Slieve Elva GWB: Summary of Initial Characterisation.

NB: eastern boundary will alter to incorporate some of the Namurian rocks on Poulnacapple Hill. Northern boundary will change when RBD boundary is finalised.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
28 - Inagh catchment Clare Co. Co.	Rivers: Murroogh/ Caher Aille.	The East Burren Complex (001926), Black Head-Poulsallagh Complex (000020), Turloughnagullaun (000071).	66 *(Note: this value will change when GWB boundary is finalised.)*

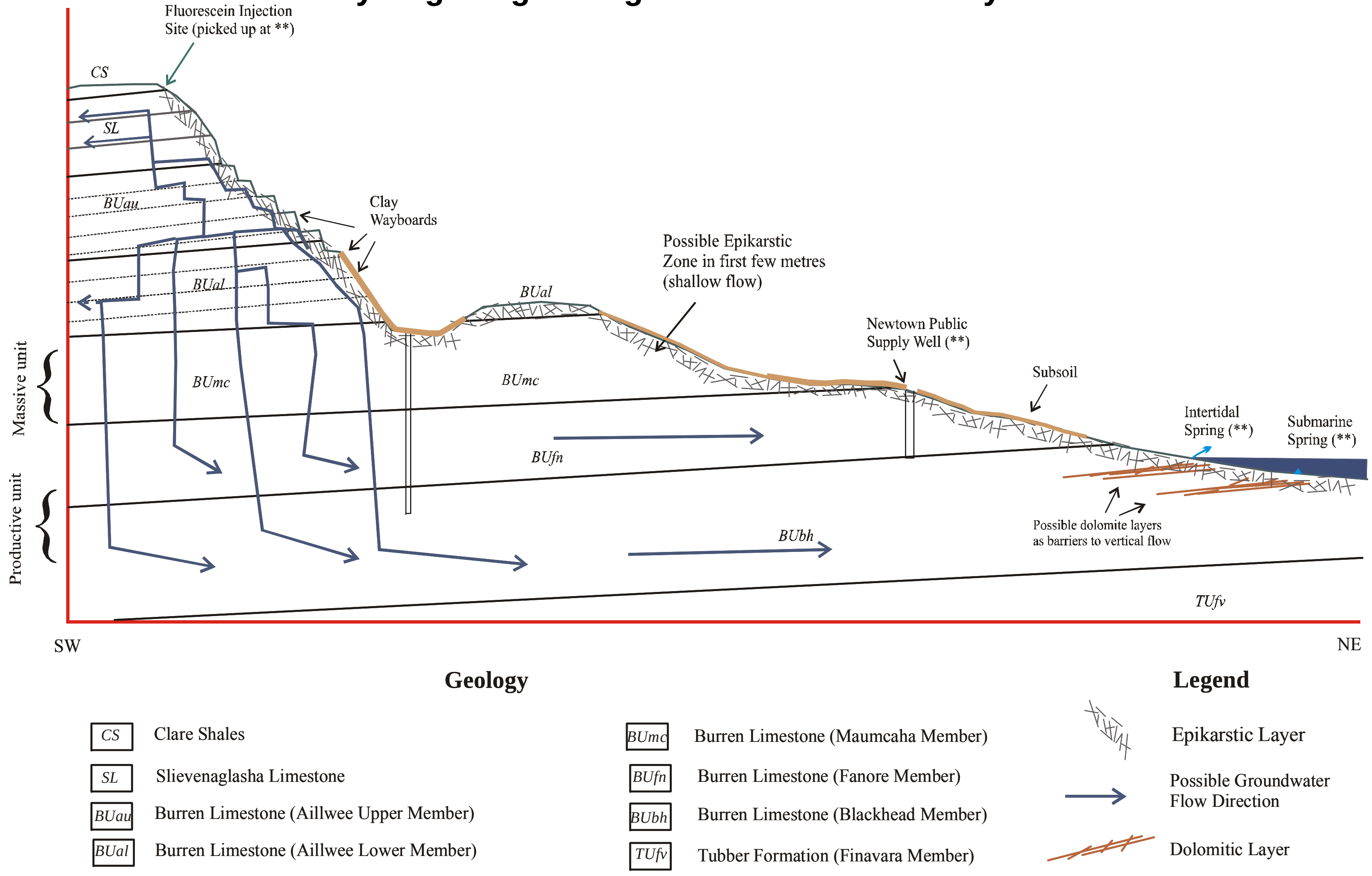
Topography		The GWB is shaped like ‘ʌ’, as it curves around the Namurian rocks at the top of Slieve Elva in the Milltown Malbay GWB. Ground elevation within the GWB ranges from sea level to over 300 mAOD. Slopes are steep, terminating in the classical flat-topped hill profile. The terrain is steepest in the north of the GWB on the slopes of Slieve Elva and the Caher/ Murroogh River valley. The ground level generally increases eastwards and northwards, from the coast to the high ground surrounding Slieve Elva around which the GWB divides, and at Poulnacapple Hill and Gleninagh Mountain in the east and north of the GWB. The ground is less steep in the southern parts of the GWB. The Caher/ Murroogh River, which flows NW to the coast, is a permanent river. In dry conditions, drainage density over most of the GWB is very low. In wet conditions, ephemeral rivers rise and flow along their old courses in dry valleys. Land drainage is poor over the Namurian rocks in the eastern upland 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 **Pu:** Poor aquifers which are generally unproductive.
	Main aquifer lithologies	Dinantian Pure Bedded Limestones form most of the aquifer in the GWB. There are small areas of Namurian Shales along part of the eastern GWB boundary.
	Key structures	This area is relatively unfolded. Bedding dips to the south at consistently low angles of 1-2^o. 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. They have probably exerted a control on the locations and orientations of the valleys. 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 and are spaced on a dm-m scale. 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. 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 80-150 m/h in the area draining to St. Brendan’s Well and of 70 m/h in the coastal Poulsallagh. 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 of the limestone aquifer, and also occur at elevations below present day base level. In the Namurian Shales, groundwater flows in the fractured 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. Subsoil is thicker along the Caher/ Murroogh River valley and small areas along the coast.
	% 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 part of the Caher/ Murroogh River and small areas at the coast. Here, vulnerability is High. Over the Namurian strata in the east of the GWB, vulnerability ranges from Extreme to Low.

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 and south 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)	The groundwater flowing to deeper levels within the conduit system feeds very large springs on the periphery of this GWB. There are known large submarine/intertidal springs off the coast at Poulsallagh, Doolin and Dereen-Trawee. The Fisherstreet spring is close to the coast near Doolin. 2.5 km off the coast, there is a spring called the Oughtdarra resurgence (correct grid refs in geodata?). The spring flows are not accurately known, but are thought to be >1,750 m^3/d and are probably much larger. Within the GWB, there are three risings. The Killeany spring is used for the Lisdoonvarna-Killeany WS. Average flow is 355 m^3/d, and it reportedly dries up in summer. Overflow from the spring sinks back into the aquifer to re-emerge augmented at St. Brendan's Well. The Caher/ Murroogh and Aille Rivers are fed by Caher spring and St. Brendan's Well respectively. St. Brendan's spring low flow is 151,200 m^3/d, whilst the Caher River is estimated to flow at about 72,000 m^3/d.
	Main discharge mechanisms	Local discharges are to the small springs and streams within this GWB. These streams often sink within a short distance of the risings. The main discharges are to the peripheral springs around the coast in the intertidal zone and further offshore. There are also two large springs at about 150 mAOD (the Caher and Killeany springs) and one at 110 mAOD (St. Brendan's Well).
	Hydrochemical Signature	There are no data from within this GWB readily available for analysis. Groundwaters originating in the adjacent Burren GWB and rising in the Ennis GWB or in the Western RBD have a calcium-bicarbonate hydrochemical signature. Hydrochemical analyses indicate that groundwater is Moderately Hard, with moderate alkalinities that are less than total hardness, and conductivities in the range 310–460 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 the Newtown borehole (near Ballyvaughan) in July 1998, temperature, conductivity and pH ranged from 10.75 to 11.75°C, pH ranged from 6.75 to 7.5 and conductivity ranged from 300 to 580 µS/cm. A significant drop in conductivity was recorded at the WS soon after a period of heavy rainfall. At the springs and boreholes, water quality is generally relatively good with low levels of chemical contaminant indicators such as chloride, nitrate and potassium. 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 Ballyvaughan valley, for example. 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. 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.

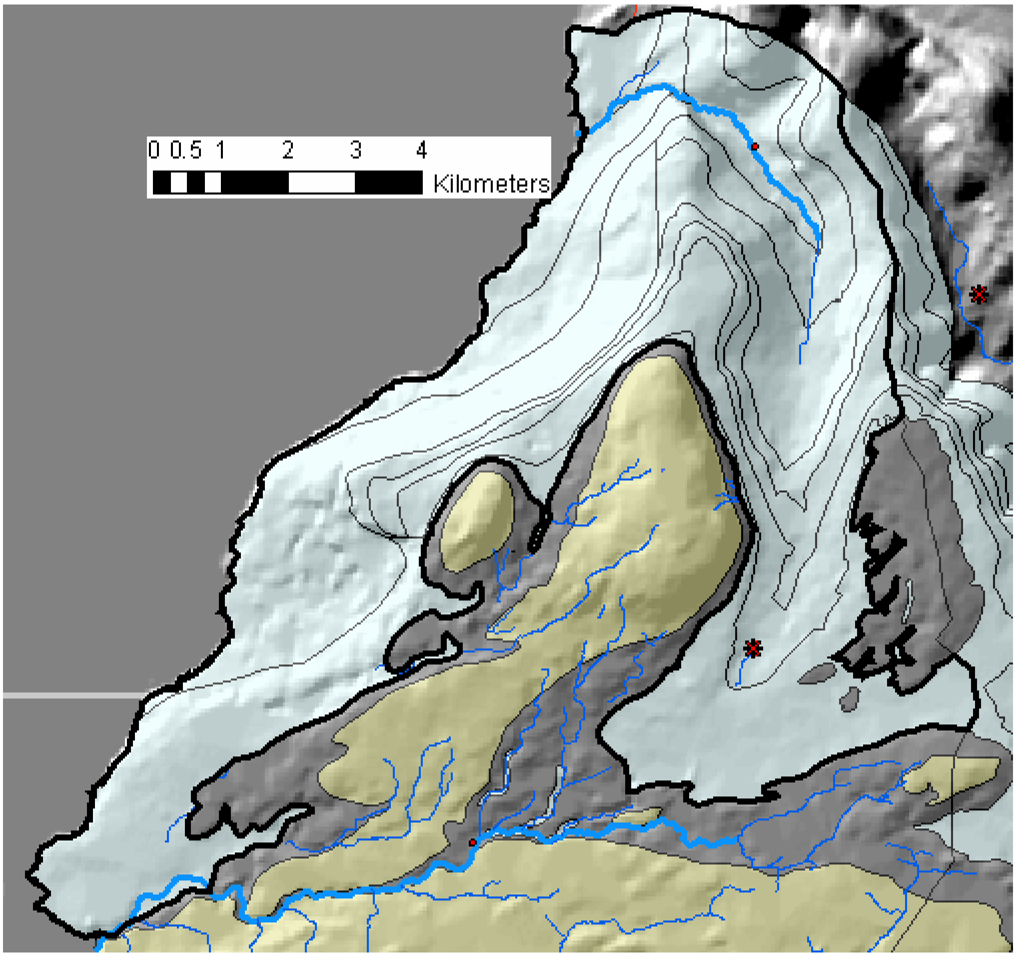
Groundwater Flow Paths	There is no intergranular porosity or permeability in the rocks of this GWB. Dissolutional enlargement of bedding planes and the N-S and E-W joints has created permeability. Groundwater is likely to flow in three main hydrogeological regimes: (1) An upper, shallow, highly karstified 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. 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 1. Streams emerging as springs at the intersection of bedding planes with the ground surface often 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). A high proportion of the flow to the large springs 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 seasonal water level variation on the order of 10's of metres. 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. In this GWB, runoff from the southern edges of the Namurian shale caps of Slieve Elva and Poulacapple are proven to feed Killeany and St. Brendan's springs. Groundwater emerging at these springs flows off onto the adjacent Milltown Malbay GWB as the Aille River. Runoff from the north and west of these shale caps drains to the north and west, feeding Caher spring and the coastal springs. There is a proven underground connection from the adjacent Burren GWB into this GWB (Cronin *et al.*, 1999). Most discharge points are at the coast. There are caves and ancient phreatic half-tubes along the coast and at higher elevations, that were controlled by the stratigraphy and attesting to a higher baselevel. St. Brendan's Well (110 mAOD) occurs where it does because the limestone aquifer passes underneath the low transmissivity Namurian rocks at this point. The Caher and Killeany springs occur at approximately the same elevation (150 and 140 mAOD respectively). It is not clear what the control on these risings is.

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 effects of heavy rainfall can be seen in the water quality at springs 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 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. The Caher River is a shallow, limestone, spring-fed stream (part of the Black Head-Poulsallagh complex NHA). It is the largest perennial river found in the high Burren. The water stays on the surface largely because much of the river bed is sealed with boulder clay (Simms, 2001). However, in its lower reaches it flows underground for some of its course during dry periods.
Conceptual model	• The GWB is shaped like '∧', as it curves around the Namurian rocks at the top of Slieve Elva. It is bounded to the west by the coast, and to the south by the contact with the low transmissivity Namurian rocks of the Milltown Malbay GWB, under which the limestones pass. The eastern and northern boundaries are topographic, and are implied groundwater divides. Slopes are steep, terminating in the classical flat-topped hill profile. The terrain is steepest in the north of the GWB, but less steep in the southern parts of the GWB. • 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 through the thin subsoils or at rock outcrop. Point recharge occurs at the numerous swallow holes along the margins of the GWB where acidic surface waters run off the Namurian shales and peaty areas. There are also losing river stretches. • 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 likely to be both shallow deep. Seasonal water level fluctuations vary, depending on the position within the groundwater system. They can be extreme, varying by 10's of metres. Groundwater 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. Some of the groundwater will spend at least some time on the surface of the GWB, but most does not emerge until it reaches the large springs at the periphery of the GWB (at the coast). Due to the strong focussing of flow in subsurface karst conduits, groundwater discharges to several large springs rather than many small springs. • Tracing has proven a subsurface connection between the adjacent Burren GWB and this GWB. The volume of groundwater crossing the boundary between the two (which is defined by the surface water catchment) is unknown, but is not likely to be large. • Where the limestone aquifer dips south beneath the Namurian rocks of the Milltown Malbay GWB, groundwater is forced to the surface, at St. Brendan's Well. These spring waters feed the Aille River. • The Caher/ Murroogh River is one of the few perennial streams in the Burren. It is fed by a large spring and the river is prevented from sinking into the aquifer by boulder clay lining part of its length. In the lower reaches, the river disappears beneath ground level in dry weather.
Attachments	Schematic diagram of groundwater flow (Figure 1).
Instrumentation	Stream gauges: 28009.
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. 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. Simms, M. (2001) Exploring the Limestone Landscapes of the Burren and the Gort Lowlands: A guide for walkers, cyclists and motorists. Burrenkarst.com, Belfast, 64 pp. Aquifer chapters: Dinantian Pure Bedded Limestones; Namurian Shales.
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: 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). The hydrogeological regime in this GWB is very similar.



From: Cronin, C., Daly, D., Deakin, J., Kelly, D., Drew, D. and Johnston, P. (1999) *Ballyvaughan Public Supply: Groundwater Source Protection Zones*.



Rock units in GWB

Rock unit name and code	Description	Rock unit group
Black Head Member (BUbh)	Limestone and dolomite with corals	Dinantian Pure Bedded Limestones
Aillwee Member (BUaw)	fossiliferous limestone with claybands	Dinantian Pure Bedded Limestones
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
Slievenaglasha Formation (SL)	Cherty limestone, crinoidal intervals	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