Clara GWB: Summary of Initial Characterisation.

<table>
<tr><th colspan="2">Hydrometric Area
Local Authority</th><th>Associated surface water features</th><th>Associated terrestrial ecosystem(s)</th><th>Area (km²)</th></tr>
<tr><td colspan="2">25 - Brosna catchment
Offaly and Westmeath Co. Co.'s</td><td>Rivers: Brosna, Monaghanstown, Gageborough, Silver, Clodiagh, Suck, Blackwater, Tullamore, Shannon, Little, Boora, Island, Cloghatanny.
Streams: Dysart, Ballynagreine, Syonan Castle, Moate, Durrow Abby, Pollagh, Derrycooly.
Canals: Lacy's, Supply.
Loughs: Slanestown, Mount Dalton, Ennell, Atallan, Moylisker, Yellow, Fin, Nanag, Ballinderry, Cuith, Roe, Ballykilmore.</td><td>Walshestown Fen (001731), Fin Lough (Offaly) (00576), Lough Nanag Esker (000910), Lough Coura (000909), Ferbane Bog (000575), Moyclare Bog (000581), Clara Bog (000572), Lough Ennell (000685), Cloncrow Bog (New Forest) (000677), River Shannon Callows (000216).</td><td>712</td></tr>
<tr><td>Topography</td><td colspan="4">The groundwater body is roughly rectangular, with the long axis orientated NE-SW, in line with the structural grain. The outline is very irregular, and two other GWBs (Ferbane and Woodfield Bridge) are completely contained within it. Within this large GWB, the topography ranges between flat-lying through undulating to hilly. Elevation within the GWB ranges from less than 40 mAOD next to the Lower River Shannon in the west of the GWB, to 200 mAOD at Knocastia in the north of the GWB. Only small areas along the NW and NE boundaries are over 120 mAOD. Ground elevation generally decreases to the southwest. In the SW half of the GWB, elevations are typically 50-70 mAOD or less. In the NW, elevations range from 70-110 mAOD. Rivers follow the topography: tributaries to the River Brosna generally flowing NW and SW to the River Brosna, which flows southeast to the Lower River Shannon.</td></tr>
<tr><td rowspan="5">Geology and Aquifers</td><td>Aquifer categories</td><td colspan="3">Nearly all aquifers within the GWB are Ll: Locally important aquifers which are moderately productive only in local zones. There are small strips of diffusely karstified limestone in the NW of the GWB that are too small to be classified as 'Regionally Important'. The very small area of Volcanic rocks is currently classified as an Lm: Locally important aquifer which is generally moderately productive.</td></tr>
<tr><td>Main aquifer lithologies</td><td colspan="3">Dinantian Pure Unbedded Limestones and Dinantian Upper Impure Limestones are the major rock unit groups within the GWB. Dinantian Lower Impure Limestones and Dinantian (early) Sandstones, Shales and Limestones are also present in the south, whilst there are small areas of Dinantian Pure Bedded Limestone in the northwest. There are very small areas of Devonian Old Red Sandstone along the NW border, and tiny areas of Volcanic rocks at the bottom of the NE boundary.</td></tr>
<tr><td>Key structures</td><td colspan="3">The major structures affecting the distribution of rock types are large folds and major faults. A large anticlinal fold orientated NE-SW occurs down the centre of the southern half of the GWB. The higher transmissivity rocks in the core of this fold form the Ferbane GWB, which is completely surrounded by lower transmissivity rock units of this GWB. The Dinantian (early) Sandstones, Shales and Limestones, Lower Impure Limestones and Pure Unbedded Limestones radiate outwards from the elongated core. The Upper Impure Limestones occur in small areas in the south, but are predominant in the northern half of the GWB, where a major syncline in the same NE-SW orientation has these rocks in its core, on either side of which are Pure Unedded Limestones. Major NW-SE normal faults cross-cut the fold axes almost at right angles. There are also major ENE-WSW (including the Ferbane fault) WNW-ESE faults crossing the GWB.</td></tr>
<tr><td>Key properties</td><td colspan="3">A pumping test in the Dinantian Pure Unbedded Limestones at Shinrone, to the south of this GWB, indicated a transmissivity of approximately 27 m^2/d. Most of the flow was through a fault zone at more than 50 mbgl. 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 of transmissivities for this rock unit group in this area. A pumping test at Lorrha WS in the nearby Nenagh GWB indicates an aquifer permeability of 5 m/d in the Upper Impure Limestones. The borehole there intercepts a large fissure, so 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. The Banagher WS, abstracting from the same rock unit group in the Banagher GWB, has similar characteristics: a single large fault zone supplies the source, resulting in a transmissivity estimate of 45-70 m^2/d, but a thin flowing interval permeability estimate of 20 m/d. 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. The Dinantian (early) Sandstones, Limestones and Shales rock unit group that confines the sandstones of this GWB have permeabilities of $< 10^{-2}$ m/d. The small areas of karstified Pure Bedded Limestones will have relatively high transmissivities. Within all rock units, storativities are low. Groundwater gradients in the generally low-lying areas will be on the order of 0.002 to 0.02, but may be slightly steeper in the highest areas of the GWB.
(data sources: Rock Unit Group Aquifer Chapters, GWPS Reports, Source reports, see references)</td></tr>
<tr><td>Thickness</td><td colspan="3">The Dinantian Pure Unbedded Limestones, and the Dinantian Lower and Upper Impure Limestone aquifers are more than several hundreds of metres thick. However, permeability tends to decrease rapidly with depth. Most flow occurs in the upper ≤ 15 m, in the zone that comprises a weathered layer and a connected fracture zone below this, although deeper flows may occur along faults or significant fractures, or occasionally bedding-parallel dissolution planes within the Pure Unbedded Limestones. In the Pure Unbedded Limestones east of Lough Derg, epikarst has been observed that has a thickness of up to 1-2 m. There is likely to be epikarst in the region of this GWB also. The maximum thickness of Dinantian (early) Sandstones, Shales and Limestones is less than 100 m. Again, groundwater flow is confined to the top 15 m in the main. The Pure Bedded Limestones will have an epikarstic layer, below which there is a diffusely-karstified network of fissures and conduits down to around 30 m below rock head.</td></tr>
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Overlying Strata	Lithologies	*[Information to be added at a later date]*
	Thickness	Depth to bedrock varies significantly over this large GWB. Parts of this area were near the ice margin during the Ice Age, hence wide variation is no surprise. In general, subsoil is less than approximately 12 m thick, and most frequently is less than 6 m. However, there are very deep subsoils recorded across the GWB. In the thin strip between Ballydangan and Ballycumber, subsoil thicknesses of 15-58 m are recorded where esker gravels and probably outwash fans are mapped. In the NE part of the GWB, depth to rock records of up to 86 mbgl are recorded, with some very deep subsoils adjacent to relatively shallow subsoils. It is not clear what the influence on subsoil thickness is in this area – thickness variations may be associated with fault zones and breccia. There are very few, isolated outcrops in the GWB, which mainly occur on slightly elevated ground.
	% area aquifer near surface	*[Information to be added at a later date]*
	Vulnerability	*[Information to be added at a later date]*
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 one known swallow hole in the area accepts point recharge from surface waters.
	Est. recharge rates	*[Information to be added at a later date]*
Discharge	Important springs and high yielding wells (m^3/d)	There are no High (> 2,160 m^3/d) yielding springs in this GWB. The Moate WS spring has an Intermediate (430 m^3/d < yield < 2,160 m^3/d) yield of 1136 m^3/d (EPA database). Other known springs in the GWB have Low (< 430 m^3/d) yields. There are no Excellent (> 400 m^3/d) yielding wells known in the GWB. Two boreholes with Good yields (100 m^3/d < yield < 400 m^3/d): Cloghan WS (170 m^3/d – EPA database; not used as of 1999 information – GSI database); Bopar/ BOPA Meat Products Ltd (Clara) (up to 218 m^3/d – GSI database). Other boreholes within the GWB abstract less than 100 m^3/d; it is not known if they are capable of yielding more. *[More information may be added at a later date]*
	Main discharge mechanisms	Groundwater discharges to gaining streams and rivers crossing the GWB, and to the small springs within the GWB. Three specific dry weather flows on the River Brosna and Lough Ennell tributaries that cross Pure Unbedded Limestones and Upper Impure Limestones range from 0.38-83 l/s/km^2. These values indicate that the aquifers have low storativity and cannot sustain summer baseflows. There are some very high specific DWFs computed for stations within this GWB (1.91-3.7 l/s/km^2) – in these rivers, baseflows are sustained by high porosity gravel deposits.
	Hydrochemical Signature	Data for this GWB are limited. Groundwaters from aquifers within this groundwater body have a calcium-bicarbonate signature. By analogy with nearby similar GWBs, groundwaters are Very Hard (typically ranging between 380–450 mg/l as $CaCO_3$), with high electrical conductivities (650–800 µS/cm). Alkalinity is also high, but less than total hardness (250-370 mg/l as $CaCO_3$). These values are typical of groundwater from limestone rocks and typical of groundwater across Co. Offaly (Cronin, 1999). pH is generally neutral. At springs, or other systems where throughput is rapid, groundwaters have lower dissolved solids. 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 in the Lower Impure Limestones (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. 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). Groundwaters in the overlying gravel deposits and gravel aquifers have similar compositions to pure limestone bedrock aquifers, but may contain less total dissolved solids if throughput is rapid.

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. Zones of high permeability can be encountered near fault zones and in areas of intensive fracturing. There may be limited karstification in the Upper Impure Limestones in the slightly more pure limestone zones. The Pure Unbedded Limestones may also have had their transmissivity enhanced further by dissolution of calcium carbonate along fracture, joint and bedding planes. There is probably an epikarstic layer of 1-2 m at the top of the pure unbedded limestones. 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. Significant yields can be encountered where fault zones are intercepted by boreholes. Often, these flowing intervals behave in a confined way and, when the water level falls beneath the inflow level, yields decrease and drawdowns increase rapidly. Generally speaking, these rocks are unconfined where subsoils are thin or gravelly. Groundwater may be locally confined where it flows beneath the low permeability bases of the raised bogs as, for example, at Clara Bog (NHA 000572). The Dinantian (early) Sandstones, Limestones and Shales rock unit of this GWB itself confines the partly-underlying Ferbane GWB aquifer. Examination of data in the GSI well database shows that water levels are shallow, usually less than 10 m below surface. In the low-lying areas underlain by impure limestones, groundwater levels are between 2 and 7 mbgl. Next to the rivers, water levels will be closer to ground level. Water levels in the Lower Impure Limestones near Moate vary by up to 4 m annually and generally range between 3-6 mbgl (Figure 1). This relatively large variation indicates low aquifer storage. In the bedrock aquifers, groundwater flow paths are generally short, on the order of 30-300 m, with groundwater discharging to the streams and rivers that traverse the aquifer and to small springs. Local groundwater flows are determined by the local topography. There is no regional flow system in these aquifers. There are several locally important ***potential*** gravel aquifers and gravelly deposits overlying this bedrock GWB: The most extensive of these are the mainly unsaturated esker gravels between Ballydangan and Ballynahown in the west, the potential Little River Gravel Aquifer in the SW, The Ballycumber-Clara potential Gravel Aquifer in the centre of the GWB, and the potential Horseleap Gravels in the north of the GWB.
Groundwater & Surface water interactions	The streams and rivers crossing the aquifer are generally gaining, and groundwater comes to surface as springs. Due to the shallow groundwater flow in this aquifer the groundwater and surface waters are closely linked. There are several fens and wetlands in the area that are dependent on groundwater. For example, Ferbane Bog and Moyclare Bogs have quaking areas and mineralised flushes. Cloncrow Bog (New Forest) has a small nutrient-rich flush on the bog. At the River Shannon Callows, there is a 'petrifying stream' with associated species-rich calcareous flush. Fin Lough is a shallow calcium rich-lake with species-rich alkaline fens and swamp woodland. Lough Ennell is a marl lake with an alkaline fen. At Lough Nanag Esker there is both dry and wet grassland. Lough Nanag is vulnerable to drainage and eutrophication. Lough Coura is a small in-filled lake that has evolved from lake to dry fen. The interest lies in this very well-documented succession, the situation which may rely at least to some extent on groundwater levels. Walshestown Fen is groundwater dependent.
Conceptual model	• The GWB is roughly rectangular and orientated NE-SW. Surface water catchment divides define the SW, NW and NE edges of the GWB, but part of the NW edge coincides with the Lower River Shannon. It is bounded on SE by the contact between the low transmissivity rock units of this GWB and the karstified Pure Bedded Limestones of the adjacent Tullamore GWB. Topography ranges from low-lying to hilly. • The GWB is comprised of generally low transmissivity and storativity rocks. Where gravel deposits or potential gravel aquifers overlie the bedrock aquifer, this can contribute to the storage. • The rocks of this GWB confine the high transmissivity sandstone aquifer of the Ferbane GWB, which this GWB encircles. • Flow occurs along fractures, joints and major faults. Flows in the aquifer are typically concentrated in a thin approximately 15 m zone at the top of the rock although deeper groundwater flow in hydraulically isolated fault zones can occur. Within the pure limestones, transmissivity may have been enhanced further by dissolution of calcium carbonate along fracture and bedding planes. An epikarstic layer of 1-2 m is likely to exist at the top of the Pure Unbedded Limestones. Limited karstification has taken place in the Upper Impure Limestones. • Diffuse recharge occurs across most of the GWB (except for areas overlain by bogs), but particularly where rock outcrops or where subsoils are thin. Where the water table is close to the surface potential recharge may be rejected. • The aquifers within the GWB are generally unconfined. Areas where confined conditions occur include beneath the raised bogs (e.g. Clara Bog) and in the deeper, isolated fault zones. Depending upon the local topography, the water table can vary between a few metres up to 15 m below ground surface. Flow path lengths are short (≤ 30-300 m). Groundwater flows to the surface water bodies and to springs, with local flow directions controlled by local topography. A regional flow system does not exist. • The Dinantian (early) Sandstones, Limestones and Shales rock unit of this GWB confine the partly-underlying Ferbane GWB aquifer. • 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. Groundwater and surface water interactions require special attention where terrestrial ecosystems are dependant on a sustainable balance between the two. • There are several gravel aquifers or potential gravel aquifers overlying this bedrock GWB: The most extensive of these are the potential Little River Gravel Aquifer in the SW, the Ballycumber-Clara potential Gravel Aquifer in the centre of the GWB, and the potential Horseleap Gravels in the north of the GWB.

Attachments	Groundwater hydrograph (Figure 1), Hydrochemical signature (Figure 2).
Instrumentation	Stream gauges: 07047, 25011*, 25013, 25014*, 25015*, 25018*, 25032, 25034*, 25035, 25037, 25041*, 25046, 25050*, 25052, 25085, 25107, 25108, 25124*, 25130, 25133, 25135, 25136, 25137, 25138, 25140, 25142, 25143, 25146, 25204, 25215, 25217, 25221, 25222, 25224, 25324, 25326, 25329, 26033, 26153, 26253. *(Stations marked with * have specific dry weather flows calculated.)* EPA Water Level Monitoring boreholes: Moate (WES 030) EPA Representative Monitoring points: Ferbane/Belmont WS (OFF 12), Ballinderry (WES 09).
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. Cronin, C., Daly, D. (1999). *An Assessment of the Quality of Public and Group Scheme Groundwater Supplies in County Offaly*. Geological Survey of Ireland report to Offaly County Council. 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. Kelly, C. *Shinrone WS – Groundwater Source Protection Zones*. Geological Survey of Ireland Report to Offaly Co. Co., in preparation. Motherway, K., Hunter Williams, N. & Wright, G.R. (2002) *Lorrha WS, Groundwater Source Protection Zones*. Geological Survey of Ireland, 15 pp. Aquifer chapters: Dinantian Upper Impure Limestones; Dinantian Pure Unbedded Limestones; Dinantian Lower Impure Limestones; Dinantian (early) Sandstones, Limestones and Shales; Dinantian Pure Bedded Limestones; Devonian Old Red Sandstones; Basalts and other Volcanic rocks.
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

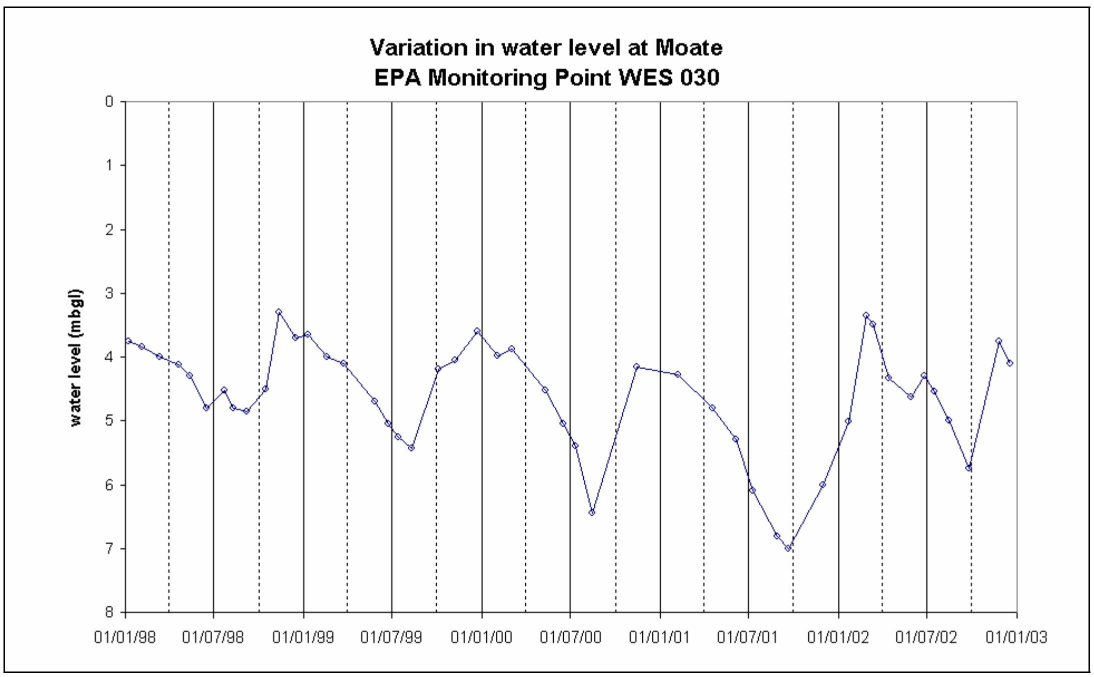

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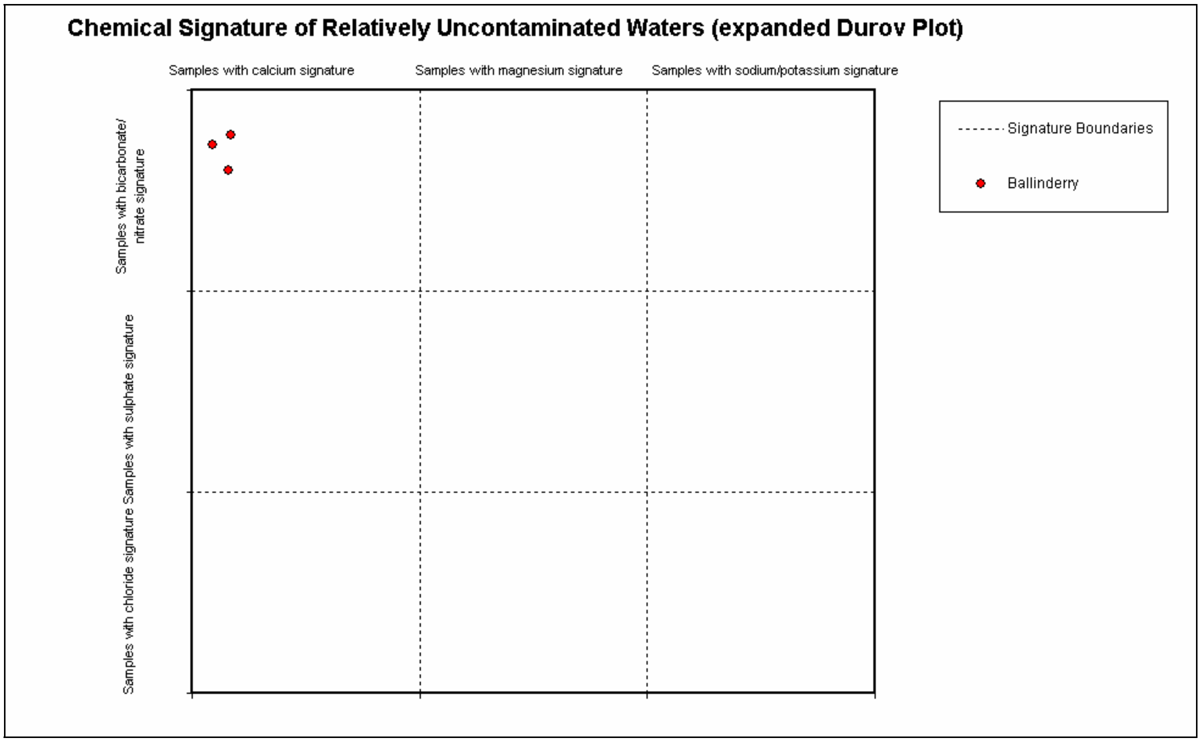
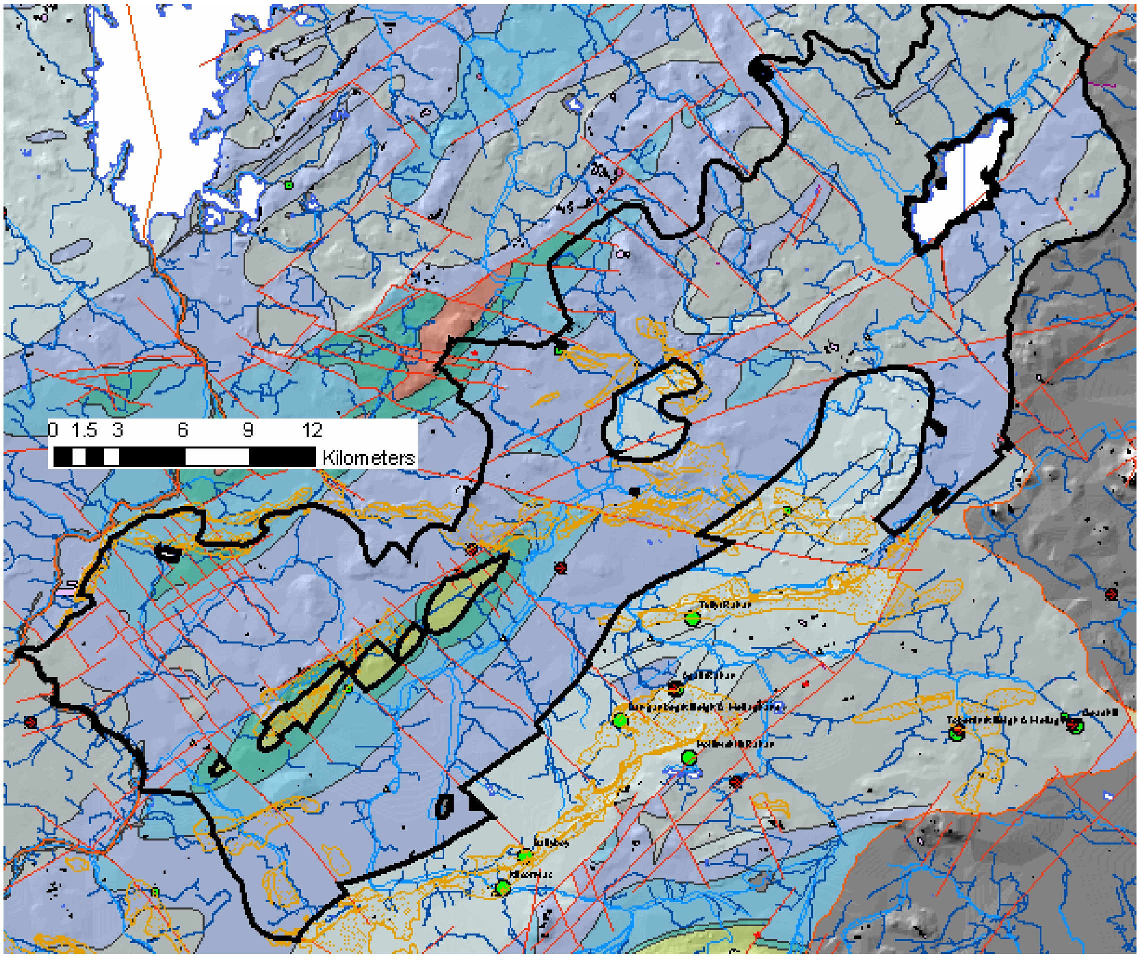
Figure 2: Hydrochemical signature



NB: Ballinderry sampling point is in Dinantian Pure Unbedded Limestones.



Rock units in GWB

Rock unit name and code	Description	Rock unit group
Waulsortian Limestones (WA)	Massive unbedded lime-mudstone	Dinantian Pure Unbedded Limestones
Lucan Formation (LU)	Dark limestone & shale (`Calp)	Dinantian Upper Impure Limestones
Ballysteen Formation (BA)	Dark muddy limestone, shale	Dinantian Lower Impure Limestones
Navan Group (NAV)	Limestone, sandstone, mudstone	Dinantian (early) Sandstones, Shales and Limestones
Allenwood Formation (AW)	Thick-bedded limestone, locally peloidal	Dinantian Pure Bedded Limestones
Old Red Sandstone (undifferentiated) (ORS)	Red conglomerate, sandstone, mudstone	Devonian Old Red Sandstones
Agglomerate (Va)		Basalts & other Volcanic rocks
Waulsortian Limestones (WA)	Massive unbedded lime-mudstone	Dinantian Pure Unbedded Limestones
Lucan Formation (LU)	Dark limestone & shale (`Calp)	Dinantian Upper Impure Limestones