Ennis GWB: Summary of Initial Characterisation.

Note that parts of the western and northern GWB boundaries will alter. This description is written for the current status.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
27 - Fergus catchment Clare & Galway Co. Cos.	Rivers: Fergus, Castlelodge*, Castle, Millbrook, Ballygriffy, Poulacorry, Carheeny, Claureen or Inch, Clareen, Moyree, Druminshin, Craggaunboy, Shallee, Spancehill, Carrownanelly, Owenslieve. Loughs: Rockforest, Templebannagh, Coolreash, Ballyeighter, Ballinlisheen, Water, Muckanagh, Gorr, Turkenagh, Monana, Ballyogan, George, Ballynacaugh, Parkeighteragh, Moyree, Salannacutteen, Cullaun, Shandangan, Ballyportry, Inchiquin, Machreenfin, Boy, Knockaundoo, Nabrichoge, Garr, Ballyteige, Atedaun, Hennessy, Caheraphuca, Cragmoher, Dromore, Shanvally, Ballycullinan, Raha, Nagall, Reagh, Loughaunore, Curraderra, Namuck, Faunrusk, Keelaun, Cloonleen, Licknaun, Stonepark, Ballyallia, Cappagh, Cleggan, Ballymaley, Ballymachill, Loghaun, Curtaun, Ardamullivan, Carheeny, Cregg, Scarriff, Beg, Skehanagh, Girroga, Ardnamurry, Tooreen, Dromdoolaghty, Cloonawee, Castletown, Kilbreckin, Naslatty, Edenvale, Ballybeg, Killone, Laghtyshaughnessy, Loughannirra, Awock, Colman's, Doo, Aslaun. Fiddaun, Termon*, Bunny*, Travaun*, Loum*, Avatia*, Mannagh*, Briskeen*, Duff*, Skeardeen*, Castle*, Skaghard*, Aughrim*, Oona*, Awaddy*, Pollifern*, Monreagh*. *(Loughs and rivers marked with * may be in an area that becomes part of the Western RBD.)*	Ballyallia Lake (000014), Lough Cleggan (001331), Ballyogan Lough (000019), The East Burren Complex (001926), Ballycar Lough (000015), Ballycullinan Lake (000016), Fergus Estuary and Inner Shannon, North Shore (002048), Termon Lough (001321), Cahircalla Wood (001001), Moyree River (000057), Dromore Woods and Loughs (000032).	341 *(Note: this value will decrease when the RBD boundary is finalised.)*

Topography		The GWB is elongated in a N-S direction, and is about 34 km long. It is about 20 km wide in the northern part, narrowing to about 8 km in the south. In general, the ground is 10- 40 mAOD, and flat-lying to gently undulating. In the lower part of the GWB, the Fergus River has a very low gradient of 0.0009 (K.T. Cullen & Co., 2001). Ground elevation within the GWB ranges from sea level to just over 120 mAOD. The highest ground occurs along the western boundary, at the contact with the Namurian rocks of the Craggaunboy GWB. The northern limit of the GWB is marked by the change in slope to the upland karst area of the Burren GWB. This occurs at approximately 60 mAOD. Drainage is good, except in the very lowest areas next to the estuary. There are a number of sinking streams and rivers in the area.
Geology and Aquifers	Aquifer categories	The majority of the GWB comprises an **Rk^c**: Regionally important karstified aquifer dominated by conduit flow. Along the eastern margin of the GWB, there are narrow bands of **Lm:** Locally important aquifers which are generally moderately productive, and small areas of **Ll:** Locally important aquifers which are moderately productive only in local zones. There are small areas of **Ll** aquifer in the very south of the GWB also.
	Main aquifer lithologies	Dinantian Pure Bedded Limestones form most of the aquifers in the GWB. There are small areas of Dinantian Pure Unbedded Limestones in the east and very south of the GWB.
	Key structures	Gentle ENE-WSW trending anticlines and synclines dominate and there are numerous N-S cross faults. The degree of deformation decreases moving northwards through the county. Bedding dips at low angles of approximately 10-20^o. There is a deep-seated area of deformation – the Fergus Shear Zone, which trends in a narrow band from the Fergus Estuary NNE through Ennis towards Gort. The faulting is not easily recognised on the surface although there are subtle indications of it. The fracturing over most of the area is principally in the N-S and E-W directions and this controls zones of high permeability. Near the Fergus Shear Zone, fold axes are rotated slightly anticlockwise because of the lateral movement along the fault.
	Key properties	Karstification is ubiquitous in this GWB. As with most karstic systems, permeability and transmissivity data are very variable. Transmissivity in karstified aquifers with conduit flow can range from <1 m^2/d up to a few thousands of m^2/d. Due to groundwater being generally concentrated in conduits, very low yielding or failed wells can occur adjacent to very high yielding boreholes. Groundwater travel times through the conduits are rapid (up to 240 m/h in the Lower Fergus Valley) although it appears that flow in the east-west direction may be slower than that which is north-south. A dye-tracing study at the Pouladower spring indicates N-S travel times of 141-181m/h and E-W travel times of 67-149 m/h. Rapid velocities recorded for groundwater in this area imply flow through relatively sizeable conduits. Storativity in this aquifer is low (effective porosity ~1.5-2.5%). *(data sources: Rock Unit Group Aquifer Chapters, Clare GWPS and Source Reports, see references)*
	Thickness	The total succession of the Dinantian Pure Bedded Limestones are 100's of metres thick. However, most groundwater flows in an epikarstic layer a few metres thick and in a zone of interconnected solutionally-enlarged fissures and conduits below this. Work relating to the flooding around Ennis (K.T. Cullen & Co., 2001) suggests that "karst features are generally 10 metres below ground level." Deeper groundwater flow can occur in areas associated with faults. On Aughinish island, on the south side of the Shannon Estuary, there are very deep (~ 60 mbsl) conduits that relate to an ancient baselevel. There may be such conduits in this area, but they are not known; field work would be required to confirm their presence or otherwise.

<table>
<tr><td rowspan="4">Overlying Strata</td><td>Lithologies</td><td>[Information to be added at a later date]</td></tr>
<tr><td>Thickness</td><td>Subsoil thicknesses over the GWB range between 0 m and 15 m. Median subsoil thicknesses in the area, according to the GSI database, are approximately 7 m. Outcropping rock is extensive, particularly in the north of the GWB; the percentage area of outcrop decreases southwards. In the catchment area of the Drumcliff spring (northwest of Ennis), Deakin (2000) reports that drumlins are common.</td></tr>
<tr><td>% area aquifer near surface</td><td>[Information to be added at a later date]</td></tr>
<tr><td>Vulnerability</td><td>Vulnerability ranges from Extreme to Low. In the north of the GWB, vulnerability is predominantly Extreme with areas of High vulnerability. In the south of the GWB, vulnerability is mainly High, with areas of Extreme vulnerability. Across the whole GWB, there are NE-SW orientated small areas of Moderate vulnerability. In the very south of the GWB, adjacent to the estuary, there is an area of Low vulnerability.</td></tr>
<tr><td rowspan="2">Recharge</td><td>Main recharge mechanisms</td><td>Both point and diffuse recharge occur in this GWB. Swallow holes and collapse features provide the means for point recharge. Linear/ point recharge occurs along river reaches and where rivers sink underground. Surface water draining off the low permeability Namurian rocks to the west of this GWB sinks into the aquifers of this GWB. Diffuse recharge will occur over the entire GWB via rainfall percolating through the subsoil. The lack of surface drainage in several parts of this GWB indicates that potential recharge readily percolates into the groundwater system. In low-lying areas with a high water table in this highly transmissive aquifer, there can be some rejected recharge, i.e. a proportion of the effective rainfall is rejected due to lack of storage space in the aquifer. During winter, the ‘drainage system’ of the aquifer can be overwhelmed by the volume of rainfall, and flooding is common in the area around and to the south of Ennis.</td></tr>
<tr><td>Est. recharge rates</td><td>[Information to be added at a later date]</td></tr>
<tr><td rowspan="3">Discharge</td><td>Important springs and high yielding wells (m^3/d)</td><td>Elmvale Spring (27,600 m^3/d – low flow discharge)*
Aglish Spring (1296 m^3/d – mean flow)*
Shandangan Springs (4320 m^3/d – mean flow)*
Rinnamona Springs (1469 m^3/d – mean flow)*
Drumcliff WS Springs (15,000 m^3/d – safe yield est.)
Pouladower boreholes (6735 m^3/d)
Pouladower Spring (10,000 m^3/d – low flow, 62,400 m^3/d – high flow)*
Scarriff/ Tubber GWS (yield 218 m^3/d, abstraction unknown).

Note: springs marked with an * are proven to or are probably fed by groundwater originating in the upland karst area of the Burren GWB.</td></tr>
<tr><td>Main discharge mechanisms</td><td>The main discharges are to the streams and rivers crossing the body and to the large springs found within the body. In winter groundwater will discharge to the many turloughs found in the area.</td></tr>
<tr><td>Hydrochemical Signature</td><td>Groundwaters within this GWB have a calcium-bicarbonate hydrochemical signature. Hydrochemical analyses indicate that groundwater at Drumcliff WS spring is Moderately Hard (151–250 mg/l as $CaCO_3$), with alkalinities of 180–272 mg/l (as $CaCO_3$) and conductivities of 290–560 µS/cm. At the Pouladower spring groundwater is also Moderately Hard water (151–250 mg/l as $CaCO_3$), with alkalinities of 140–185 mg/l (as $CaCO_3$) and conductivities of 314–462 µS/cm. These values are all lower than would normally be expected from a typical limestone aquifer water, suggesting that the groundwater residence time in the carbonate environment is relatively short. At Drumcliff, the coefficient of variation of conductivity is high, and this suggests rapid response to recharge with flow in large conduits.

Water quality at Drumcliff fluctuates throughout the year with the poorer quality analyses being returned during the winter months and during periods of heavy rainfall. Colour, turbidity and iron have all exceeded the EC Drinking Water Directive maximum admissible concentrations (MAC) on occasion almost every year. Total coliforms and E. coli are also often present. Aluminium has also been found to exceed the MAC (max 0.31 mg/l Al; Sept 1994) although concentrations in the Groundwater Protection Scheme project analyses were less than the Guide Level in both cases. Nitrate concentrations are always low (<10 mg/l NO_3) and chloride levels range 20–45 mg/l Cl which are slightly higher than the background levels (10–20 mg/l) but are still not a cause for concern. At Pouladower spring, water quality is generally relatively good with low levels of chemical contaminant indicators such as chloride, nitrate and potassium. Bacteriological analyses however, often show the presence of faecal coliforms (E. coli), although this is typical in a karst spring, due to the presence of sinking streams, extreme vulnerabilities and rapid subsurface velocities. Colour is the main problem parameter with respect to the EU drinking water requirements and it often exceeds the MAC. Iron is not as much of a problem as it is at Drumcliff Spring and is seldom at a level which is cause for concern.

Elsewhere in the limestones in the catchment area, similar problems with E. coli., iron, colour and turbidity are reported (Coxon and Drew, 1998). The Namurian rocks to the west of the area, or the sandstones and overlying peat to the east, may be the origin of some of the suspended matter, although there may also be a contribution from ancient infilled unconsolidated deposits in karst depressions and/or the epikarst.</td></tr>
</table>

Groundwater Flow Paths	There is no intergranular porosity or permeability in the rocks of this GWB. Dissolutional enlargement of bedding planes and the N-S and E-W joints has created permeability. The GWB is highly karstified; localised high permeability zones give rise to rapid groundwater velocities. Groundwater is likely to flow in three main hydrogeological regimes: (1) an upper, shallow, highly karstified weathered zone, known as the epikarst, in which groundwater moves quickly, through solutionally enlarged conduits, in rapid response to recharge; (2) a deeper zone, where groundwater flows through interconnected, solutionally enlarged conduits and cave systems which are controlled by structural deformation (principally in the north-south and east-west directions) and bedrock lithologies. Groundwater flows along the less permeable, cherty units until it intersects a vertical fissure; and (3) a more dispersed slow groundwater flow component in smaller fractures and joints outside the main conduit systems. The epikarst is thought to be relatively modern, being formed after the last ice age, while the deeper karst is likely to be a remnant of not only recent solution, but also glacial and pre-glacial solution. All three groundwater flow regimes will be hydraulically connected in places with the degree of interconnection depending on the presence of less permeable bedrock units and the faults and joints associated with the structural deformation, particularly the north-south and east-west fault systems. K.T. Cullen & Co. (2001) concluded from drilling a programme in the Ennis area that karstification is generally limited to 10 m or less below the ground surface. Deakin (2001) considers that lithological variation in the form of the cherty Ballard Member of the pure limestone Burren Formation has a strong influence of the location of the Pouladower Spring, and also forms a barrier between this spring and the Drumcliff spring 2.5 km to the south. Runoff from the adjacent Namurian Craggaunboy and Lissycasey GWBs is acidic due to the shales and overlying peaty subsoils and it quickly dissolves the carbonate limestone rocks. This has resulted in a ring of swallow holes, sinks and large cave systems at the boundary between the two units where karstification processes are still active today. Numerous examples of this occur around the Burren where runoff from the Namurian rocks sinks underground into the limestones within a short distance. It is probable that a high proportion of the flow to the springs is in direct-route, underground, solutionally enlarged conduits in the limestones, with a somewhat lesser contribution from the smaller, more diffuse network of fissures and conduits in the surrounding rock. The proportion of flow travelling through large conduits will vary with different water levels: there is likely to be more flow in the diffuse fissures at lower water levels. Heavy rainfall can cause temporary high water levels in the shallow epikarst zones, and pulses of recharge can displace material which is normally relatively undisturbed. Bacteria are a common problem in karst areas as groundwater travel times are so short and vulnerability generally extreme. The fluctuations in colour and bacteria and, occasionally, iron, are all typical of a karst environment with a rapid 'flashy' response to rainfall events and short residence times. Despite the highly conduitised nature of the flow, a regional water table exists. The water table responds to the seasonal rainfall pattern. The seasonal variation is highest in the recharge areas and lower in the discharge areas. For example, at the Drumcarran More swallow hole, which links underground to the Pouladower springs, seasonal variation is 4.5 m. At a borehole near a spring in the same general area (Toberateaskan), the water level varies by about 0.5 m (K.T. Cullen & Co. Ltd.). At Corofin, next to the Fergus River between Inchiquin and Atedaun Loughs, the water table fluctuates from 1-3 mbgl over the year. In this low-relief area, the water table is generally not far beneath ground level. Over most of the GWB, groundwater levels are within 5 m of the surface. However, there are recorded water levels of between 10 and 27 mbgl. Some of these data can be explained by the location of the boreholes in relatively high areas. Some boreholes, however, are situated on or near river banks and indicate that there are areas within the aquifer isolated from the main conduits. In the main, boreholes with deep water levels have Poor or Moderate yields. Groundwater levels respond quickly to rainfall events due to the general absence of subsoil cover. In storm events, water levels in the swallow holes and other point recharge features back up and are higher than the true water table. This means that flooding in the Ennis area is generally not caused by the water table rising, but due to the inability of swallow holes to accept high recharge rates and transmit surface water into the subsurface. In the Ennis area, the regional flow pattern is towards the River Fergus. Groundwater contours elongate along the length of the tributaries, indicating high permeability zones along these features. Whilst the River Fergus is tidal in its lower reaches, the K.T. Cullen study (2001) indicated that, in the area near to the coast, there is no tidal effect on groundwater.

Groundwater & Surface water interactions	There is an effective hydraulic interconnection between groundwater and surface water in the karst limestone: much of the groundwater will spend at least some time on the surface and vice versa. The Fergus River, for example, although it now has two artificial stretches of channel, at one time did not have a continuous path to the sea. There are a number of sinks and rises along its course and, depending on climatic conditions, at any given site the river water may be recharging the groundwater system or vice versa. Rivers crossing the limestone aquifer have low summer baseflows, and flows are often flashy. The effects of heavy rainfall can be seen in the water quality at Drumcliff Spring within two days and this also highlights the sensitivity of the system. Particular effects of surface water on the groundwater system are seen in the limestone areas adjacent to the Upper Carboniferous Clare Shales. The shales, and overlying sandstone and shale units, are of much lower permeability than the limestones, and most of the effective rainfall runs off in surface water streams to the lower lying limestones. The shaly rocks give rise to highly acidic water that dissolves the carbonate rocks. This has resulted in a ring of swallow holes, sinks and large cave systems at the boundary between the two units where karstification processes are still active today. Surface water flowing off the Namurian rocks in the west and the Devonian Sandstone and Impure limestones in the east are in the zone of contribution to the Drumcliff and Pouladower springs. The surface water sinks into the karst groundwater system and potentially reaches the springs. There are several groundwater-dependent ecosystems within the GWB, including naturally eutrophic loughs, calcareous loughs and alkaline fens, and oligotrophic calcareous turloughs.
Conceptual model	• The terrain in this GWB is generally flat-lying to gently undulating. It is bounded to the south by the coast and estuary, to the west by the contact with the low transmissivity Namurian rocks of the Craggaunboy and Lissycasey GWBs, to the east by the lower transmissivity limestones of the Crusheen and Tulla – Newmarket-on-Fergus GWBs. The SE boundary is coincident with a surface water and implied groundwater divide. • The northern boundary of the GWB is complex: the western part of the northern boundary is delineated on the basis of topography, since the hydrogeological regime in the upland karst of the Burren GWB area is so different from the lowland karst system of this GWB. The 60 m elevation contour approximately coincides with the change in slope, so this is used to subdivide the karstic aquifer that runs from north to south Co. Clare. Groundwater cross-flows from the Burren GWB into this GWB. • The eastern part of the northern boundary is a surface water catchment divide that is also the RBD boundary. Groundwater flows to both the north and the south of this surface water divide via a fairly complicated system of underground conduits that link the loughs in this region. • The GWB predominantly comprises highly karstified limestones in which groundwater is transmitted through a network of conduits and an epikarstic zone. The E-W and N-S fracture network and the bedding planes have been enlarged by dissolution, resulting in a highly transmissive aquifer with rapid groundwater flow in which the more permeable zones have specific orientations. The aquifer has low storativity. • Both diffuse and point recharge occur. Recharge occurs diffusely through the subsoils or at rock outcrop. Point recharge occurs at the numerous swallow holes in the GWB and also along losing river stretches. Surface water running off the adjacent Craggaunboy and Lissycasey GWBs enters the karstic aquifer at the margin via swallow holes. • The aquifer is unconfined. The water table is generally shallow, within 5 m of ground surface and often within 1-2 m. Seasonal water table fluctuations vary, depending on the position within the groundwater system. In recharge areas, annual variation can be on the order of 5 m, whereas in discharge areas, water levels vary by only 0.5 m. • There is a complex and dynamic relationship between rainfall, river flows and groundwater movement, which is largely controlled by the distribution and throughput capacity of the network of karstic conduits. Groundwater in this body generally shows a rapid response to recharge and groundwater velocities in the subsurface can be rapid. • Due to the strong focussing of flow in subsurface karst conduits, groundwater discharges to several large springs rather than many small springs. Groundwater also discharges to the rivers and streams crossing the GWB and, in winter, to the turloughs. In the north of the GWB, some loughs do not have surface water outlets or inlets, but are connected to other surface water bodies via a complicated karst network. For example, Termon Lough may drain underground to the Western RBD. • Rivers are both losing and gaining, depending upon the location within the system, and also upon the time of year. In late summer, rivers may be losing, but gaining in the rest of the year. • The surface water and groundwater systems are well interconnected throughout the catchment. Much of the groundwater will spend at least some time on the surface and vice versa. Flooding in low-lying areas is a problem. Severe flooding occurs because, during intense rainfall events, swallow holes cannot accept high recharge rates and transmit surface water into the subsurface; the degree of flooding at the swallow holes is more-or-less independent of the level of the water table. K.T. Cullen & Co. (2001) conclude that the level of flooding at swallow holes in the Ennis area is a function of the intensity and duration of the rainfall event, the topography around the swallow hole, and the carrying capacity of the conduit. • Surface water flowing off the Namurian rocks in the west and the Devonian Sandstone and Impure limestones in the east are in the Zone of Contribution to and Source Protection Areas of the Drumcliff and Pouladower springs. The surface water sinks into the karst groundwater system and potentially reaches the springs.
Attachments	Groundwater hydrograph (Figure 1), Hydrochemical signature (Figure 2).
Instrumentation	Stream gauges: 27002, 27003, 27004, 27009, 27021, 27023, 27024, 27028, 27061, 27064, 27066, 27067, 27070, 27091, 27092. EPA Water Level Monitoring boreholes: Corofin (CLA038). EPA Representative Monitoring boreholes: Ennis WS (CLA 9), Tubber GWS (CLA 21).

Information Sources	Coxon, C. and Drew, D. (1998) Interaction of Surface Water and Groundwater in Irish Karst Areas: Implications for Water Resource Management. *Proceedings of IAH Congress*, Las Vegas, Sept. 1998. Deakin, J. (2000) Ennis Public Supply – Drumcliff Spring, Co. Clare. Geological Survey of Ireland Report to Clare Co. Co., 13 pp. Deakin, J. (2000) Ennis Public Supply – Pouladower Spring, Co. Clare. Geological Survey of Ireland Report to Clare Co. Co., 13 pp. Deakin, J. and Daly, D. (2000) *County Clare Groundwater Protection Scheme.* Geological Survey of Ireland Report to Clare Co. Co., 67 pp. K.T. Cullen & Co. (2001) *Ennis Main Drainage and Flooding Study: Preliminary Report.* Volume III, Part II, Hydrogeology Final Report. Report for Ennis U.D.C. 51 pp. plus figures and appendices. Aquifer chapters: Dinantian Pure Bedded Limestones; Dinantian Pure Unbedded Limestones.
Disclaimer	Note that all calculations and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae

Figure 1: Groundwater hydrograph

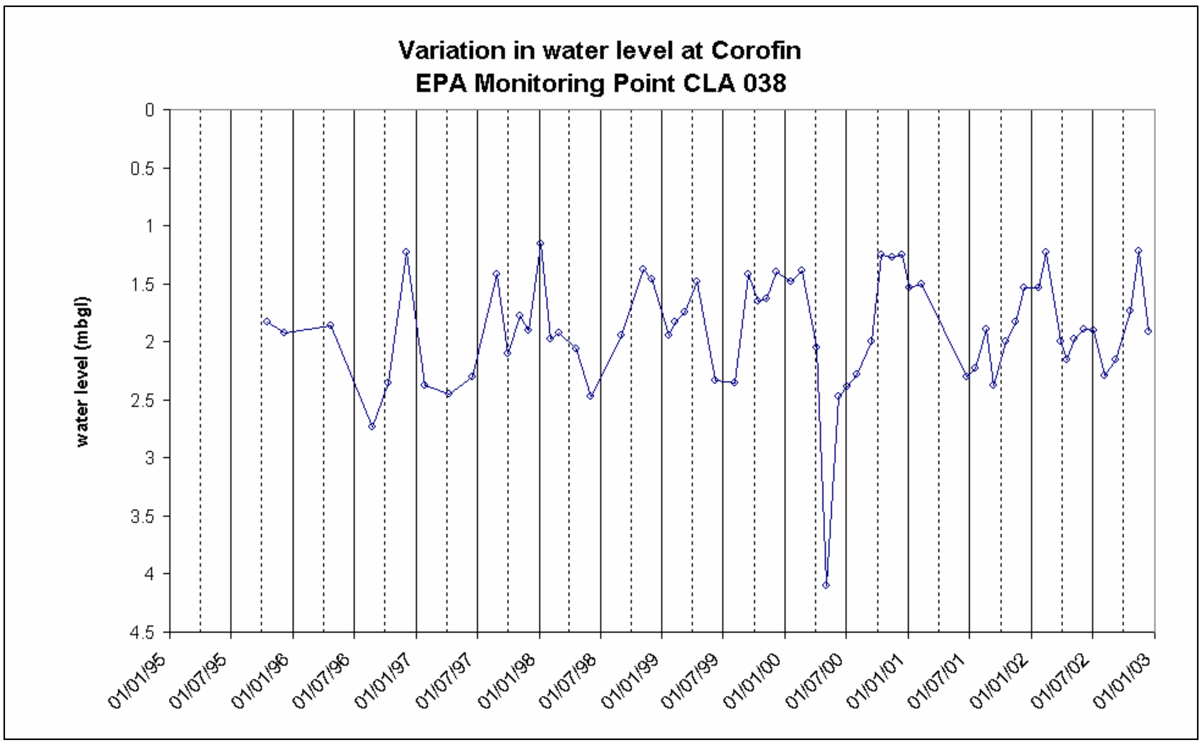
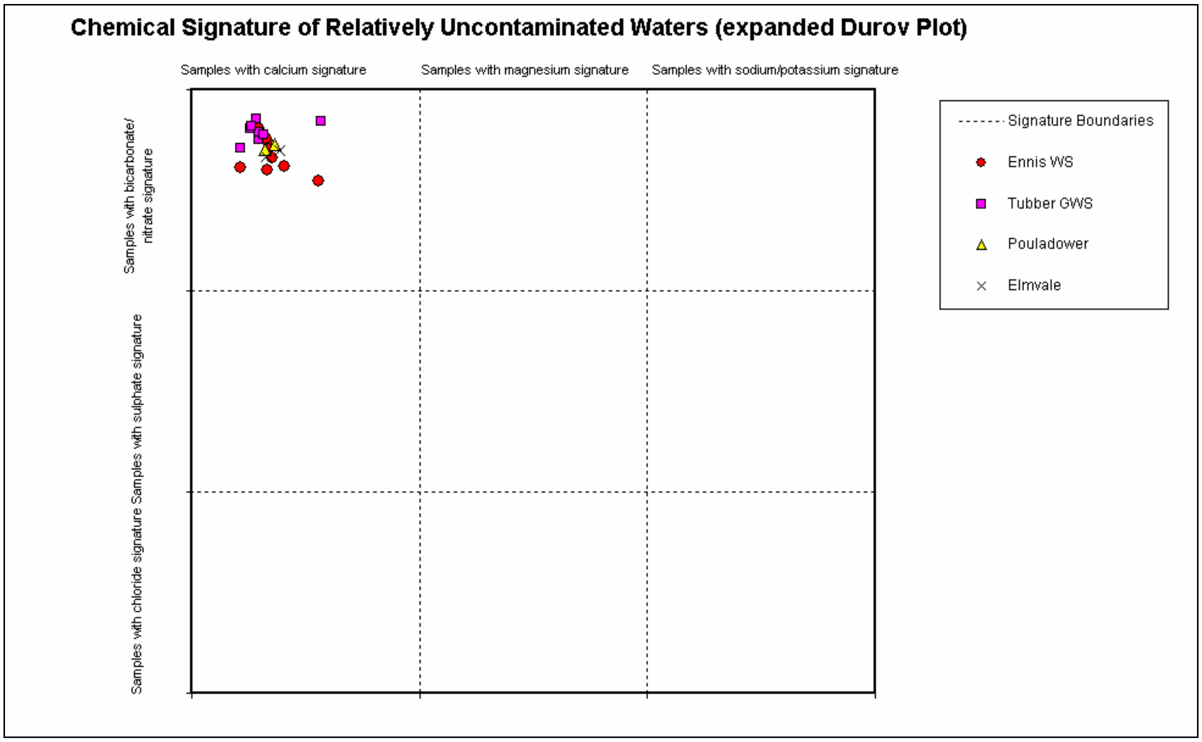
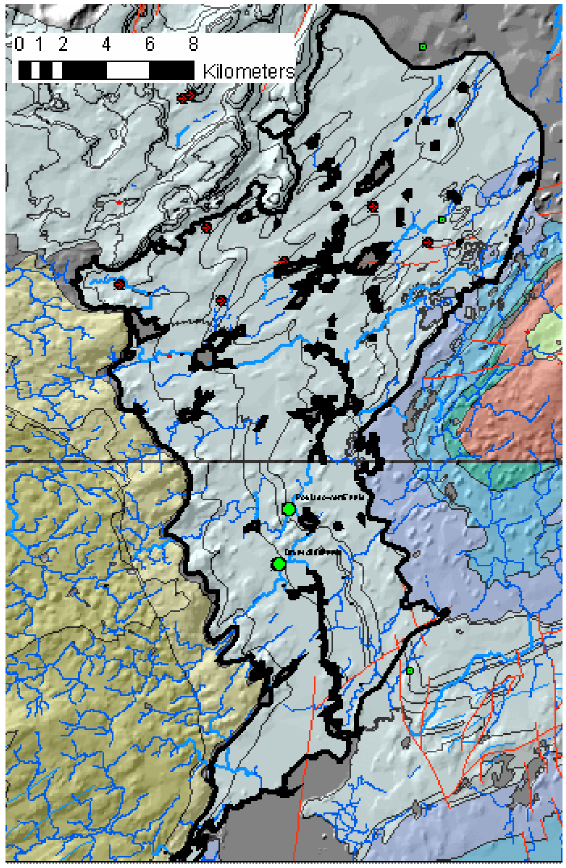


Figure 2: Hydrochemical signature





Rock units in GWB

Rock unit name and code	Description	Rock unit group
Ballycar Formation (BC)	Dark grey fine cherty limestone	Dinantian Pure Bedded Limestones
Burren Formation (BU)	Pale grey clean skeletal limestone	Dinantian Pure Bedded Limestones
Aillwee member (lower) (BUal)	bedded & massive fossiliferous limestone	Dinantian Pure Bedded Limestones
Aillwee & Maumcaha Members (BUam)	Massive to thick bedded clean limestone	Dinantian Pure Bedded Limestones
Aillwee Member (upper) (BUau)	fossiliferous limestone with Davidsonia	Dinantian Pure Bedded Limestones
Aillwee Member (BUaw)	fossiliferous limestone with claybands	Dinantian Pure Bedded Limestones
Ballard Member (BUbd)	Fine-grained dark limestone with cherts	Dinantian Pure Bedded Limestones
Hawkhill Member (BUhh)	peloidal limestone with chert	Dinantian Pure Bedded Limestones
Maumcaha Member (BUmc)	massive limestone sparsely fossiliferous	Dinantian Pure Bedded Limestones
Oolitic limestone (oo)		Dinantian Pure Bedded Limestones
Slievenaglasha Formation (SL)	Cherty limestone, crinoidal intervals	Dinantian Pure Bedded Limestones
Tubber Formation (TU)	Crinoidal & cherty limestone & dolomite	Dinantian Pure Bedded Limestones
Cregmahon Member (TUcm)	Crinoidal limestone with cherts	Dinantian Pure Bedded Limestones
Castlequarter Member (TUcq)	monotonous limestone and dolomite	Dinantian Pure Bedded Limestones
Fiddaun Member (TUfd)	peloidal limestone	Dinantian Pure Bedded Limestones
Newtown Member (TUnt)	cherty limestone	Dinantian Pure Bedded Limestones
Cregmahon Member (TUcm)		Dinantian Pure Bedded Limestones
Visean Limestones (undifferentiated) (VIS)	Undifferentiated limestone	Dinantian Pure Bedded Limestones
Mudbank limestone (mk)		Dinantian Pure Unbedded Limestones
Slievenaglasha Formation & Mudbank limestone (mkSL)	Cherty limestone, crinoidal intervals	Dinantian Pure Unbedded Limestones
Waulsortian Limestones (WA)	Massive unbedded lime-mudstone	Dinantian Pure Unbedded Limestones