Investigation of Submarine Groundwater Discharge and Preferential Groundwater Flow-paths in a Coastal Karst Area using towed Marine &Terrestrial Electrical Resistivity

Yvonne O'CONNELL*, Eve DALY, Garret DUFFY & Tiernan HENRY
Biogeoscience Group, Department of Earth and Ocean Sciences, National University of Ireland, Galway, Ireland.
*(y.oconnell1@nuigalway.ie)

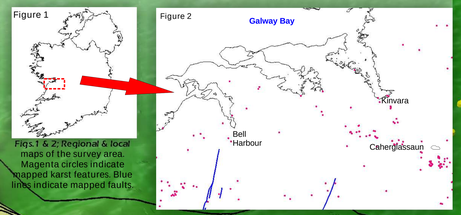
Poster Background Legend:
Background shows DEM of survey area.
Black lines indicate geological boundaries between various limestone formations (GSI).
Yellow circles indicate mapped karst feature (GSI).
Blue lines indicate faults (Pracht, 2004).

1. INTRODUCTION

Large volumes of groundwater, containing nutrients and contaminants enter the coastal waters of southern Galway Bay on the west coast of Ireland through intertidal and submarine groundwater discharge (SiGD). The SiGD occurs through karstified Carboniferous limestone in a major karst region comprising the Burren and Gort Lowlands. The Carboniferous limestones have experienced extensive dissolution resulting in the development of an underground network of conduits and fissures across the region.

Groundwater discharge to the sea in this area is exclusively intertidal and submarine. There is no surface drainage from rivers. Storage in the karst is limited and typical winter rainfall conditions result in the karst system becoming saturated. Temporary lakes (turloughs) form in low-lying areas and act as large reservoirs which provide storage to enable the transmission of the large volumes of water in the system to the sea.

This research aims to investigate preferential groundwater flow-paths and SiGD locations in order to quantify the groundwater-seawater interactions in the coastal zone providing information that will help to assess the impact of climate-driven flooding and sea-level rise on coastal communities and lead to better management of coastal karstic aquifer systems in Ireland.



Figs 1 & 2; Regional & local maps of the survey area. Magenta circles indicate mapped karst features. Blue lines indicate mapped faults.

2. MARINE ERT & SUB-BOTTOM PROFILING

Work is ongoing in Kinvara Bay in the east of the survey area. The bay is the focal point for much of the groundwater drainage from the lowlands south and east of Kinvara. Groundwater discharges extensively in the intertidal zone at the head of the bay with calculated SiGD rates as high as 198 m^3s^{-1}(Cave & Henry, 2011).

Fig.3; Photo of ERT equipment & cable towed behind boat during Kinvara ERT

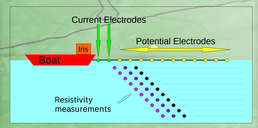


Fig.4; Schematic of ERT cable towed behind boat using Dipole Dipole array.

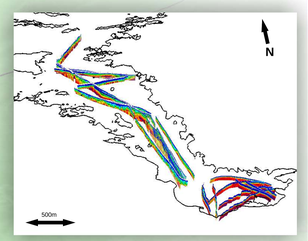


Fig.5; ERT profiles displayed in Fledermaus as vertical images along tow track (vertical exaggeration x5).

Towed ERT profiles (Figures 3 & 4) employing Dipole-Dipole, Schlumberger and Modified Wenner arrays (from Mansoor & Slater, 2007) were recorded throughout the bay (Figure 5).

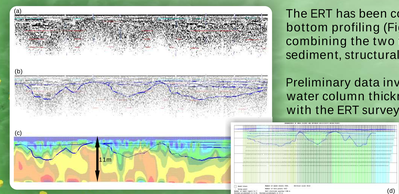


Fig. 6: (a) Chirp profile, (b) Interpreted boundaries, (c)overlay of boundaries with ERT & (d) ERT inversion model with boundaries.

The ERT has been coupled with high-resolution digital chirp sub-bottom profiling (Figure 6). In the absence of ground truthing data, combining the two techniques would allow the determination of sediment, structural and lithological variations beneath the sea floor.

Preliminary data inversions are constrained by incorporating the water column thickness and conductivity, recorded simultaneously with the ERT survey. In addition, multiple layer boundaries interpreted from the sub-bottom profiling (Figure 6b) are being incorporated in to the model (Figure 6d), further constraining the inversion process. The combined inversion should allow improved data interpretation to facilitate more accurate assessment of SiGD locations.

3. STRUCTURALLY CONTROLLED SUBMARINE GROUNDWATER DISCHARGE

Bell Harbour is a small shallow bay located to the west of the survey area. It contains a number of known SiGD points. As part of a broader investigation of the surrounding catchment area, geophysical investigations have recently been carried out to investigate the possibility that the SiGD is linked to the structural geology of the area.

A number of NNE-SSW trending faults are exposed in the limestone hills to the southwest of the bay (Pracht et al, 2004) (Figure 7). In the low-lying areas surrounding the bay and harbour, the faults have not been mapped due to lack of exposure.

Projection of the main fault to the NNE runs through a groundwater fed lake (Muckinish Lough) and through a series of the submarine discharge (SGD) points within the bay. This would imply that the SGD is structurally controlled. To test this hypothesis, terrestrial ERT profiles were recorded at mapped and projected fault locations and towed ERT profiles were recorded within the bay. Profiles were recorded normal to the fault line where possible.

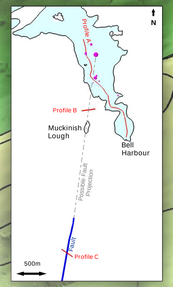


Fig. 7: Map of Bell Harbour with SGD points indicated by magenta circles, red lines indicate ERT profiles & blue line indicates mapped fault.

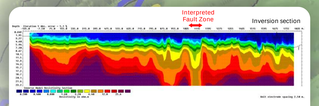


Fig. 8a: Towed profile A.

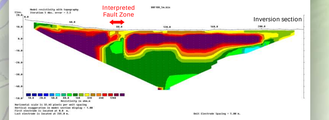
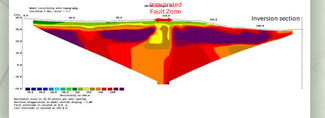


Fig. 8b: Terrestrial profile B adjacent to shoreline.



Fifure 8c: Terrestrial profile C recorded normal to mapped fault.

A towed Schlumberger profile (A), investigating to approximately 20 m below the seabed was recorded in the bay (Figure 8a). Two terrestrial Dipole-Dipole profiles (B & C), investigating to 50 m below ground level (Figures 8b & 8c), were recorded at the locations indicated on Figure 7.

Vertical low resistivity zones recorded in all profiles have been interpreted as indicating the presence of a fault zone confirming the hypothesis that the fault projects to the NNE and influences the SGD in the bay (Figure 9).

Fault resistivities on Profile C recorded 2.5km south of the bay were of the order of 150-500 Ohm-m. Fault resistivities on Profile B nearest to the bay were of the order of 40-80 Ohm-m reflecting probable saline intrusion in to the fault zones.

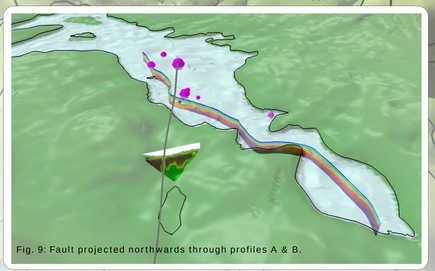


Fig. 9: Fault projected northwards through profiles A & B.

4. GROUNDWATER CONDUIT INVESTIGATIONS

Fig.10; ERT profile Locations. Model conduits indicated by magenta lines. Arrows indicate direction of groundwater flow.

Caherglassaun Lough is located in the southeast of the survey area. Technically a lake, it is fed and drains to groundwater. It is fed by subsurface conduits which drain from uplands to the east. The lake acts as a large reservoir and is prone to flooding during periods of high rainfall. The lake also exhibits a tidal influence despite its location 5.5 km southeast of the seashore.

In this area, groundwater flows in 3 modes (GSI, 2004) - (1) via the epikarst generally extending from 1-10m below ground level as indicated in Figure 13a, (2) via solutionally enlarged conduits and cave systems, extending up to 30m below the epikarst; and (3) via smaller fractures and joints which are linked to the main conduit systems .

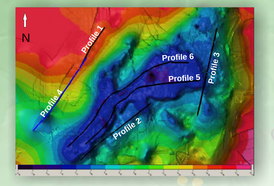


Fig.11; Topographic contours of Caherglassaun Lough.

Fig.12; Photo of cable towed behind boat at Caherglassaun Lough.

A report into the groundwater system of this region (OPW 1998) proposed the conceptual conduit model indicated in Figure 6. Limited information about the dimensions of the conduits is known. To confirm the validity of the model, Dipole-Dipole ERT profiles were recorded around and towed across the lake.

Profiles 1 & 4 (Figure 13a) recorded west of, and down hydraulic gradient from the lake, recorded resistivites as low as 25 Ohm-m focused as two adjacent solutionally enlarged conduits at depths from approx. 0 to -20 mOD. Attempts to model these features gives approx. conduit dimensions of 20x40m assuming a freshwater resistivity of 20 Ohm-m (Figure 13c).

Towed Profile 5 (Figure 13b) also recorded a low resistivity zone (<400 Ohm-m) within the bedrock indicating probable conduits.

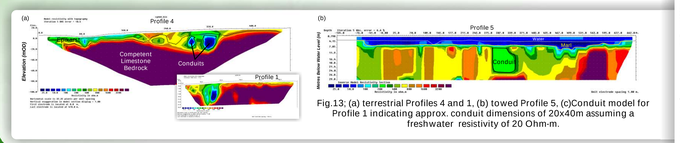


Fig.13; (a) terrestrial Profiles 4 and 1, (b) towed Profile 5, (c)Conduit model for Profile 1 indicating approx. conduit dimensions of 20x40m assuming a freshwater resistivity of 20 Ohm-m.

References

Cave R. & Henry T.. Intertidal and submarine groundwater discharge on the west coast of Ireland, Estuarine, Coastal and Shelf Science 92, 2011.
Geological Survey of Ireland 2004. Kinvara/Gort GWB:Summary of Initial Characterisation. 1st Draft August 2004, www.gsi.ie.
Geological Survey of Ireland website: www.gsi.ie
OPW, 1998. An Investigation of the Flooding Problems in the Gort Ardrahan Area of South Galway Final Report, Office of Public Works/ Jennings O'Donovan and Southern Global Water.
Mansoor N. & Slater L.. Aquatic electrical resistivity imaging of shallow-water wetlands, Geophysics, Vol. 72, No. 5, 2007.
Pracht M. et al 2004. Geology of Galway Bay. Geological Survey of Ireland, 2004.

Acknowledgements
I would like to acknowledge the Griffith Geoscience Research Fund & my EOS colleagues for their help in the fieldwork & data processing.

The work contained in this poster is based on research grant-aided by the Department of Communications, Energy and Natural Resources under the National Geoscience Programme 2007-2013. The views expressed in this study are the author's own and do not necessarily reflect the views and opinions of the Minister for Communications, Energy and Natural Resources".