Cong-Robe GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
30 Mayo and Galway Co. Co's.	**Rivers**: Robe, Bulkan, Bunnadober, Cloonbur, Buldan, Scardaun, Ballindine. **Streams**: Cloondaver Stream North. **Canals**: Cong Canal **Lakes**: Bekan, Black, Clare, Crahery, Crohery, Drumady, Deen, Aglimmy, Corrib, Mask, Nambrackkeagh, Nanannagh, Shea, Pig Islands, Pollbaun, Polleamagur, Turloughmarlagh.	Lough Carra/Mask Complex (001774), Carrowkeel Turlough (000475), Kilglassan/Cahervoostia Turlough Complex (000504), Greaghans Turlough (000503), Skealoghan Turlough (000541), Ardkill Turlough (000461), Clyard Kettle Holes (000480), Mocorha Lough (001536), Lough Corrib (000297), Ballymaglancy Cave (000474).	440

Topography	The GWB occupies the area between Claremorris and Clonbur. The land surface is undulating with ground elevations ranging from 10-130 mAOD, sloping gently to the southwest. In the eastern area there are drumlinoid features. Elevations are highest (70-130 mAOD) in the northeast of the GWB and lowest in the southwest around L. Mask (5 mAOD). The GWB is bounded by surface water catchments to the northwest and southeast. At the westerly extent it is bounded by the shores of L. Mask and its most southerly section is bounded by L. Corrib.	
Geology and Aquifers	**Aquifer categories**	The main aquifer category in this GWB is: **Rk^c:** Regionally important karstified aquifer dominated by conduit flow.
	Main aquifer lithologies	This GWB is composed of Dinantian Pure Bedded Limestones.
	Key structures	Few faults are mapped in this area; this may reflect the lack of major variation in the rock lithology. The dips are generally less than 5^o in a southerly direction. Between L. Mask and Cong, the bedrock dips $2\text{-}5^o$ to the southeast and in the vicinity of Cong the bedrock dips $10\text{-}15^o$ to the northwest, thus in the area of Cong there is a shallow syncline dipping to the southwest. Well defined N-S and E-W joint sets are evident throughout the area (Drew and Daly, 1993).
	Key properties	**Karstification** is widespread, and in the area of Cong the limestones are extremely karstified (Drew and Daly, 1993). Recorded karst features number 93, but are considered to represent only a fraction of existing features. Turloughs are particularly prevalent in the vicinity of Hollymount. All but two (classed as turloughs) of the currently known karst features occur to the south of the River Robe. It is likely that this is due to the presence of thicker till north of the Robe. Stream density is far greater to the north of the River Robe, illustrated in Figure 1. **Transmissivity and Storativity:** Specific capacities of 1 m^3/d/m and 240 m^3/d/m were obtained for two boreholes in the vicinity of Hollymount, implying variability in transmissivity (Coxon and Drew, 1986). Transmissivity is estimated to range from 1 m^2/d to greater than 250 m^2/d. Well hydrographs show a range of responses to rainfall. This is illustrated in Figure 2. The responses range from less than 1m to greater than 5m. Storativity is low - approximately 0.01-0.02 (Daly, 1985). Many of the spring flows rise and fall quickly in response to rainfall events reflecting the low storativity. Drew and Daly (1986) suggest that the residence time for a tracer is about ten times the initial transit time, indicating low storativity. Furthermore during prolonged drought many springs cease to flow and well yields drop significantly. **Groundwater Velocity, Gradient and Flow directions:** Tracer tests indicate variable groundwater velocities. Groundwater velocities have been measured at 10-100m/hr (Drew and Daly, 1993). Faster velocities exist between L. Mask and L. Corrib – measured 250-600 m/hr. To the east and north of Hollymount flow directions are generally expected to be to the southwest and west. In the area to the south of Hollymount flow directions are east to west under hydraulic gradients of 0.0008-0.00175 (Coxon and Drew (1986); Drew and Daly (1993)). This is illustrated in Figure 3. Between L. Mask and Cong Springs the flow directions are to the south. Although, there are two surface water catchments within the GWB, a *key* aspect is that groundwater can flow across the surface water divides and beneath surface water channels, as evidenced by a positive tracer test linking a turlough east of Cregduff spring to Fountainhill spring (Coxon and Drew, 1986). This is illustrated in Figure 4. As can be seen by comparing Figure 4 and 5 groundwater flow directions do not always relate to expected flow patterns. This is also the case between L.Mask and L. Corrib: tracer tests show there are N-S flow lines between L. Mask and L. Corrib but from the interpreted water table map for the area E-W flow lines could be inferred (Drew and Daly, 1986).
	Thickness	Tracer tests and chemistry suggest that maximum groundwater flux is in the uppermost 10-15 m but karstification extends to a depth of 50m (25 m below sea level) in the Cong area (Drew and Daly, 1993). However, during high water conditions the saturated zone increases in thickness by less than 10 m, thus large amounts of groundwater flows at low stage conditions, i.e., at depths of up to 20-25 m below sea level.
Overlying	**Lithologies**	Till is the dominant subsoil type, covering approximately 64% of the GWB. Cutover Peat comprises 13% of the area. Sand/gravel covers approximately 3% and alluvium approximately 1%. A full breakdown of the subsoil lithology is given in Table 1.

	Thickness	To the west and south of Kilrush, the subsoil thickness is markedly less, as evidenced by the occurrence of "karstified bedrock at surface" and "rock at surface" – predominantly in the western and southwestern parts of the GWB. To the east of Kilrush the thickness of the till is up to 20 m in places (Coxon and Drew, 1986).
	% area aquifer near surface	Approximately 15% is classified as "karstified bedrock at surface" and "rock at surface" using the subsoils classification. The majority of this area is in the western and southwestern areas.
	Vulnerability	*[Information to be added at a later date]*
Recharge	**Main recharge mechanisms**	Both point and diffuse recharge occur. Diffuse recharge occurs via rainfall percolating through permeable subsoil and rock outcrops. Despite the presence of peat and till, point recharge to the underlying aquifer occurs by means of swallow holes and collapse features/dolines. Dolines have been recorded even in areas of thick peat deposits (Hickey et al, 2002). Point recharge occurs via many small sinks that are present in the low permeability till areas where the subsoil is breached. Along the whole southeastern shore of L. Mask there are swallow holes. Recharge also occurs along 'losing' sections of streams. Water from the Cong canal recharges to groundwater along its entire length and in all but the highest groundwater conditions (Drew and Daly, 1993). Along the river Robe, downstream of Kilrush recharge to groundwater occurs as the water table drops below the bed of the river.
	Est. recharge rates	*[Information to be added at a later date]*
Discharge	**Large springs and large known abstractions (m^3/d)**	Large Springs: Hatchery Springs (150,000 m^3/d) (Cong canal is dry), Bunatober (5,000 m^3/d), Cregduff (7,000 m^3/d), Fountainhill Cross (12,000 m^3/d), Loop Spring (750 m^3/d), Kilrush (1,500 m^3/d), Ballindine (3,000 m^3/d). Total 'natural' spring discharge at Cong was approximately 3 million m^3/d.
	Main discharge mechanisms	The main discharges are to the streams and rivers north of the River Robe and to the large springs to the south. Most of the drainage reaches L. Mask before leaving the lake via a large number of sinks on its southern shore. The two lakes are interconnected by complex conduit systems. Cong Springs is the outlet for the outflow from L. Mask to L. Corrib. Artificial routing of groundwater is also an important discharge mechanism: examples include the Cong Canal and the artificial conduit linking the Cregduff springs to the River Robe. Streams flowing east off the Silurian rocks of the Maam-Clonbur GWB sink underground at the contact with the limestones, emerging from small springs to the south of L. Mask or from the large springs at Cong (Drew and Daly, 1993).
	Hydrochemical Signature	The groundwater has a calcium bicarbonate signature. Data are available for Lissatava GWS (spring) and Ballindine PWS (spring) and selected parameters are presented as follows. Alkalinity (mg/l as $CaCO_3$): Lissatava, N= 13, range 106-416, median 340. Ballindine, N= 15, range 100-380, median 332. Total Hardness (mg/l): Lissatava, range 122-452, median 376 (very hard). Ballindine, range 126-400, median 368. Conductivity (μS/cm): Lissatava, range 612-822, median 730. Ballindine, range 640-752, median 724.
Groundwater Flow Paths		These rocks are generally devoid of intergranular permeability. Groundwater flows through fissures, faults, joints and bedding planes. In pure bedded limestones these openings are enlarged by karstification which significantly enhances the permeability of the rock. Karstification can be accentuated along structural features such as fold axes and faults. Groundwater flow through karst areas is extremely complex and difficult to predict as evidenced by flow lines delineated from tracer tests contrasting with water table maps. 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). Flow velocities can be rapid and variable, both spatially and temporally. Rapid groundwater flow velocities indicate that a large proportion of groundwater flow takes place in enlarged conduit systems. Groundwater flow in highly permeable karstified limestones is of a regional scale. Flow path lengths can be up to a several kilometres in length. Overall groundwater flow will be towards the rivers and lakes, but the highly karstified nature of the bedrock means that locally, groundwater flow directions can be highly variable.

Groundwater & Surface water interactions	The area is drained by the River Robe and its tributaries, however the present day drainage network has been changed by arterial drainage that took place early in the nineteenth century. The Bulkan River located in the western part of the GWB is an artificial outlet for the waters from Cregduff spring. Similarly other turloughs have been linked to Cross Springs via channels up to 8 m deep (Coxon and Drew, 1986). The Cong Canal is a famous artificial conduit, linking L. Mask to L. Cong. Figures 5 and 6 show the pre/post arterial drainage network. According to Coxon and Drew (1983), much of the current stream network is a wet weather runoff system that is inactive during summer months. Thus, prior to drainage, streams sank underground via the turloughs present in the GWB. Many of the streams have well defined losing stretches where they lose water to the underground system (Daly, 1985). All outflows from the entire L. Mask catchment become groundwater before entering L. Corrib. During the winter months there is a disproportionate increase in the flow downstream of Kilrush in the river Robe due to large inflows of groundwater to the river associated with high water tables. During the summer the situation is reversed, with upstream discharges up to 300% greater than downstream due to water being lost via the stream bed to groundwater below as the water table is below that of the river (Drew and Daly, 1993). There is a high degree of interconnection between groundwater and surface water in karstified limestone areas such as in this GWB. Even though large areas of peat and tills overlie the body, collapse features in these areas provide a direct connection between the surface and the groundwater systems. Streams flowing east off the Silurian rocks of the Maam-Clonbur GWB sink underground at the contact with the limestones, emerging from small springs to the south of L. Mask or from the large springs at Cong (Drew and Daly, 1993). The close interaction between surface water and groundwater in karstified aquifers is reflected in their closely linked water quality. Any contamination of surface water is rapidly transported into the groundwater system, and vice versa. Furthermore, there are a number of terrestrial ecosystems within this GWB with varying dependence on groundwater (Duchas National Heritage data).
Conceptual model	• The GWB occupies the area between Claremorris and Cong. The land surface is undulating with ground elevations ranging from 10-130 mAOD, sloping gently to the southwest. Elevations are highest (70-130 mAOD) in the northeast of the GWB and lowest in the southwest around Cong (10-20 mAOD). • The GWB is bounded by surface water catchments to the northwest and southeast. At the westerly extent it is bounded by the shores of L. Mask and its most southerly section is bounded by L. Corrib. • The area is principally drained by the River Robe and its tributaries, however the present day drainage network has been changed significantly by arterial drainage that took place early in the nineteenth century. Much of the current stream network is a storm runoff system and is inactive during summer months. Prior to artificial drainage, streams sank underground via turlough sinks. • Within the GWB, a surface water catchment has been shown to be bypassed by groundwater flowing beneath surface water channels and across surface water catchment divides. Tracer tests have shown that flow lines exist that do not relate to the expected flow lines inferred from water table maps. • A large number of karst features are present, particularly in the southwestern part of the GWB. Features include turloughs, caves, dolines, swallow holes and springs. In the area of Hollymount, turloughs are particularly prevalent. • The GWB is composed primarily of karstified limestone ($\mathbf{Rk}^{c}$). Transmissivity is variable. Storativity is low. • Groundwater flows through a network of solutionally enlarged bedding planes, fissures and conduits. • Rapid groundwater flow velocities have been recorded through groundwater tracing. • Recharge occurs via losing streams, point and diffuse mechanisms. Despite the presence of peat and till, point recharge to the underlying aquifer occurs by means of swallow holes and collapse features/dolines. • Most of the groundwater flow occurs in the upper epikarstic layer and in a zone of interconnected solutionally enlarge bedding planes and fissures, generally extending to a depth of 50 m below ground. • In general, the degree of interconnection in karstic systems is high and they support regional scale flow systems. • Some areas in this GWB are of extreme vulnerability due to the thin nature of the subsoil, as well as the frequency of karst features, allowing point recharge. The potential for contaminant attenuation in such aquifers is limited. • The main discharges are to the rivers, large springs, L. Mask and L. Corrib. In winter, groundwater discharges to the many turloughs and transmitted via the artificial channels that were installed to alleviate flooding. • There is a high degree of interaction between surface water and groundwater. There are a number of terrestrial ecosystems which have varying dependence on groundwater. • The groundwater has a calcium bicarbonate signature.
Attachments	Figures 1, 2, 3, 4, 5, 6,. Table 1.
Instrumentation	**Stream gauges:** 30005, 30016, 30017, 30021, 30028, 30031, 30034, 30035, 30036, 30037, 30038, 30039, 30046, 30048, 30085, 30086, 30087. However, none around Cong are read or have any historical data (pers comm. Drew, 2004). **EPA Water Level Monitoring boreholes:** (MAY 64), (MAY 76). **EPA Representative Monitoring points:** (MAY 02), (MAY 32).

Information Sources	Coxon, C., and Drew, D.P. (1986) *Groundwater flow in the lowland limestone aquifer of eastern Co. Galway and eastern Co. Mayo, western Ireland.* In: Paterson, K & Sweeting M. (eds), New Directions in Karst, Norwich, 259-280. 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. 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 Doak, M. (1995) *The Vulnerability to Pollution and Hydrochemical Variation of Eleven Springs (Catchments) in the Karst Lowlands of the West of Ireland.* Unpublished M.Sc. thesis, Sligo Regional Technical College. Hickey, C., Lee, M., Drew, D., Meehan, R. and Daly D. (2002) *Lowland Karst of North Roscommon and Westmeath.* International Association of Hydrogeologists Irish Group. Karst Field Trip October 2002. Unpublished IAH Report. Lee, M. & Daly D. (2003) *County Roscommon Groundwater Protection Scheme.* Main Report. Roscommon County Council & Geological Survey of Ireland, 54pp. Hickey, C., Lee, M., Drew, D., Meehan, R. and Daly D. (2002) Lowland Karst of North Roscommon and Westmeath. International Association of Hydrogeologists Irish Group. Karst Field Trip October 2002. Unpublished IAH Report.
Disclaimer	Note that all calculation and interpretations presented in this report represent estimations based on the information sources described above and established hydrogeological formulae.

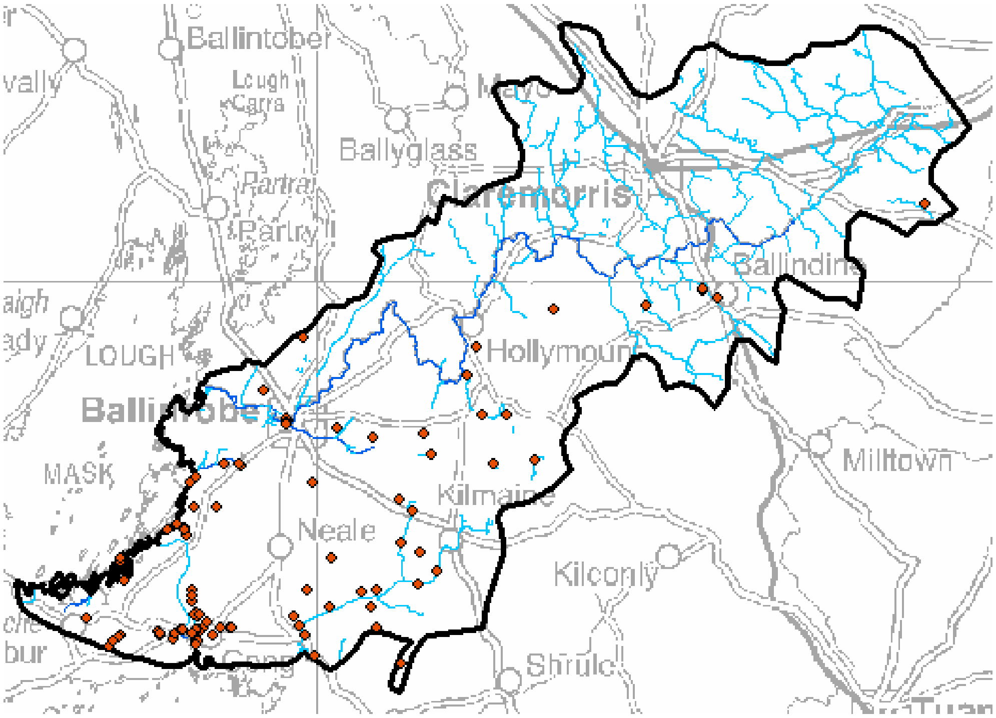


Figure 1. Illustration of the greater stream density north of the Robe and visible karst features generally occurring south of the river.
Note that the boundaries and location of the GWB are also shown.

Figure 2 Borehole hydrographs in the Ballinrobe area (After Coxon and Drew, 1986)

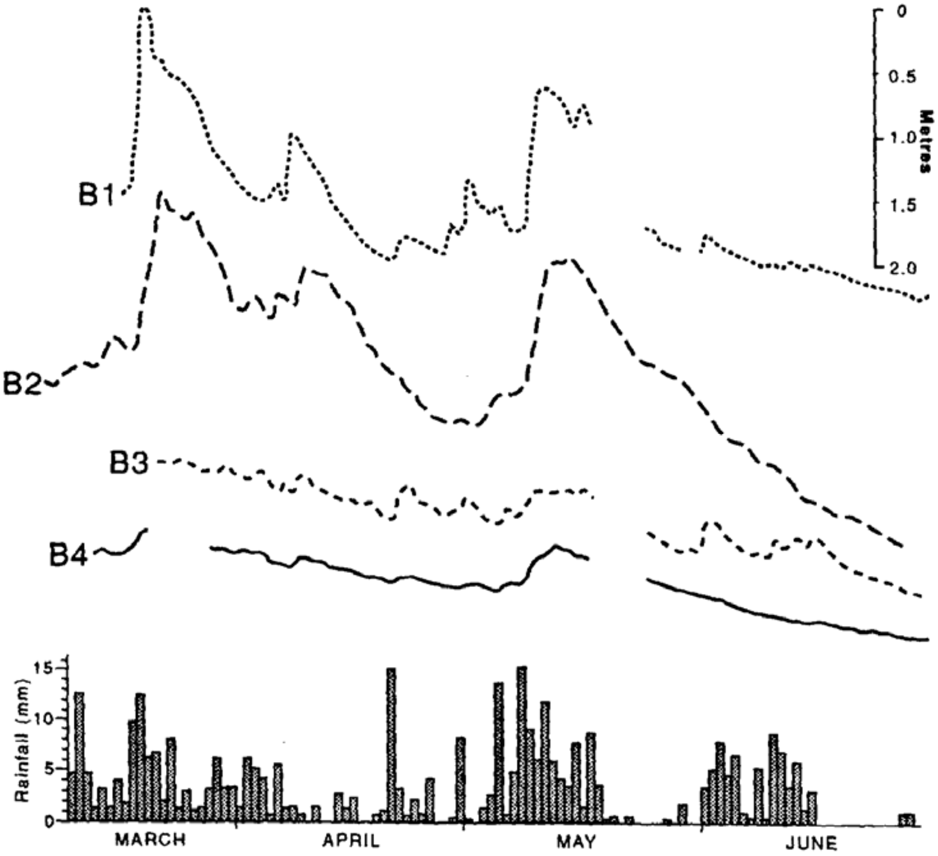


Figure 3 Water table map Cong-Robe GWB (after Coxon and Drew, 1986)

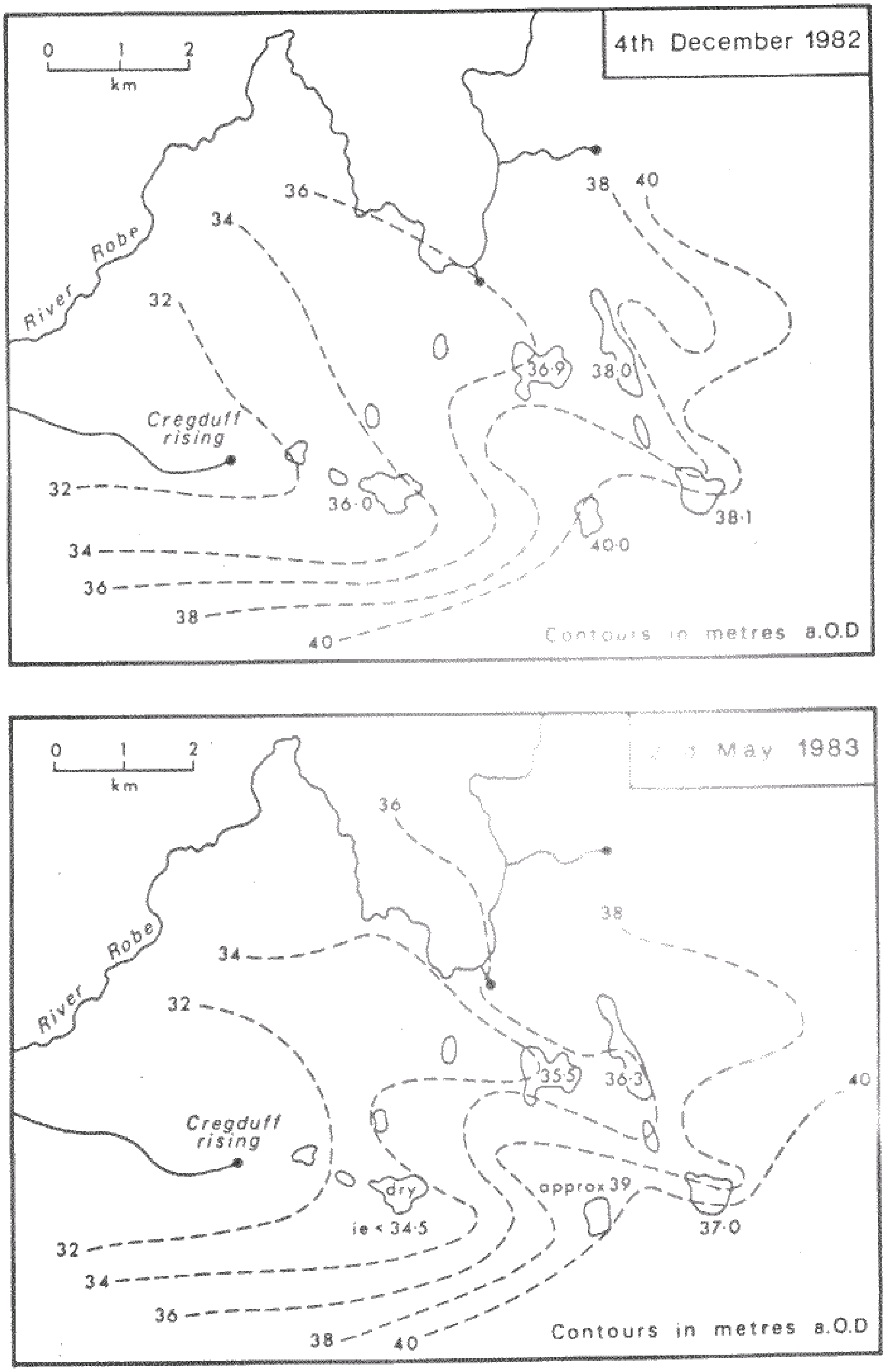


Figure 4 Tracer tests to Cregduff and Fountainhill Springs (after Coxon and Drew, 1986)

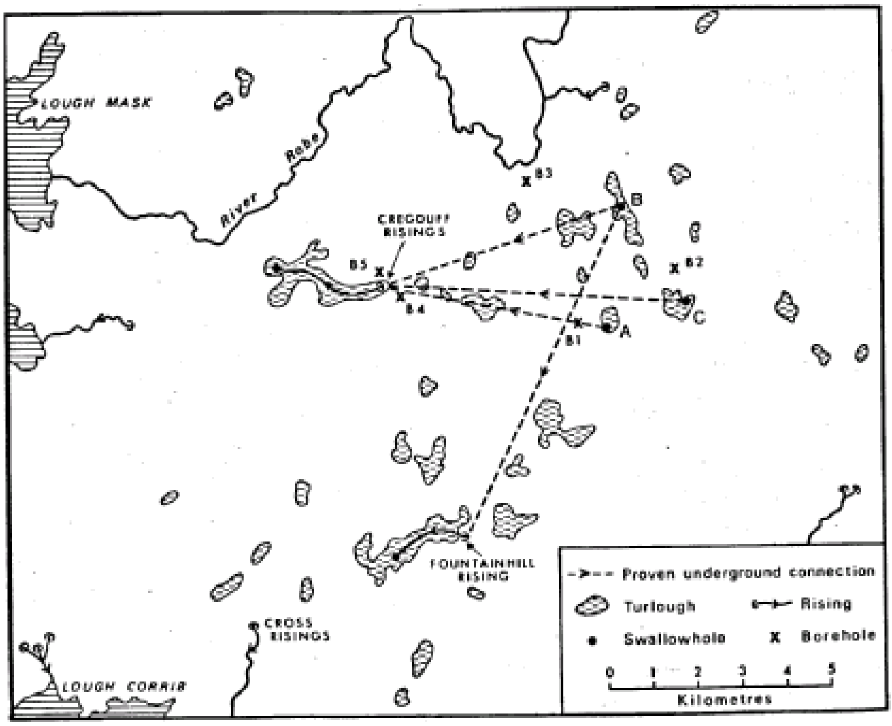
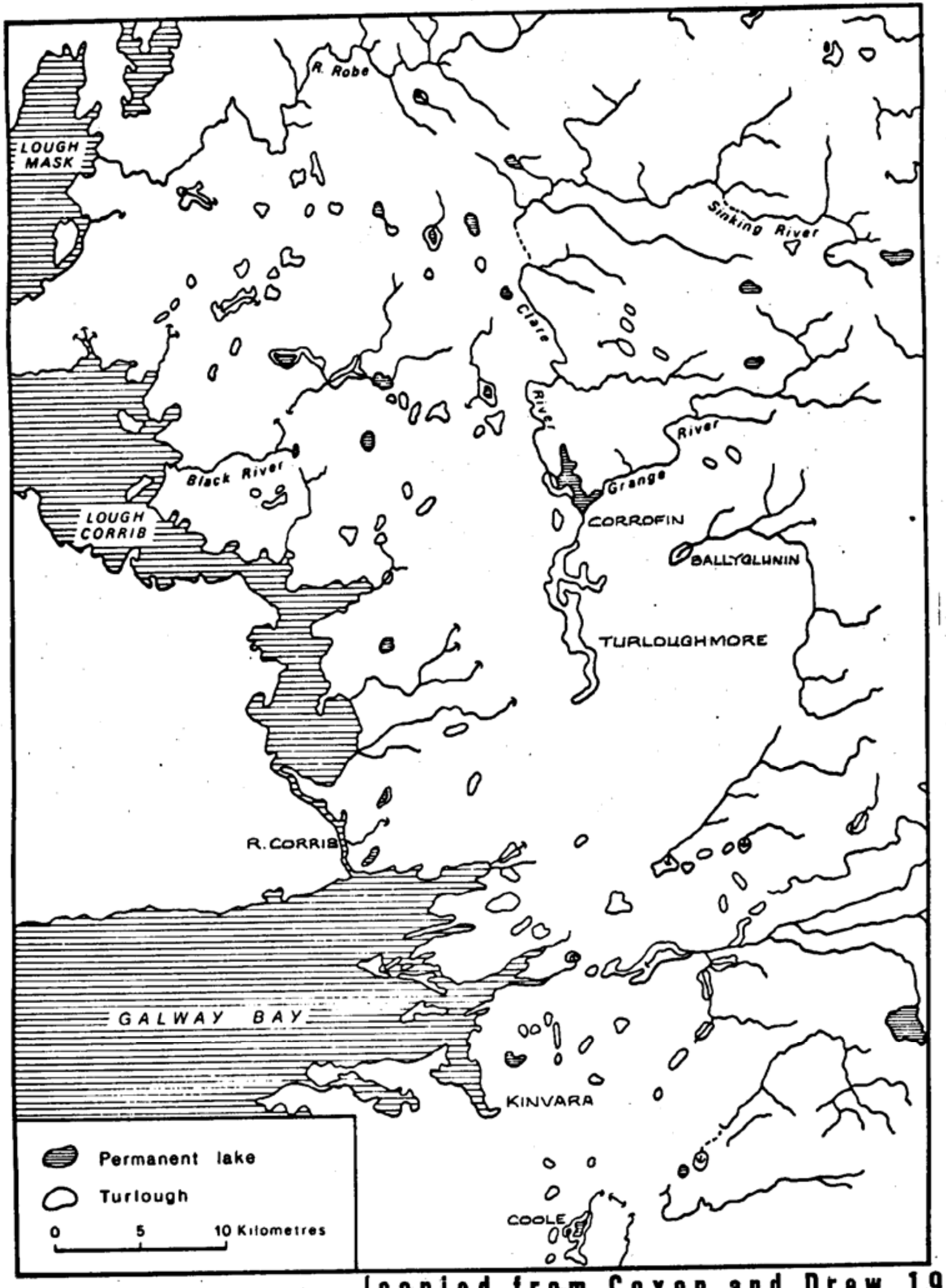


Table 1. Subsoil types in Clare-Corrib Groundwater.

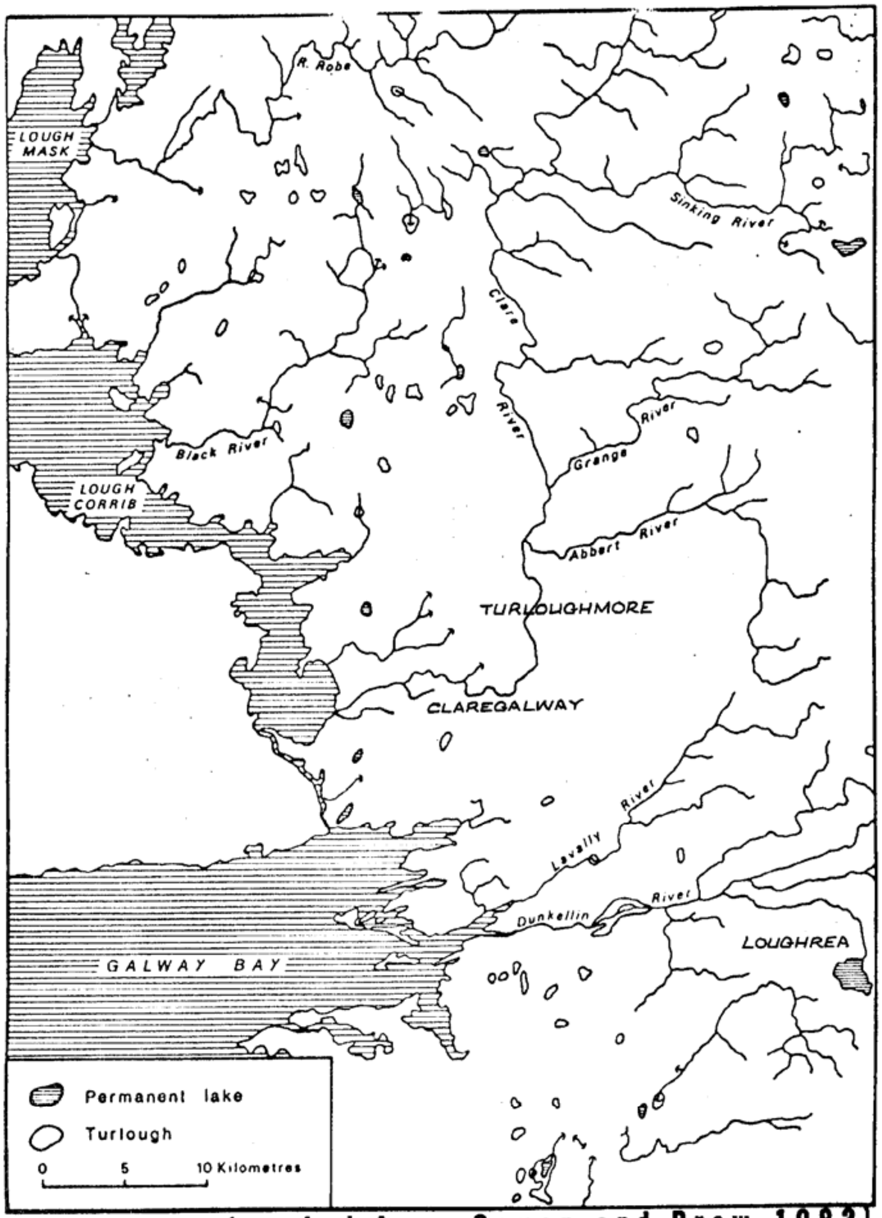
Parent Material	Code	Area sq km	approx. % cover of gwb
Alluvium	A	3.637994837	1%
Blanket Peat	BktPt	11.69248567	3%
Cutover Peat	Cut	56.02191753	13%
Eskers	Esk	1.876210259	0%
Limestone Sand/gravels (Carboniferous)	GLs	13.68548103	3%
Karstified Bedrock at surface	KaRck	60.51438824	14%
Lake Sediments undiferentiatedL	L	0.339230495	0%
Lake Sediments undiferentiatedL	Lake	1.826843357	0%
Madeground	Made	4.07413035	1%
Marl	Mrl	1.510926882	0%
Rock at Surface	Rck	4.395709499	1%
Raised peat	RsPt	0.08418063	0%
Sandstone and shale till (Lower Palaeozoic)	TLPSsS	8.623704196	2%
Limestone Till	TLs	271.5410855	62%

Figure 5 Pre Arterial Drainage.



(copied from Coxon and Drew,1983)

Figure 6 Post Arterial Drainage



(copied from Coxon and Drew, 1983)