Burren 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 Co. Co.	Rivers: Castletown. Loughs: Gortboyheen, Turloughnagullaun, Water, Aleenaun, Poulnacloneen.	The East Burren Complex (001926), Black Head-Poulsallagh Complex (000020), Turloughnagullaun (000071).	171 *(Note: this value will change when RBD boundary is finalised.)*

Topography		The GWB is roughly square, albeit with an irregular outline. Ground elevation within the GWB ranges from 20 mAOD to over 310 mAOD. However, the terrain is mainly an upland plateau, with elevations typically greater than 100 m. The highest ground (> 200 mAOD) is found mainly in the north of the GWB: on the NW boundary of the GWB at Poulnacapple and Ailwee Hill, around Slievecarran and Gortaclare Mountain on the northern boundary, and Slievenaglasha in the NE. Between the plateau areas, slopes are steep in this dissected upland karst terrain. Elevation within the GWB generally decreases southwards, although the lowest elevations are found along the northern border of the GWB. Surface drainage over the limestones is almost absent; there are a few short stretches of sinking streams and very few loughs, which generally have neither inlets nor outlets. Land drainage is poor over the Namurian rocks in the western upland part of 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 western margin of the GWB, there are **Pu:** Poor aquifers which are generally unproductive and **Ll:** Locally important aquifers which are moderately productive only in local zones.
	Main aquifer lithologies	Dinantian Pure Bedded Limestones form most of the aquifer in the GWB. There are small areas of Namurian Shales and Namurian Sandstones along parts of the western GWB boundary.
	Key structures	Gentle ENE-WSW trending folds have gently flexed the strata in this GWB. Bedding dips at low angles of less than 5^o. Bedding dips are to the south overall, although small folds in the south of the GWB cause northwards dips also. There are NNE-SSW cross faults that have exerted a control on the locations and orientations of the valleys. Veins striking N-S cut across many beds to form vertically persistent, non-stratabound arrays. They are strongly clustered, and were formed at depth. Their calcite fill has subsequently been weathered-out in many cases. The joints do not cross bed boundaries, and have regular spacings that scale with bed thickness (Gillespie *et al.*, 2001). Joint orientations are roughly N-S and E-W. The joints formed during uplift, under conditions low-differential stress conditions. The N-S and E-W fracture and vein directions control the directions of the zones of high permeability. Solutionally-enlarged bed boundaries or stylolites (horizontal pressure solution discontinuities) form sub-horizontal flow paths. Low permeability cherty or clayey layers in the succession can inhibit vertical flow.
	Key properties	Karstification is ubiquitous in this GWB – it is the classical upland karst area in Ireland, and also internationally important. 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. Tidal regression analysis at Ballyvaughn WS, just to the north of this GWB, indicates transmissivities of about 3,000 m^2/d. Groundwater travel times through the conduits are rapid. Drew and Daly (1993) report underground flow rates of 10-100 m/h in the area draining to the Elmvale spring that is situated just to the south of this GWB, in the Ennis GWB. Rapid velocities recorded for groundwater in this area imply flow through relatively sizeable conduits. Flow velocities increase by up to fourfold in flood and halve under very low flow conditions (Drew and Daly, 1993). There are many conduits draining the Burren that are more than 1 m in height, and can be up to around 5 m (G. Mullan (Ed.), 2003). In the Namurian rocks, transmissivity is low (typically <10 m^2/d in the Sandstones and significantly less in the Shales). Storativity in all aquifers 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 is 100's of metres thick. Most groundwater flows in an epikarstic layer a few metres thick and then in a zone of interconnected solutionally-enlarged fissures and conduits below this. Due to the elevation of the area, the conduits occur over >300 m (vertically) of the limestone aquifer, and also occur at elevations below present day base level. In the Namurian Shales, groundwater flows in the fractured and weathered top few metres of the rock. This shallow flow is also typical of the Namurian Sandstones, although significantly deeper confined flows are also known.
Overlying Strata	Lithologies	*[Information to be added at a later date]*
	Thickness	Subsoil is absent over much of the GWB, exposing extensive areas of karstic limestone pavement. In the west, over the Namurian rocks, subsoil thicknesses are typically between 3-9 m.
	% area aquifer near surface	*[Information to be added at a later date]*
	Vulnerability	Vulnerability is Extreme nearly everywhere. The exceptions are relatively small areas along some of the dry valleys near Castletown, in the NE of the GWB. Here, vulnerability is High and Moderate. Over the Namurian strata in the west of the GWB, vulnerability ranges from Low to Extreme.

Recharge	Main recharge mechanisms	Both point and diffuse recharge occur in this GWB. Diffuse recharge occurs over the entire GWB, with the general lack of surface drainage demonstrating that potential recharge readily percolates into the groundwater system. Swallow holes and collapse features provide the means for point recharge. Surface water draining off the low permeability Namurian rocks in the west of this GWB sinks into the limestone aquifer via potholes. Linear/ point recharge occurs along river reaches and where rivers sink underground.
	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 yielding springs within this GWB. Small springs occur within the GWB, where they emerge at the intersection of bedding planes with the ground surface. These streams flow for only a short distance before sinking again. However, the groundwater flowing to deeper levels within the conduit system feeds very large springs outwith this GWB, in areas where the topography is flatter and elevation lower. The following springs are proven or are thought to be fed by groundwater originating in this GWB: 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)* Pouladower Spring (10,000 m^3/d – low flow, 62,400 m^3/d – high flow)* Ballyvaughn WS (Newtown borehole) (yield >500 m^3/d) § Elmvale spring drains approximately 60% of the water in the Burren area (Drew, pers comm). Submarine springs are also common, for example the large springs off the coast at Ballyvaughn. *Note: springs marked with an * are in the Ennis GWB to the south. Those marked with a § are in the Western RBD, to the north of this GWB.*
	Main discharge mechanisms	Local discharges are to the small springs and streams within this GWB. However, these sink within the GWB within a short distance of the risings. The main net discharges are to the large springs outside the GWB. In winter groundwater will discharge to the turloughs in the area.
	Hydrochemical Signature	There are no data from within this GWB readily available for analysis. However, groundwater within this GWB feeds Newtown WS, and Pouladower and Elmvale springs, for which data are available. Groundwaters have a calcium-bicarbonate hydrochemical signature. Hydrochemical analyses indicate that at the Pouladower spring groundwater is Moderately Hard (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 Elmvale spring, the parameters are similar, with two conductivity measurements in the range 350-370 µS/cm. At the 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. At the Newtown borehole in July 1998, temperature, conductivity and pH ranged from 10.75 to 11.75^{o}C, 300 to 580 µS/cm, and 6.75-7.5 respectively. A significant drop in conductivity was recorded soon after a period of heavy rainfall. All major cations and anions are within the EU limits. Nitrate and chloride concentrations in particular are significantly less than EU maximum admissible concentrations (MAC). Nitrate levels range from 0.15 to 8.9 mg/l and chloride levels range from 5 to 21 mg/l across the valley. Bacteriological analysis of the raw water sample indicated high total and faecal coliform counts at the Newtown supply. Elsewhere in the karstic limestones of Co. Clare, similar problems with *E. coli.*, iron, colour and turbidity are reported (Coxon and Drew, 1998). The Namurian rocks or the overlying peat to the west of the area 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. Runoff from the Namurian rocks is acidic due to the shales and overlying peaty subsoils.

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. 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 rapidly through a dense network of solutionally enlarged conduits, in direct response to recharge. (2) A deeper zone, where groundwater moves through interconnected solutionally enlarged conduits and cave systems which are mainly controlled by: (i) bedrock lithologies. The less permeable units, e.g. chert, black dolomite and clay wayboards (clay bands) inhibit vertical groundwater flow; (ii) the dip direction of the bedding planes. Groundwater flows down dip along the surfaces of the less permeable beds; and (iii) structural deformation. Groundwater flows preferentially in the north-south and east-west directions, parallel to the major fault, vein and joint trends. The faults and veins are a particularly important factor for flow through the less permeable units. (3) A more dispersed slow groundwater flow component in smaller fractures and joints outside, but usually linked to, the main conduit systems. The epikarst receives diffuse recharge and rapidly re-distributes and focusses the water in the subsurface, where it enters the deeper network of conduits. It 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 active solution, but also glacial and pre-glacial solution. Good examples of epikarst can be seen over most of the bare rock areas of the Burren where solution has created the characteristically large klints and grikes. The interbedding of less permeable units in the limestone succession creates the step-like characteristics of many of the cave systems and is also responsible for the lack of a true water table and the many failed wells. For example, in a well drilled 10 km from the coast at Carron, a water supply was only found at near sea level. Another well drilled in the same region encountered a small supply, at moderate depth, above one of the impermeable layers. The borehole was deepened in an effort to find a larger supply but on penetrating the low permeability bed, the water flowed down the borehole to a deeper system and the well failed. Water is channelled along conduits and fissure systems and therefore rises to different levels across the region. The 'stepped' type of hydrogeological system characteristic of this GWB, in which the groundwater path of least resistance is determined considerably by the bedding planes, is shown in Figure 2. Streams emerging as springs at the intersection of bedding planes with the ground surface flow for only a short distance before sinking again. There are over 150 of these types of springs on the entire Burren plateau, of which about 50% cease to flow under low baseflow conditions (Drew and Daly, 1993). The schematic diagram and the tracer map (Figure 3) also shows that groundwater travels in both northerly and southerly directions from similar locations due to the competing influences of topography and bedding slope directions. A high proportion of the flow to the large springs outside the GWB 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, short residence times and low aquifer storage. The low storage, high transmissivity nature of the aquifer is reflected in the seasonal variation of almost 20 m at the borehole at Burren (Figure 1). 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. Acidic runoff from the Namurian shales in the west of the GWB has resulted in a ring of swallow holes, sinks and large cave systems at the boundary between the two units. Numerous examples of this occur around the Burren where runoff from the Namurian rocks sinks underground into the limestones within a short distance.

Groundwater & Surface water interactions	There is an effective hydraulic interconnection between groundwater and surface water in the karst limestone: the groundwater will spend at least some time on the surface and vice versa. Small springs rise where low permeability units intersect the ground surface. The water rising sinks back into the subsurface within a short distance. The effects of heavy rainfall can be seen in the water quality at the large springs to which groundwater discharges within a few 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 Namurian Clare Shales. The shaly rocks give rise to highly acidic runoff that dissolves the carbonate rocks, resulting 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. There are several groundwater-dependent ecosystems within the GWB. Turloughnagullaun is situated at the head of a valley. It is a diverse turlough in topography and vegetation, and is notably unmodified. It is relatively eutrophic despite its occurrence in the hilly Burren, and has rather unusual vegetation for this area. The occurrence of rare and unusual plant species adds to its scientific interest. The East Burren Complex is of international scientific interest owing to the presence of fine examples of typical Burren habitats together with an oligotrophic wetland complex of lakes, turloughs, fen, cut-over bog and calcareous marsh. The Black Head-Poulsallagh complex includes the Caher River, the only river found in the high Burren. This river is actually within the adjacent Slieve Elva GWB, but there is the possibility, in this complex system, that some groundwaters from this GWB reach the Slieve Elva GWB.
Conceptual model	• The GWB is an upland karst plateau partly dissected by steep-sided valleys. The area is very well-drained, there are short stretches of sinking streams, and very few loughs. It is roughly square in shape, with an irregular outline. It is bounded to the west partly by the contact with the low transmissivity Namurian rocks of the Craggaunboy GWB and partly by a surface water catchment divide. • The southern and eastern boundaries are delineated on the basis of topography, since the hydrogeological regime in the upland karst of this GWB is so different from the lowland karst system of the Ennis GWB. The 60 m elevation contour approximately coincides with the change in slope. Groundwater cross-flows from this GWB into the Ennis GWB. • The northern boundary is a surface water catchment divide that is also the current RBD boundary. Groundwater flows to both the north and the south of this surface water divide via an underground system of vertical and horizontal conduits. • 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. • Recharge occurs diffusely across the entire GWB. Point recharge occurs at the numerous swallow holes in the GWB and where rivers sink underground. Surface water running off the Namurian rocks enters the karstic aquifer at the margin via swallow holes. • The aquifer is unconfined. Much of the work carried out on the Burren region indicates that there is no continuous water table. Instead water is channelled along conduits and fissure systems and therefore rises to different levels across the region. Water flowing at different levels in the limestones may or may not be connected, indicating that significant vertical hydraulic gradients may exist. Water levels are generally deep. Seasonal water level fluctuations vary, depending on the position within the groundwater system. They are typically extreme, varying by 10's of metres. • In the upland areas of the Burren, about 30% of boreholes fail (Drew and Daly, 1993). Failed wells can be situated next to higher yielding boreholes. This is because flow is focussed into conduits in both the horizontal and vertical directions, and demonstrates the extreme permeability heterogeneity. • Groundwater in this body generally shows a rapid response to recharge and groundwater velocities in the subsurface can be rapid. 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. Groundwater emerging at small, sometimes seasonal, springs where the impermeable layers intersect the ground surface sinks back rapidly into the subsurface. Groundwater also discharges in winter to the turloughs. The loughs do not have surface water outlets or inlets, but are connected to other surface water bodies and the groundwater via a karst network. • Due to the strong focussing of flow in subsurface karst conduits, the bulk of the groundwater discharges to several large springs rather than the small springs. These springs are outside this GWB, both within the Shannon RBD and in the Western RBD. • Tracer studies have shown that groundwater travels in both northerly and southerly directions from similar locations due to the competing influences of topography and bedding slope directions. Tracing studies show that groundwater in this GWB flows westwards into the Slieve Elva GWB from this GWB, and southwards into this GWB from the Western RBD. • This GWB is within the Zone of Contribution to the Pouladower spring and Newtown (Ballyvaughn) borehole, and the Source Protection Area of Newtown WS. The surface water sinks into the karst groundwater system and potentially reaches the springs.
Attachments	Groundwater hydrograph (Figure 1), Schematic diagram of groundwater flow (Figure 2), Water tracing connections (Figure 3).
Instrumentation	EPA Water Level Monitoring boreholes: Burren (CLA 66). EPA Representative Monitoring boreholes: Carron WS (CLA 6).

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. Cronin, C., Daly, D., Deakin, J. & Kelly, D., Drew, D. and Johnston, P. (1999) *Ballyvaughan Public Supply: Groundwater Source Protection Zones*. Geological Survey of Ireland Report to Clare Co. Co., 10 pp plus figures. 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. Drew. D. and Daly, D. (1993) *Groundwater and Karstification in mid Galway, south Mayo and north Clare*. GSI report no. RS93/3, 86 pp. Gillespie, P.A., Walsh, J.J, Watterson, J., Bonson, C.G. & Manzocchi, T. (2001) Scaling relationships of joint and vein arrays from The Burren, Co. Clare, Ireland. *Journal of Structural Geology* **23**, 183-201. Mullan, G. (Ed.) (2003) *Caves of County Clare and South Galway.* University of Bristol Spelaeological Society, 259 pp. Aquifer chapters: Dinantian Pure Bedded Limestones; Namurian Shales; Namurian Sandstones.
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

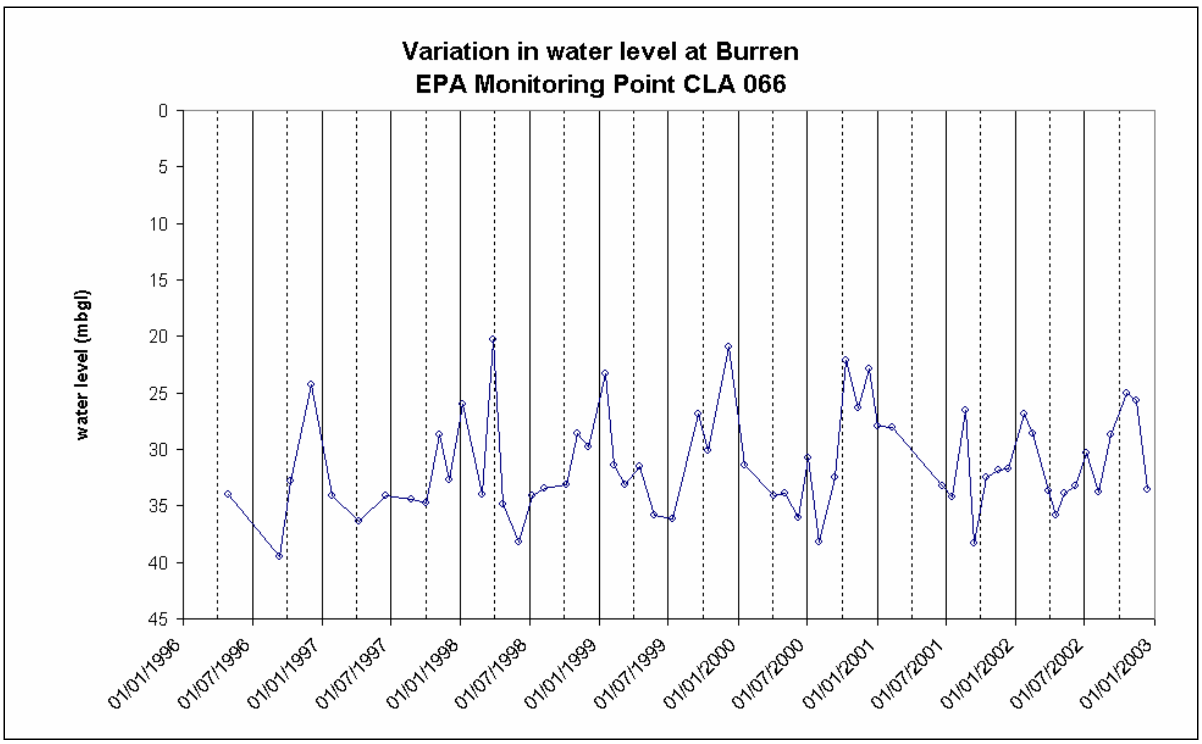
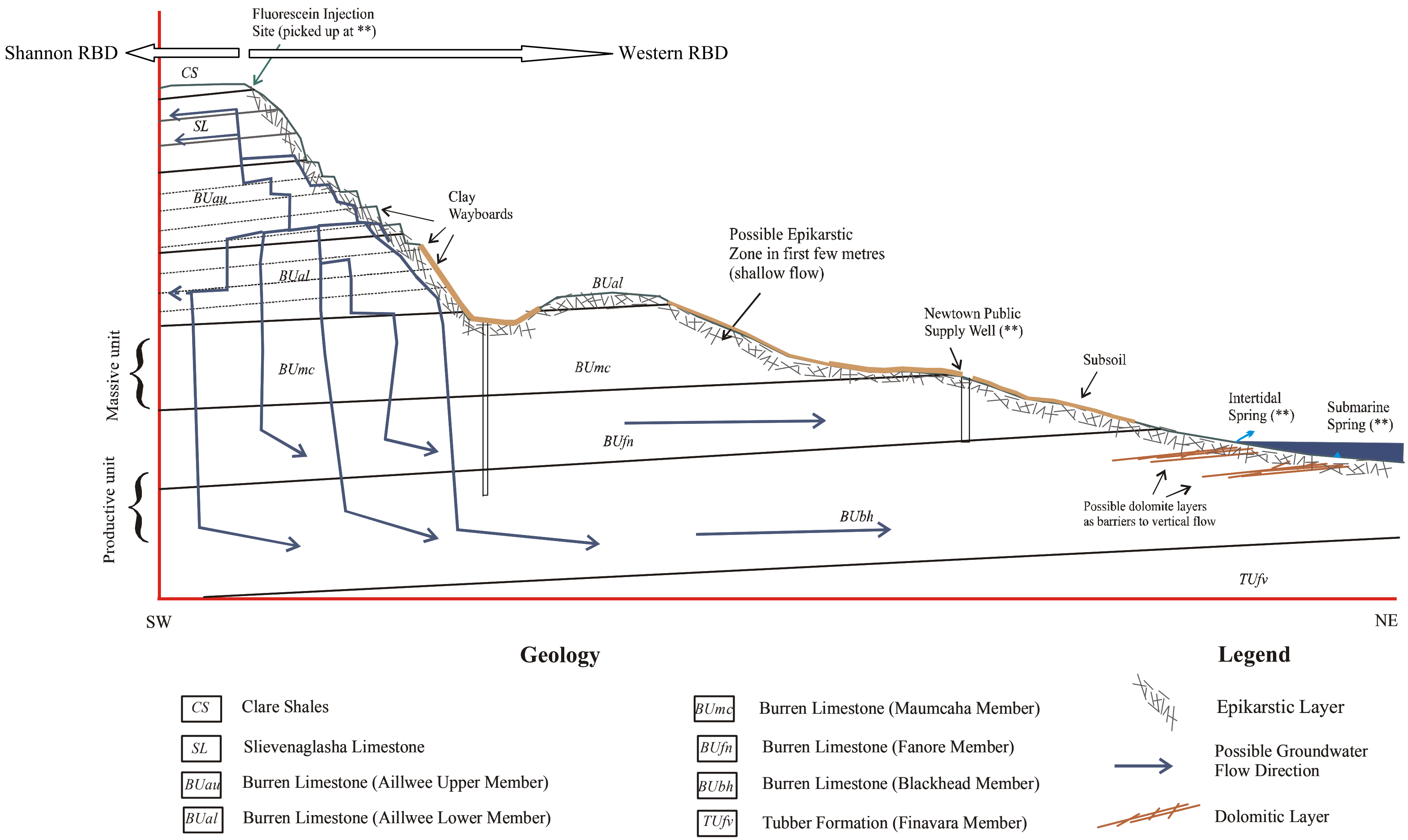
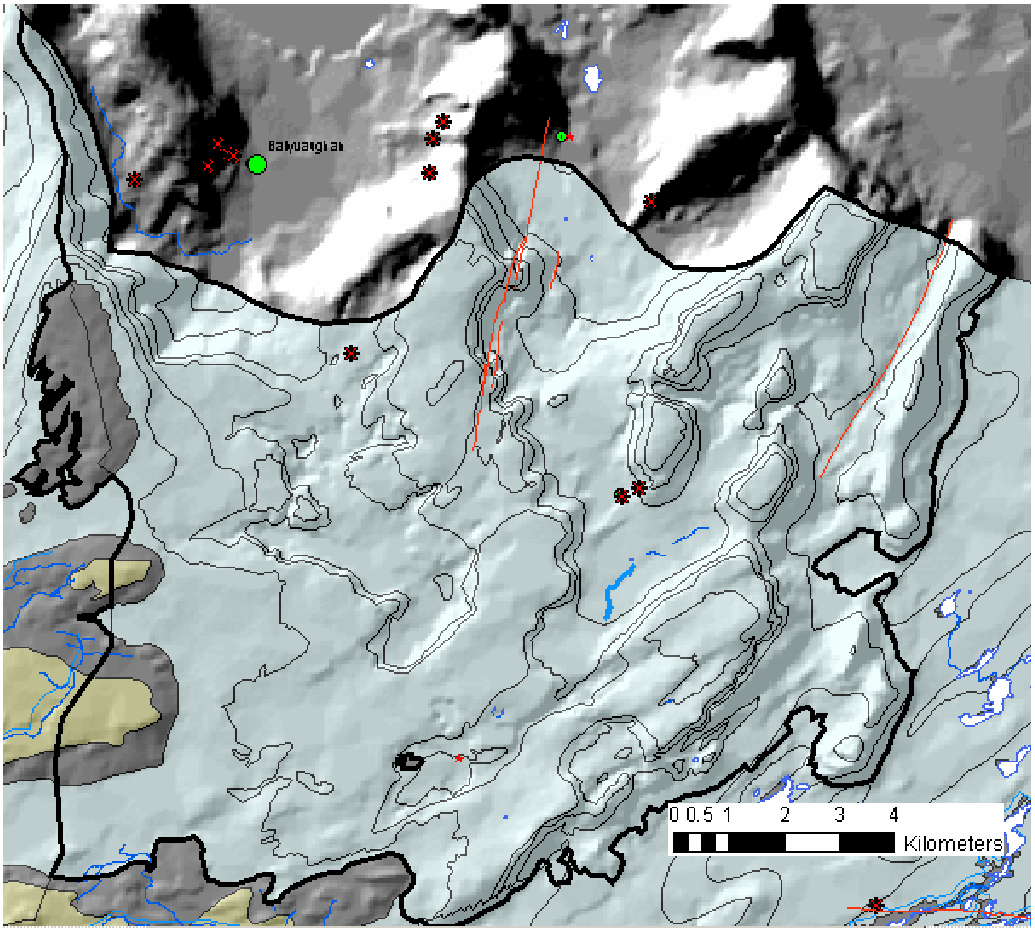


Figure 2: Schematic diagram of groundwater flow from Burren uplands (i) north to the Ballyvaghn area (Western RBD) and (ii) south to the Elmvale springs (Shannon RBD)



From: Cronin *et al.* (1999) *Ballyvaughan Public Supply: Groundwater Source Protection Zones*. GSI report to Clare Co. Co.



Rock units in GWB

Rock unit name and code	Description	Rock unit group
Aillwee Member (upper) (BUau)	fossiliferous limestone with Davidsonia	Dinantian Pure Bedded Limestones
Aillwee member (lower) (BUal)	bedded & massive fossiliferous limestone	Dinantian Pure Bedded Limestones
Fanore Member (BUfn)	dolomitised limestone with shale	Dinantian Pure Bedded Limestones
Maumcaha Member (BUmc)	massive limestone sparsely fossiliferous	Dinantian Pure Bedded Limestones
Ballyelly Member (SLbe)	nodular & crinoidal limestone with chert	Dinantian Pure Bedded Limestones
Balliny Member (SLbi)	cyclical crinoidal limestone	Dinantian Pure Bedded Limestones
Fahee North Member (SLfh)	fossiliferous limestone with chert	Dinantian Pure Bedded Limestones
Lissylisheen Member (SLll)	cyclical crinoidal limestone	Dinantian Pure Bedded Limestones
Gull Island Formation (GI)	Grey siltstone & sandstone	Namurian Sandstones
Clare Shale Formation (CS)	Mudstone, cherty at base	Namurian Shales