Ballyvaughan uplands GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
29 Clare Co. Co.	**Rivers**: Rathborney. **Lakes**: Ballyvelaghan, Luirk, Murree, Rask, Muckinish, Newtown.	East Burren Complex (001926), Termon Lough (001321), Ballyvaughan Turlough (000996), Turloughnagullaun (000071), Black Head/Poulsallagh Complex (000020).	119

Topography		The GWB occupies the northern Burren Uplands in the vicinity of Ballyvaughan. The Burren Plateau is generally at 200-300 m AOD (Drew and Daly, 1993). The highest point is Slievecarran standing at 324 mAOD. The land surface slopes steeply down to sea level at Ballyvaughan. There is one main N-S trending valley cutting into the upland plateau south of Ballyvaughan. The GWB is bounded by the coastline to the north. The eastern boundary is taken as the 60 mAOD contour line, separating the Burren Uplands from the Kinvara-Gort Lowlands. To south, a surface water catchment is taken as the boundary, which includes the catchment divide between the Shannon and the Western RBD areas. Location and boundaries are shown in Figure 1.
Geology and Aquifers	**Aquifer categories**	**Rk^c:** Regionally important karstified aquifer. **Pu:** Poor aquifer which is generally unproductive.
	Main aquifer lithologies	The GWB is almost entirely dominated by Dinantian Pure Bedded Limestones. There are approximately 0.4 km^2 of Namurian Shales capping the hill of Poulacapple, west of Ballyvaughan. Table 1 presents the rock units.
	Key structures	The limestone rock units have been gently folded from north to south. The rocks in the area are dipping approx. 1-5° to the south. Associated with folding and faulting is the development of fissures/fractures. The trend of these fractures is likely to be in a NNE-SSW orientation similar to the trend of the Ballyvaughan valley. This trend is also reflected in the Fergus River valley area and may be significant in terms of understanding the direction of groundwater flow at depth (Cronin, *et al,* 1999).
	Key properties	**Karstification** is widespread. **Transmissivity and Storativity:** Yields are variable, being distributed through all the well yield categories. Transmissivities range from 1 to greater than 5000 m^2/d. Tidal regression analysis at Ballyvaughan WS, indicates transmissivities of about 3,000 m^2/d. Productivity values are distributed throughout all the productivity categories, but are skewed to the lower end of the Productivity Index, with 75% either IV or V. Note: productivity is an index relating specific capacity to yield, and the higher the productivity the higher the transmissivity. The well yield data indicate the variability of the aquifer properties. Water table levels have high annual variations, and abstraction rates fall as the water levels drop, which indicates that the storativity is low - approximately 0.01-0.02 (Cronin, *et al,* 1999; Daly, 1985). The springs reflect the low storativity as many of the spring flows rise and fall quickly in response to rainfall events. Over 50% of the springs cease to flow under low base flow conditions (Drew and Daly, 1993). **Groundwater velocity:** Groundwater velocities are in the order of 20-150m/hr (Cronin, *et al,* 1999) in the vicinity of Ballyvaughan, where groundwater flows against the slope of the bedding. Groundwater velocities increase up to fourfold in high water conditions and halve under low flow conditions (Drew and Daly, 1993). Extensive conduit systems exist, including the cave systems at Aillwee (fossil), Poulacapple (active). Generally, conduit development is influenced by N-S and E-W joint sets (Drew and Daly, 1993). **Groundwater flow directions and gradients:** Overall, flow directions are to the north, with groundwater discharging to littoral or submarine springs on the coast. There is no surface water outlet to the sea. Groundwater can flow across surface water divides and beneath surface water channels. Some groundwater from the Burren Plateau is expected to flow to Kinvara Springs (Drew and Daly, 1993). Water sinking along the eastern flank of Poulacapple can flow to either Ballyvaughan or across the surface water divide between the Shannon and Western RBD areas. Similarly, water flows from Berneens sink to Ballyvaughan and across the surface water divide into the Shannon RBD (Cronin, *et al,* 1999). Gradients vary depending on the water level conditions but are expected to be greater than 0.005. Due to the large conduits and the low hydraulic gradient in the low lying areas, up to 2 km inland from Ballyvaughan the tide has an effect on the water levels, causing them to rise (Cronin, *et al,* 1999).
	Thickness	Most groundwater flows in an epikarstic layer (1-10 m depth) and in a zone of interconnected solutionally-enlarged fissures and conduits that extends approximately 30 m below this. Deeper inflows can occur in areas associated with faults or dolomitisation.
Overlying	**Lithologies**	Limestone till deposits occur over much of the area and are derived from the underlying limestone bedrock. The texture varies from stony to silty across the valley and is classified as "moderately" permeable (Cronin *et al,* 1999).

	Thickness	Over much of the upland mountainous areas depth to bedrock is generally < 1m. Subsoils in the valley are generally between 3 and 10 m thick and in some localised areas picked out on aerial photographs, subsoils are greater than 10 m e.g. at Lough Rask and in the vicinity of Croagh North. Depth to bedrock at the public supply well is 2.5 m thick. (Cronin, *et al,* 1999; County Clare Groundwater Protection Scheme, Deakin and Daly, 2000).
	% area aquifer near surface	*[Information to be added at a later date]*
	Vulnerability	The vulnerability for the western area, is described in the County Clare Groundwater Protection Scheme (Deakin and Daly, 2000). In this area the vulnerability classification is variable dependent on the depth to bedrock but is predominantly "extreme". From the upland area down into the valley floors, the vulnerability progresses from "extreme" to "high" to "moderate".
Recharge	**Main recharge mechanisms**	Both point and diffuse recharge occur. Diffuse recharge occurs via rainfall percolating through the permeable subsoil and rock outcrops. On the Burren plateau, rainfall on the limestone pavements enters the groundwater system immediately as diffuse recharge, and downslope, many small streams discharge from small 'internal' springs and sink as point recharge. Point recharge occurs by means of swallow holes, collapse features/dolines, and where flow is concentrated in the epikarst. Streams flowing off the non-limestone rocks sink on meeting the limestone, thus the majority of the swallow holes are located near the inland boundaries of the GWB. Recharge also occurs along 'losing' sections of streams, for example along a well defined 2 km stretch of the Owenshree River (Daly, 1985; Drew and Daly, 1993).
	Est. recharge rates	*[Information to be added at a later date]*
Discharge	**Large springs and high yielding wells (m^3/d)**	Excellent wells : Newtown – 500 m^3/d. Springs: Ballyvaughan > 2000 m^3/d, Bellharbour > 2000 m^3/d.
	Main discharge mechanisms	In the Burren area, discharge occurs to many small springs ('internal'), only for the water to sink again before discharging to larger springs ('external') located offshore or along the intertidal zone, associated with the funnel shaped inlets, for example Bellharbour. Some of the groundwater in this area is considered to discharge to the Kinvara Springs.
	Hydrochemical Signature	The groundwater has a calcium bicarbonate signature which is illustrated using an expanded Durov plot, presented in Figure 2. The range and median values for selected parameters for Ballyvaughan are given below. Ballyvaughan (N=15) Alkalinity (mg/lCaCO3): 133-289, 204 Hardness (mg/lCaCO3): 156-352, 207 Conductivity (microsiemens/cm): 362-633, 431

Groundwater Flow Paths	Groundwater flow through karst areas is extremely complex and difficult to predict. As flow pathways are often determined by discrete conduits, actual flow directions will not necessarily be perpendicular to the assumed water table contours, as shown by several tracing studies (Drew and Daly, 1993). The tracer tests show that groundwater can flow across surface water catchment divides and beneath surface water channels. Flow velocities can be rapid and variable, both spatially and temporally. Rapid groundwater flow velocities indicate that a large proportion of groundwater flow occurs in enlarged conduit systems. Groundwater flow in highly permeable karstified limestones is of a regional scale. Flow path lengths are up to ten kilometres. Overall, groundwater flow will be towards sea, but the highly karstified nature of the bedrock means that locally groundwater flow directions can be highly variable. The following section is taken and adapted from Cronin *et al,* (1999). "*There are a number of different flow mechanisms operating which are summarised below and illustrated in Figure 3.* *1) Shallow flow is occurring in the upper few metres of highly weathered and karstified limestone, commonly referred to as epikarst. Surface level karst features in the region include sink holes, caves, springs and the limestone pavement typical of the Burren landscape.* *2) It is probable that a series of vertical conduits allow flow to occur rapidly downward through the Slievenaglasha, Aillwee and Maumcaha limestones before travelling horizontally through fracture zones in the Fanore and Blackhead limestones toward the coast.* *3) Alternatively water may flow downdip through the shallow epikarst before sinking through the Maumcaha limestone. The Maumcaha limestone is generally perceived to be less permeable than the other limestones (D. Drew, pers comm) and the exact flow mechanism in this unit is not fully understood. It is likely to be more permeable in certain areas e.g. the Rathborney River sinks into the Maumcaha limestone and a number of springs also discharge from this limestone to the north of Cappanawalla. These more permeable areas may be restricted to the epikarst.* *4) Deep flow in the Fanore and Blackhead limestones travels between confining chert layers before discharging into the bay as intertidal and submarine springs. These springs are dotted along a NNE - SSW trend which probably indicates the general orientation of flow in the Ballyvaughan valley.* *5) The Rathborney River flows southward down the Rathborney valley before flowing northward into the Ballyvaughan Valley. The river sinks about 2 km south of the Ballyvaughan PWS depending on the flow conditions and travels underground in a northerly direction before discharging at the intertidal and submarine springs."*
Groundwater & Surface water interactions	There is a high degree of interconnection between groundwater and surface water, as evidenced by the many springs and sinks. The Rathborney River flows southward down the Rathborney valley before flowing northward into the Ballyvaughan Valley. The river sinks about 2 km south of the Ballyvaughan PWS depending on the flow conditions and travels underground in a northerly direction before discharging at the intertidal and submarine springs.
Conceptual model	• The GWB occupies the northern Burren Uplands in the vicinity of Ballyvaughan. The Burren Plateau is generally at 200-300 m AOD (Drew and Daly, 1993). The highest point is Slievecarran standing at 324 mAOD. The land surface slopes steeply down to sea level at Ballyvaughan. There is one main N-S trending valley cutting into the upland plateau south of Ballyvaughan. • The GWB is bounded by the coastline to the north. The eastern boundary is taken as the 60 mAOD contour line, separating the Burren Uplands from the Kinvara-Gort Lowlands. To south, a surface water catchment is taken as the boundary, which includes the catchment divide between the Shannon and the Western RBD areas. • A large number of karst features occur, including turloughs, caves, dolines, swallow holes and springs. • The GWB is composed primarily of high transmissivity karstified limestone (**Rk**^{c}). Transmissivity and well yields are variable. Storativity is low. Gradients are dependent on the water level conditions, but are expected to be greater than 0.005. • Rapid groundwater flow velocities have been recorded through groundwater tracing (20-150 m/hr). • Recharge occurs via losing streams, point and diffuse mechanisms. • In general, the degree of interconnection in karstic systems is high and they support regional scale flow systems. • Surface water catchments are often bypassed by groundwater flowing beneath surface water channels and across surface water catchment divides. • Some areas are of extreme vulnerability due to the thin nature of the subsoil, as well as the frequency of karst features, allowing point recharge. Storativity is low and the potential for contaminant attenuation in such aquifers is limited. • In the Burren area, discharge occurs to many small internal springs, from which the water sinks a short distance further on. The water from these sinks discharges to larger external springs located offshore or along the intertidal zone. Some of the groundwater in this area is considered to discharge to the Kinvara. • There is a high degree of interaction between surface water and groundwater. • The groundwater has a calcium bicarbonate signature.
Attachments	Table 1 and Figure 1, 2, 3.
Instrumentation	**Stream gauges:** **EPA Water Level Monitoring boreholes:** (CLA 065) **EPA Representative Monitoring points:** (CLA 001), (CLA 065).

Information Sources	Cronin, C., Daly, D., Deakin, J., Kelly, D., Drew, D., Johnston, P. (1999) *Ballyvaughan Public Water Supply, Groundwater Protection Zones*. Geological Survey of Ireland and Clare County Council. Daly, D. (1985) *Groundwater in County Galway with particular reference to its Protection from Pollution*. Geological Survey of Ireland report for Galway County Council. 98pp. Deakin, J., Daly D. (2000) *County Clare Groundwater Protection Scheme*. Main Report. Clare County Council & Geological Survey of Ireland. Drew, D. (2001) The Burren and the Gort-Kinvara Lowland, Groundwater Flow Systems in Karstified Limestones. Irish Group. Karst Field Trip October 2001. Unpublished IAH Report. Drew D.P. and Daly D. (1993) *Groundwater and Karstification in Mid-Galway, South Mayo and North Clare.* A Joint Report: Department of Geography, Trinity College Dublin and Groundwater Section, Geological Survey of Ireland. Geological Survey of Ireland Report Series 93/3 (Groundwater), 86 pp
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae.

Table 1. List of Rock units

Rock unit name and code	Description	Rock unit group	Aquifer Classification
Aillwee member (lower) (BUal)	bedded & massive fossiliferous limestone	Dinantian Pure Bedded Limestones	Rkc
Balliny Member (SLbi)	cyclical crinoidal limestone	Dinantian Pure Bedded Limestones	Rkc
Ballyelly Member (SLbe)	nodular & crinoidal limestone with chert	Dinantian Pure Bedded Limestones	Rkc
Black Head Member (BUbh)	limestone & dolomite with corals	Dinantian Pure Bedded Limestones	Rkc
Castlequarter Member (TUcq)	monotonous limestone and dolomite	Dinantian Pure Bedded Limestones	Rkc
Coranellistrum Formation (CT)	Medium to thick-bedded pure limestone	Dinantian Pure Bedded Limestones	Rkc
Fahee North Member (SLfh)	fossiliferous limestone with chert	Dinantian Pure Bedded Limestones	Rkc
Fanore Member (BUfn)	dolomitised limestone with shale	Dinantian Pure Bedded Limestones	Rkc
Finavarra Member (TUfv)	bioturbated limestone with dolomite	Dinantian Pure Bedded Limestones	Rkc
Hawkhill Member (BUhh)	peloidal limestone with chert	Dinantian Pure Bedded Limestones	Rkc
Maumcaha Member (BUmc)	massive limestone sparsely fossiliferous	Dinantian Pure Bedded Limestones	Rkc
Newtown Member (TUnt)	cherty limestone	Dinantian Pure Bedded Limestones	Rkc
Tubber Formation (TU)	Crinoidal & cherty limestone & dolomite	Dinantian Pure Bedded Limestones	Rkc
Clare Shale Formation (CS)	Mudstone, cherty at the base	Namurian Shales	Pu

Figure 1 Location and Boundaries of GWB

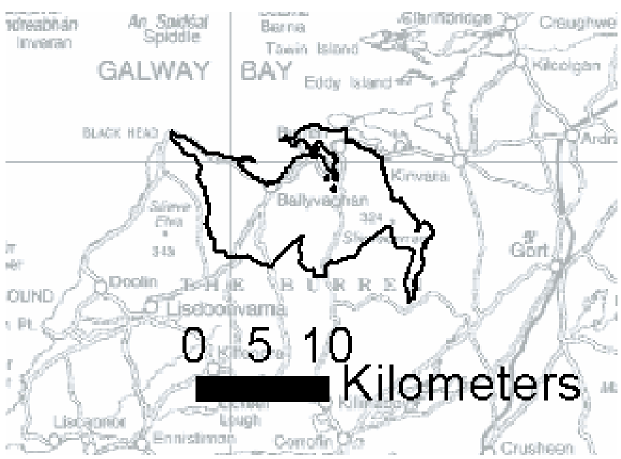

Figure 2

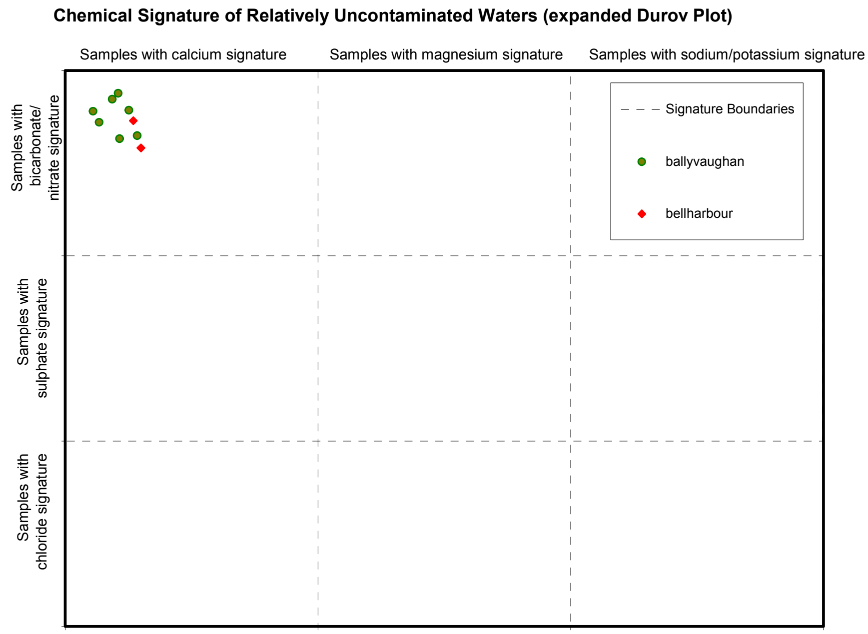

Figure 3 Conceptual model of hydrogeology of the Ballyvaughan GWB (taken from Cronin *et al,* 1999)