill Formation (KH)	Pale and red sandstone, grit and claystone	Devonian Old Red Sandstones
Lacka Sandstone Formation	Conglomerate, sandstone and marl	Devonian Old Red Sandstones
Hollyford Formation (HF)	Greywacke, siltstone & grit	Silurian Metasediments and Volcanics
Broadford Formation (BF)	Fine to conglomeratic graded greywacke	Silurian Metasediments and Volcanics
Slieve Bernagh Formation (SB)	Fine and some coarser greywacke	Silurian Metasediments and Volcanics
Knockshigowna Formation (KG)	Greywacke sandstone, siltstone & slate	Silurian Metasediments and Volcanics
Fairy Hill Conglomerate Formation (FC)	Chert, sandstone & quartz conglomerate	Silurian Metasediments and Volcanics
Volcanics (undifferentiated)		Basalts & other Volcanic rocks