Clarinbridge GWB: Summary of Initial Characterisation.

Hydrometric Area Local Authority	Associated surface water features	Associated terrestrial ecosystem(s)	Area (km^2)
29 Galway Co. Co.	**Rivers**: Ballynamanagh, Dunkellin, Craughwell/Dooyertha, Clarinbridge, Kilcolgan, Toberdoney, Corrib, Raford. **Streams**: Carra **Lakes**: Ballinderreen, Cloghballymore, Derreen, Fingall, Kinlea, Loughaunagarraun, Loughaunrone, Parkatleva, Pollnacirca, Stillhouse, Toberawoneen, Tullaghnafrankagh.	Castletaylor Complex (000242), Greganna Marsh (000253), Galway Bay Complex (000268), Kiltiernan Lough (001285), Lough Fingall Complex (000606), Monivea Bog (000311), Rahashane (000322).	375

Topography	The GWB occupies the area between Galway, Athenry, Kinvara and Loughrea, with Clarinbridge at a central location along the coastline. The land surface is low lying and relatively flat, with elevations ranging from sea level to 60 mAOD. The GWB is bounded to the west by the coastline, to the east by the poor aquifer lithologies of the Loughrea GWB, and to the north and south by surface water divides. Location and boundaries are shown in Figure 1.

Geology and Aquifers

Aquifer categories	**Rkc:** Regionally important karstified aquifer. There are small isolated areas (8% of the total area) of **PI:** Poor aquifer, generally unproductive except for local zones.
Main aquifer lithologies	Dinantian Pure Bedded Limestones dominate the GWB. Table 1 gives a list of rock units present in the GWB.
Key structures	Broad open folds with north northeasterly trends predominate with the beds dipping at low angles. A NE-SW trending fault extends into the GWB through Athenry.
Key properties	**Karstification** is widespread, with 97 features recorded. This is considered to represent only a fraction of existing features. **Transmissivity and Storativity:** Yields are variable, being distributed through all the well yield categories. 83% are either “excellent” (>400 m^3/d) or “good” (100-400 m^3/d), and 17% are either “poor” (<40 m^3/d) or “moderate” (40-100 m^3/d) [N=59]. The median yield is 218 m^3/d. Specific capacity values are available for 16 wells. The range is 0.87-1800 m^3/d/m, with a mean of 6 m^3/d/m, thus transmissivities range from 1 to greater than 3000 m^2/d. Transmissivity is estimated from test pumping data to be greater than 3000 m^2/d north of Ardrahan (O’Neill, 2002). Productivity values are distributed throughout all the productivity categories, with 53% either IV or V. Note: productivity is an index relating specific capacity to yield, and the higher the productivity the higher the transmissivity. Interpretation from groundwater flow directions and water tracing tests indicate that a zone of higher transmissivity exists stretching inland from the main Kilcolgan estuary (Drew and Daly, 1993). This zone is shown in Figure 2. The well yield data indicate the variability of the aquifer properties. Water table levels have high annual variations (0.5-18 m) (Drew and Daly, 1993), which indicates that the storativity is low - approximately 0.01-0.02 (Daly, 1985). Furthermore, the sites of greatest annual fluctuations coincide with the location of the main turloughs. The springs reflect the low storativity as many of the spring flows rise and fall quickly in response to rainfall events. **Groundwater velocity:** are in the order of 12-210 m/hr depending on location and groundwater levels. Groundwater velocities are in the order of 12-90 m/hr to Clarinbridge springs and 4-210 m/hr to Dunkellin springs. Groundwater velocities increase by 1.5 in high water conditions. The data suggest a zone of higher transmissivity stretching inland from the main discharge points at the head of the estuaries (Drew and Daly, 1993). **Groundwater flow directions and gradients:** Overall, flow directions are to the west, with groundwater discharging to littoral and intertidal springs at the head of the main estuaries. Figures 3 and 4 show groundwater flow directions under low flow and high flow conditions. Gradients were calculated by Drew and Daly (1993), given below and these reflect an increase in aquifer properties from east to west.

Typical gradients	Western area	Mid basin region	Eastern area
Summer	0.0009	0.003	0.008
Winter	0.002	0.004	0.017

Thickness	Most groundwater flows in an epikarstic layer a couple of metres thick and in a zone of interconnected solutionally-enlarged fissures and conduits that extends approximately 35 m below this. Deeper inflows can occur in areas associated with faults or dolomitisation. Significant fracturing occurs at 8-14 m above sea level and at 15-35 m below sea level (Drew and Daly, 1993).

<table>
<tr><td rowspan="4">Overlying Strata</td><td>Lithologies</td><td>Limestone Till dominates the GWB, accounting for over 75% of the area.</td></tr>
<tr><td>Thickness</td><td>Depth to bedrock ranges from 0-13 m over the southern half of the GWB and 0-20 m over the northern half. Daly (1985) provides analysis on the depth to bedrock and shows that from east to west the general thickness decreases from greater than 3 m to less than 3 m.</td></tr>
<tr><td>% area aquifer near surface</td><td>[Information to be added at a later date]</td></tr>
<tr><td>Vulnerability</td><td>[Information to be added at a later date]</td></tr>
<tr><td rowspan="2">Recharge</td><td>Main recharge mechanisms</td><td>Both point and diffuse recharge occur. Diffuse recharge occurs via rainfall percolating through the permeable subsoil and rock outcrops. Point recharge occurs via swallow holes distributed across the GWB and via discrete sinks located in the beds of the main rivers, which generally rise to the east of the area on the poorer aquifers of the Loughrea GWB and flow onto the purer limestones of this GWB. Thus the majority of the sinks tend to be in the eastern side of the GWB. Migration of the active sink progresses upstream until the uppermost sink can take all the flow. Generally, the intake capacities of the sinks decreases in an upstream direction (Drew and Daly, 1993).</td></tr>
<tr><td>Est. recharge rates</td><td>[Information to be added at a later date]</td></tr>
<tr><td rowspan="3">Discharge</td><td>Large springs and high yielding wells (m^3/d)</td><td>Springs: (mean discharge, Drew and Daly, 1993): Kilcolgan > 100,000 m^3/d, Oranmore >30,000 m^3/d, Clarinbridge >60,000 m^3/d, Kilcornan >40,000 m^3/d

Excellent wells: Athenry: 1,855 m^3/d, 2,180 m^3/d (2), 8000 m^3/d.

420 m^3/d (2), 523 m^3/d (2), 545 m^3/d (5), 545.5 m^3/d (3), 654 m^3/d, 740 m^3/d, 811 m^3/d, 873 m^3/d,</td></tr>
<tr><td>Main discharge mechanisms</td><td>The large springs located at the head of the main estuaries are the main groundwater discharge points. There are also numerous springs located inland, many associated with turloughs. Some of the springs associated with the turloughs also act as sinks (estavelles) for 10-50 days a year (Drew and Daly, 1993). Springs located inland tend to cease to flow during low flow conditions. The two main rivers (Lavally and Dunkellin) drain much of the area and prior to the arterial drainage of the nineteenth century they never maintained an overland course to the sea. For most of the year the rivers (75% for the Dunkellin) sink in turloughs and in wetter conditions the turloughs overflow allowing the artificial channels to conduit water to the sea.</td></tr>
<tr><td>Hydrochemical Signature</td><td>The GWB has a calcium bicarbonate signature as illustrated in Figure 5.

The range and median values for selected parameters for Clarinbridge and Athenry are given below.

<table>
<tr><th></th><th>Clarinbridge (n=6)</th><th>Athenry (n=12)</th></tr>
<tr><td>Alkalinity (mg/l CaCO3)</td><td>276-348;282</td><td>154-376;320</td></tr>
<tr><td>Hardness (mg/l CaCO3)</td><td>300-372;326</td><td>197-400;342</td></tr>
<tr><td>Conductivity (microsiemens/cm)</td><td>607-725;615</td><td>494-743;692</td></tr>
</table>

The coastal springs become brackish under low flow conditions for the whole or a part of the tidal cycle. Salinity has not being detected in boreholes drilled close to the sea even after being pumped intensively (Drew and Daly, 1993).

Surface water derived from the Loughrea GWB have higher concentrations of dissolved iron (0.2-0.7 mg/l in the Lavally River).</td></tr>
<tr><td colspan="2">Groundwater Flow Paths</td><td>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 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 can be up to a several kilometres. Overall, groundwater flow will be towards the two main rivers and ultimately the main springs, but the highly karstified nature of the bedrock means that locally groundwater flow directions can be highly variable. Figures 2 and 3 shows the flow directions in low and high conditions. Figure 5 shows the traced flow lines in the area.</td></tr>
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Groundwater & Surface water interactions	The area is drained by the rivers Lavally and Dunkellin and their tributaries, however the present day drainage network has been changed by arterial drainage that took place early in the nineteenth century. Figures 6, 7 and 8 show the pre/post arterial drainage network. According to Coxon and Drew (1983), much of the current stream network is a wet runoff system that is inactive during summer months. Thus prior to drainage, streams sank underground via the sinks within turloughs, approximately 5-15 km from the coast, before being discharged as springs on the coast. Artificial channels link the lower part of the catchments to the sea which conduit water during wet periods. The drainage density has increased from 0.2 to 4.0 km/km^2 (Drew, 1984). 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 GWB, collapse features in these areas provide a direct connection between the surface and the groundwater systems. 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.
Conceptual model	• The GWB occupies the area between Galway, Athenry, Kinvara and Loughrea, with Clarinbridge at a central location along the coastline. The land surface is low lying and relatively flat, with elevations ranging from sea level to 60 mAOD. • The GWB is bounded to the west by the coastline, to the east by the poor aquifer lithologies of the Loughrea GWB, and to the north and south by surface water divides. • 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 tend to be steeper inland. A zone of higher transmissivity stretches inland from Kilcolgan. • Rapid groundwater flow velocities have been recorded through groundwater tracing. • Recharge occurs via point and diffuse mechanisms. Point recharge occurs via swallow holes and via discrete sinks located in the beds of the main rivers. The majority of the sinks in the rivers tend to be in the eastern side of the GWB. • The large springs located at the head of the main estuaries are the main groundwater discharge points. The two main rivers (Lavally and Dunkellin) drain much of the area and prior to the arterial drainage of the nineteenth century they never maintained an overland course to the sea. In winter groundwater discharges to the many turloughs and transmitted via the artificial channels that were installed to alleviate flooding. • 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. • 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 30 m. • Groundwater storage in karstified bedrock is low and the potential for contaminant attenuation in such aquifers is limited. • There is a high degree of interaction between surface water and groundwater. Prior to drainage, streams sank underground via the sinks within turloughs, approximately 5-15 km from the coast, before being discharged as springs on the coast. Artificial channels link the lower part of the catchments to the sea which conduit water during wet periods.
Attachments	Table 1, 2, 3 and Figure 1, 2, 3, 4, 5, 6, 7 and 8.
Instrumentation	**Stream gauges:** 29001*, 29002, 29003, 29004*, 29005, 29006*, 29007, 29010, 29011, 29012, 29013, 29014, 29015. * Adjusted dry water flow available **EPA Water Level Monitoring boreholes:** (GAL265), (GAL275) **EPA Representative Monitoring points:** (GAL004), (GAL019)
Information Sources	Daly, D. (1995) *A report on the Flooding in the Glenamaddy area.* Groundwater Section Report File 2.2.7. 34pp. 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. Drew, D.P. (1984). *The effect of Human Activity on a Lowland Karst Aquifer.* In A. Burger (Ed) Hydrogeology of Karstic Terrains : Case histories. International Association Hydrogeologists, Hannover, Vol 1. (1984) p195-200. 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. Naughton, M. (1975) *Groundwater and related features in a temperate limestone area.* B.A. (Mod) Dissertation, (unpublished). Geography Department, Trinity College Dublin. O'Neill Groundwater Engineering. (2002). Project Number 840101. Permission for the continuance and extension of quarry use and retention of plant at Tonroe, Ardrahan, Co. Galway.

Disclaimer	Note that all calculations 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 in GWB

Rock unit name and code	Description	Rock unit group	Aquifer Classification
Newtown Member (TUnt)	Cherty limestone	Dinantian Pure Bedded Limestones	Rkc
Burren Formation (BU)	Pale grey clean skeletal limestone	Dinantian Pure Bedded Limestones	Rkc
Visean Limestones (undifferentiated) (VIS)	Undifferentiated limestone	Dinantian Pure Bedded Limestones	Rkc
Metagabbro & orthogneiss suite (Om)	Undifferentiated	Granites & other Igneous Intrusive rocks	Pl

Figure 1. Location and boundaries of GWB

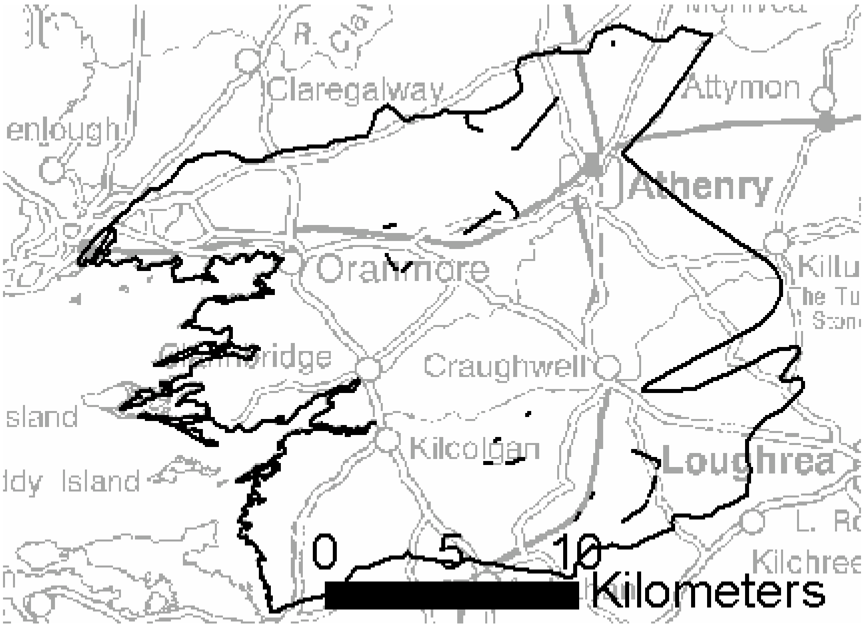
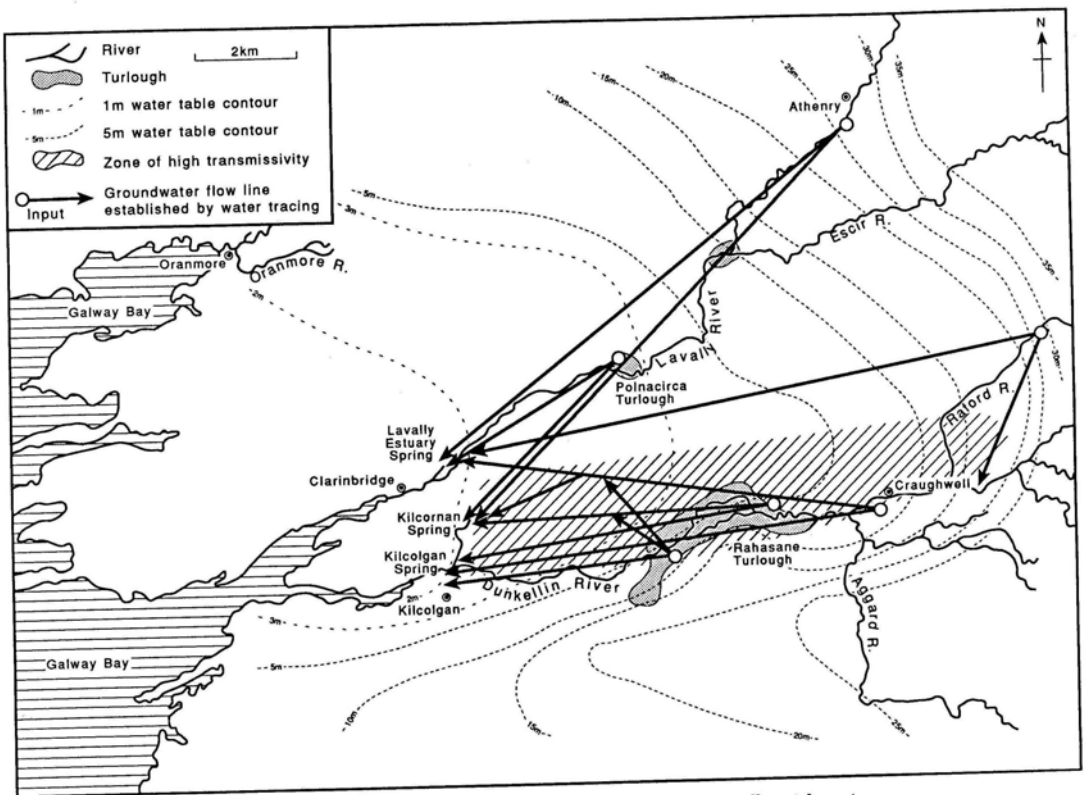


Figure 2. Groundwater flow lines established from tracing and zone of high Transmissivity (taken from Drew and Daly, 1993).



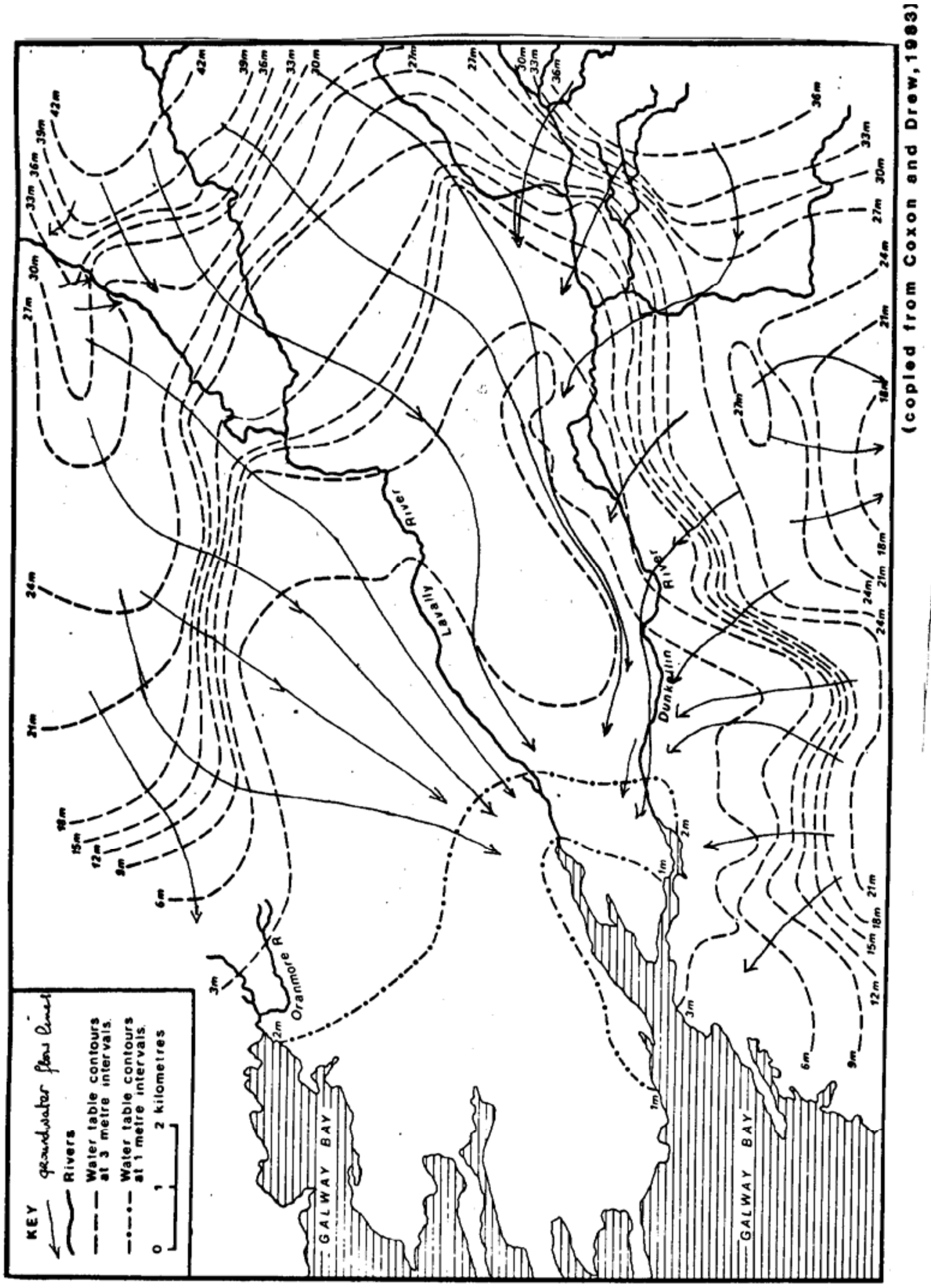


Figure 3 Groundwater flow directions during low flow conditions (taken from (Drew and Daly, 2993).

Figure 4 Groundwater flow directions and levels during high flow conditions (taken from Drew and Daly, 1993).

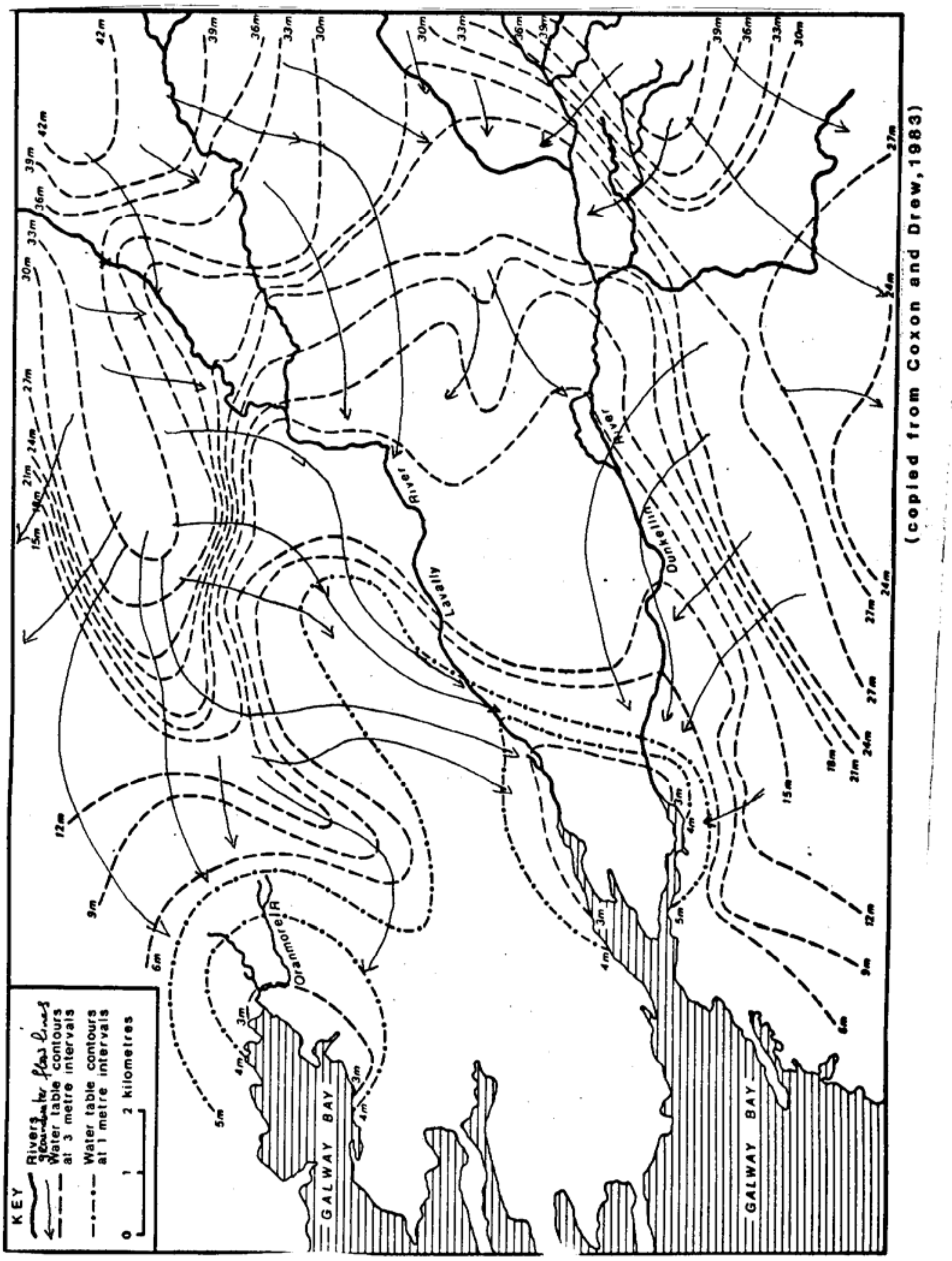
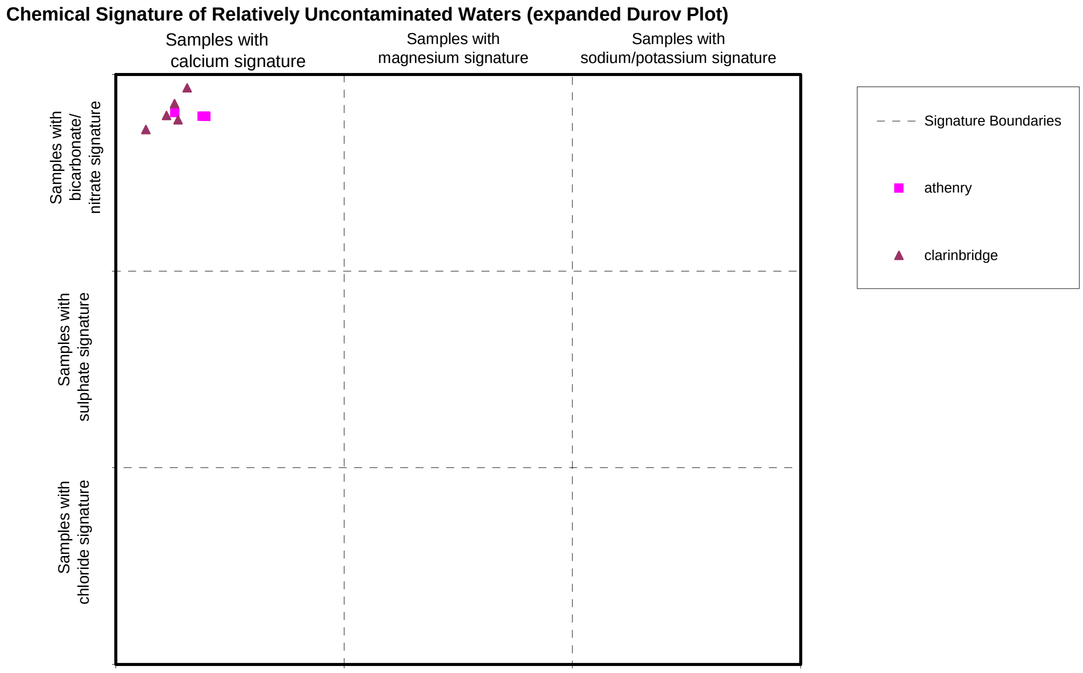


Figure 5 Expanded Durov plot showing hydrochemical signature.



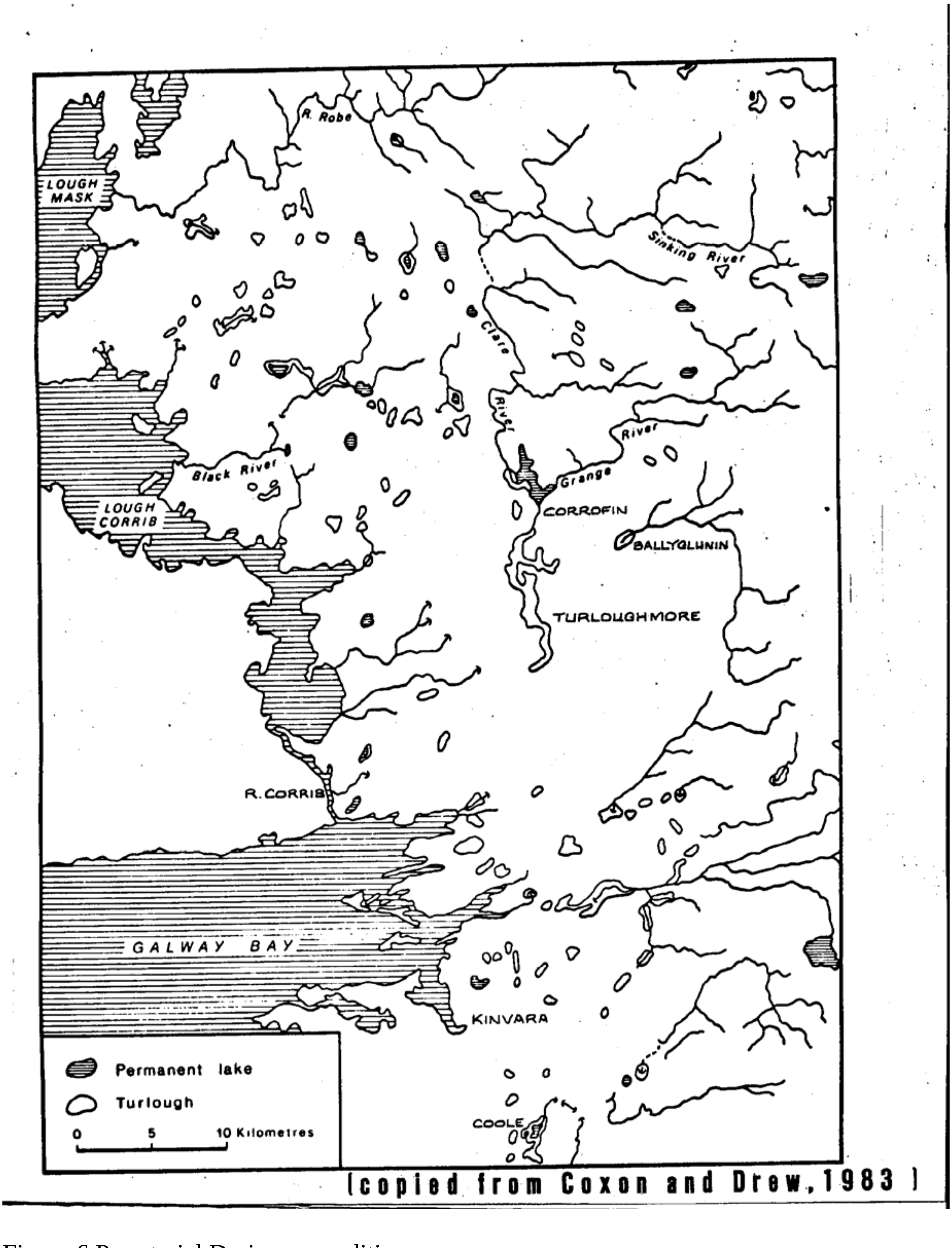
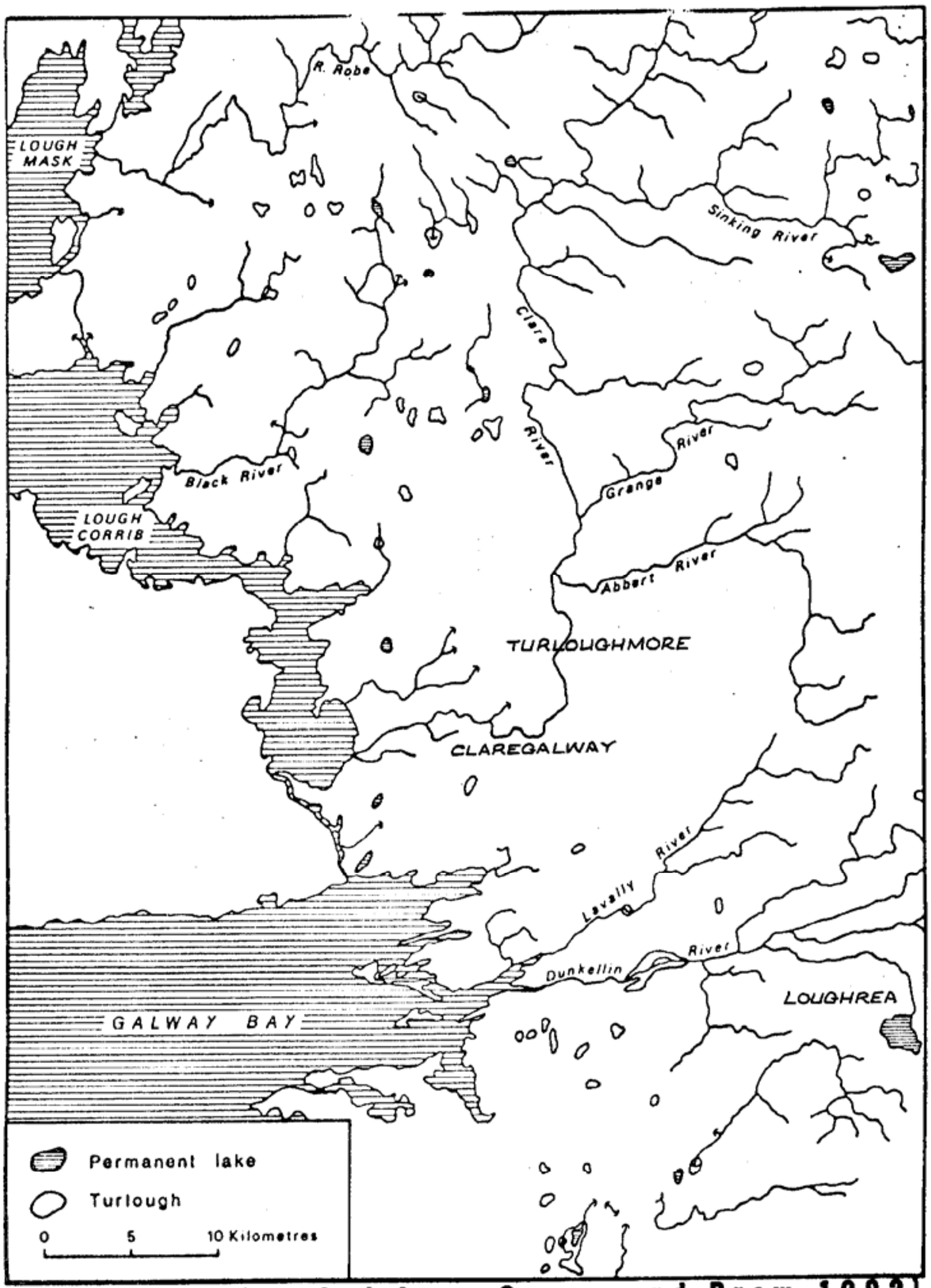


Figure 6 Prearterial Drainage conditions

Figure 7 Post arterial drainage conditions.



(copied from Coxon and Drew, 1983)

Figure 8 Pre/post drainage conditions of the Clarinbridge area (taken from Drew, 1984).