ASPECTS OF THE HYDROGEOLOGY OF NORTHERN IRELAND

Field Guide

International Association of Hydrogeologists (IAH) Irish Group

2021

Cover page: ***View northwest from the northern flanks of Slieve Binnian, across the Ben Crom Reservoir and the northwestern Mournes in County Down, into the drumlin lowlands of the Poyntzpass Valley, County Armagh.***

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Programme

Saturday 16th October

9.35 Lisburn

Introduction to the field trip, and the area around Lisburn.

The ‘Barbour Well’ and the NI Water Lisburn groundwater abstraction scheme

- **Well History,**
- **NI Water’s use of groundwater (past and future)**
- **Challenges**
- **Changing Policy – Pro’s & Con’s**

Conor Lydon

12.00-12.45 Lunch at Applegreen M2, Newtownabbey

13.30 Garron Plateau and the Antrim Uplands

- **Blanket Bog Hydrogeology, and related environmental aspects**

Ray Flynn

16.15 Loughareema and Murlough Bay

- **The vanishing lake**
- **Rain and surface water interacting with subsurface karstic chalk aquifers**
- **Importance of geological structures including faults and unconformities**

Mark Cooper and Paul Wilson

Sunday 17th October

09.15 Gortmore Viewpoint

- **The view along the north coast, Lough Foyle, Inishowen Peninsula, and Magilligan Foreland**

Mark Cooper and Paul Wilson, with contributions from Ray Flynn

09.45 Magilligan Umbra

- **Completed management work**
- **Tree felling**
- **Buckthorn removal**
- **Hydrogeology**
- **Ecology**

Kyle Hunter, Paul Wilson and Andy Crory

11.15 Magilligan Umbra

- **The network of pumping / monitoring wells installed approx.. 75cm below ground, excavated 'Live' while we are there (shifting sands)**

Ray Flynn, with contributions from Thomas Rowan

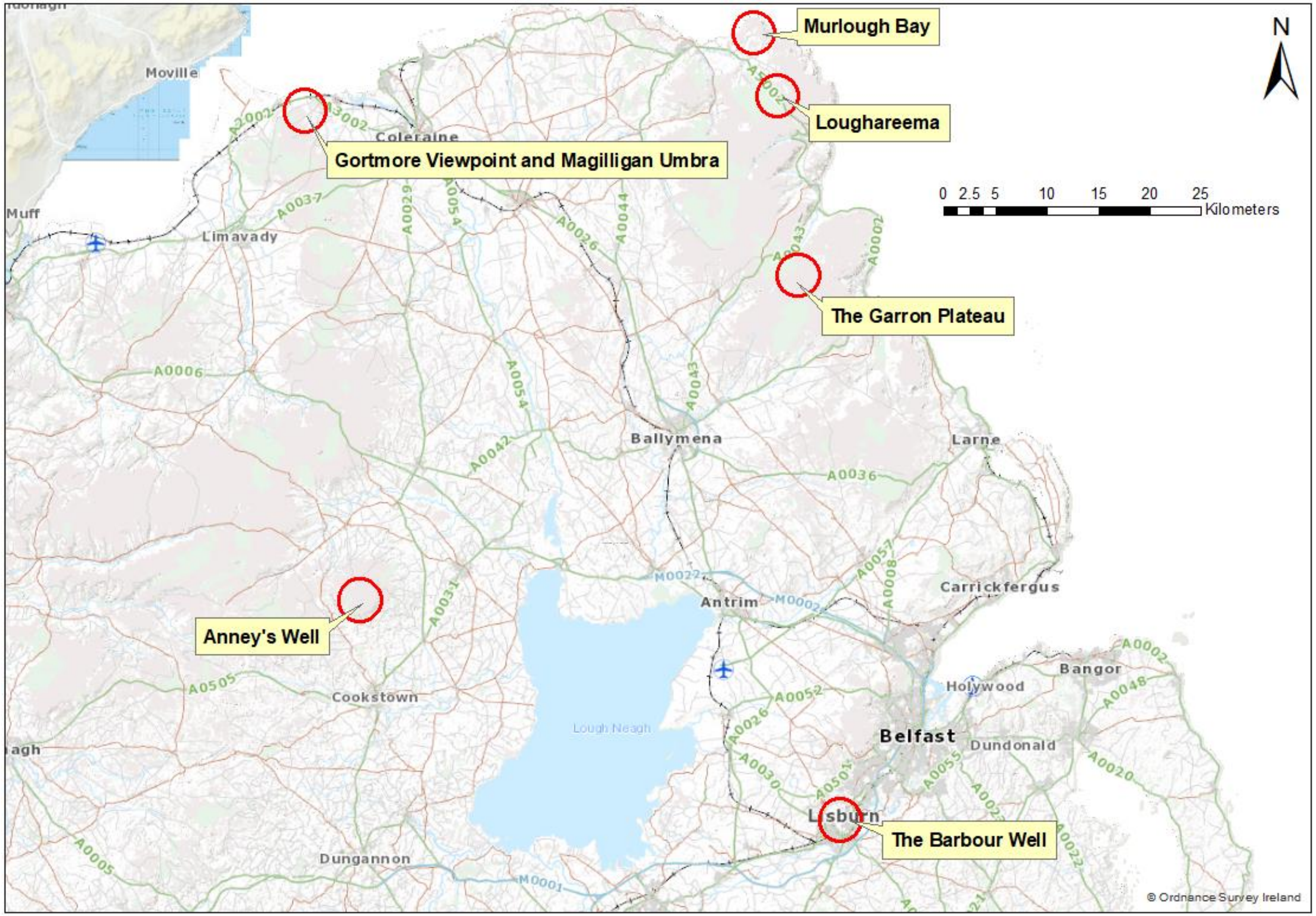
12.45-13.45   Lunch in Silky's Bistro, Dungiven

14.15 Anney's Well

- **Balancing Water Supply requirements**
- **Impact on water dependent receptors**
- **Testing works and findings**

Conor Lydon and Paul Wilson

Location Map



Preface Map, showing field trip stops and other selected localities mentioned in this guide (O.S. Licence EN 0057921).

Preface

It’s good to be back, out there, in the air, meeting with colleagues, with friends, again.

Sharing ideas, thoughts, laughs, jests, and the odd vicious jibe.

And to be International is also somewhat joyous, given that we have just gone through a tough eighteen months of restrictions, on every scale, at every level.

Are we not so lucky to be able to do this job? Does the sun not shine on us most days, unbeknownst to us when things might seem drab?

To me, this is the theme of this year’s Field Trip … how lucky we are as Hydrogeologists to have such a beautiful (yes, beautiful!), healthy, and invigorating occupation. Something that we always love, but as time goes on any taking this for granted should continue to diminish, year on year.

We head to Northern Ireland for our 2021 Annual Field Trip, crossing the border for the first time in many a year.

The discussion should be fierce, as ever !

I, and all on the IAH Committee, hope you enjoy the trip.

Robbie Meehan
IAH Field Trip Secretary, 14th October 2021

Acknowledgements

This field guide would not have been possible without significant efforts from many people, to whom the IAH are most appreciative.

All contributors produced excellent write-ups of sites, and thanks are due to all for giving us their time in preparation and delivery of the excursion. Paul Wilson’s ideas cultivated the majority of the content of the two-day trip, and his willingness to suggest different ways of doing things have made the preparation all the more fruitful and enjoyable.

We would like to thank Northern Irish Water, Mrs. Black at Anney’s Well and all other landowners for giving us permission to visit their lands, and it should be borne in mind that any future visits should only ensure when permission has been sought.

Thanks also to McCaffrey coaches, and to McCaffrey Coaches’ bus driver, for getting us around safely, and to all of the IAH Committee for help and advice.

1. An introduction to the geology of Northern Ireland.
Mark Cooper

This account provides a broad perspective of the geology of Northern Ireland comprising the counties of Tyrone, Londonderry, Antrim, Down, Armagh and Fermanagh. The landscape of Northern Ireland is remarkably varied considering its relatively small area of about 14 000km^2 and is a reflection of the diverse geology on which it has been shaped. Figure 1 provides a geological sketch map of this region showing the rock types occurring in relation to the major towns and cities. This account outlines the geology to a depth of at least a kilometre and summarises the current and historical use of the geological resources in the area.

Much of the surface geology of the province has been surveyed in great detail and can be examined in numerous quarries, stream and coastal exposures of rock and surface deposits. A large number of shallow boreholes, though mainly in urban areas, also provide information on the near-surface geology. Insight into the deeper geology is provided through a collection of about 45 deep boreholes, with depths greater than 200 m, drilled across the region during the last 40 years or so, in search of hydrocarbons, minerals and geothermal resources. A new geophysical survey carried out by low flying aircraft, referred to as the 'Tellus Project', has recently provided new high-resolution data that reveal patterns of the Earth's gravity and magnetic field. Understanding these patterns, when combined with geophysical seismic data obtained by sending sound waves through the ground, allows interpretation of the geological structure to a depth of several kilometres.

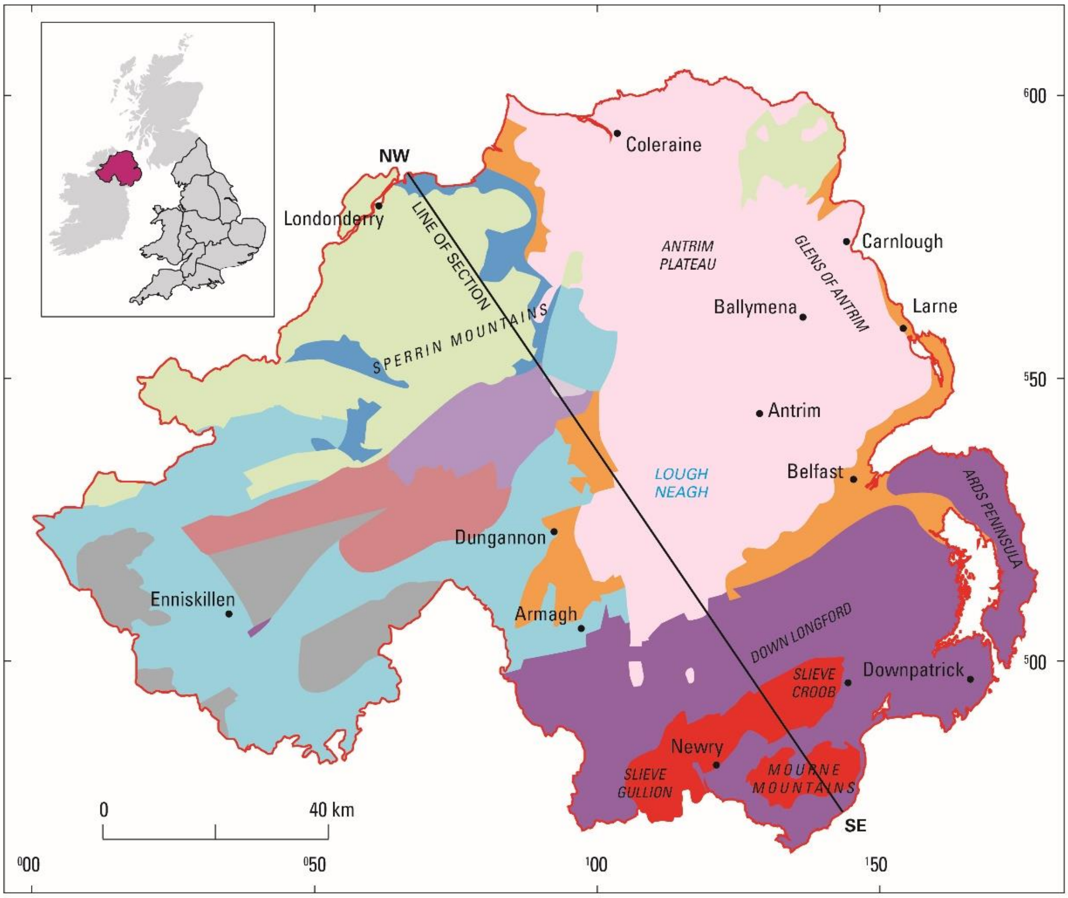
Geologically recent surface deposits

Northern Ireland has widespread geological deposits of relatively recent origin, known as superficial deposits, which formed during the last 2-3 million years of the Earths' history spanning the Ice Ages and Interglacial periods. By far the most abundant of these are glacial sediments, made of mixtures of clay, silt, sand and gravel that were laid down by the repeated growth and decay of former ice-sheets. Other sediments continue to form in lakes, rivers, estuaries and coastlines, whilst on high ground raised bogs of peat have steadily accumulated. Some of the most dramatic glacial landscapes are found in the Sperrin Mountains of counties Londonderry and Tyrone where the mountain ridges are separated by deeply eroded steep-sided valleys. In Antrim, Down and Armagh glacial deposits have been shaped into ridges and swarms of whale-back hills known as drumlins. Most of the superficial deposits are soft and easily eroded, as they have not been deeply buried and consolidated to form strong rocks.

Geology at depth

Below the superficial deposits, or with just a cover of soil where such deposits are absent, are older rocks which geologists broadly split into two distinct types:

- The *sedimentary bedrock geology* is composed of quite hard rocks which were deposited a few hundred to tens of millions of years ago as layers of



Age (My)	Map/Section Descriptor	Geological sub-units	Text sub-units	Text Descriptor
55–60	Palaeogene Igneous Rocks	Mourne granites Antrim Plateau	Basalt lava and granite	Younger Granites
70–275	Permian to Cretaceous sediments	Chalk and Lias groups Mercia Mudstone, Sherwood Sandstone and belfast Groups	Limestones and sandstones Red sandstones and mudstones	Younger Sedimentary Bedrock
315–345	Carboniferous Sediments	Coal Measures	Grey mudstones, sandstone and coal	Older Sedimentary Bedrock including Older Granites
		Carboniferous Limestone and mudstones (Tyrone Group)	Limestone and mudstone	
		Roe Valley Group	Sandstone	
365–415	Devonian Sediments and Igneous Rocks	Fintona and Cross Slieve groups, Newry Granites	Red Sandstones and granite	
430–460	Ordovician and Silurian Rocks	Hawick and Gala groups	Sandstones and mudstones	Basement Rocks
		Leadhills Supergroup	Sandstones	
470–1000	Ordovician Igneous Rocks and Precambrian Metamorphic Rocks	Tyrone Volcanic Group	Gabbro, granite and volcanic rocks	
		Southern Highland Group Argyll Group	Metamorphosed sediments	

Figure 1: Geological sketch map showing the range and distribution of different rock types in Northern Ireland, in relation to the major towns and cities. The extent of the Northern Ireland region is shown on the inset map of the United Kingdom.

sediments in shallow seas, coastal plains or by the action of ancient river systems in times when Northern Ireland lay closer to the Equator and the climate and landscape were very different from those of today.

- The *basement geology,* which underlies the sedimentary bedrock, is over 430 million years old and mainly comprises harder, denser rocks which have been strongly compacted and folded. The basement rocks comprise strongly folded and faulted sedimentary rocks, rocks that are products of volcanic activity (volcanic rocks) or formed from the solidification of molten rock below ancient volcanoes (igneous rocks) and rocks which may have started as either sediments or intrusions but have subsequently been changed into a different form by the high temperatures and pressures which they have been subjected to since (metamorphic rocks).

In the course of the past 650 million years there have been periods when the area of Northern Ireland formed a landmass and was being eroded, and other periods when it was sinking and new layers of sediment were being deposited. The history of erosion and deposition has not been the same in all parts of Northern Ireland. The oldest sedimentary bedrocks are sandstones, siltstones and mudstones. These rocks were buried and deformed by the forces of continental plates moving against each other.

Subsequently, younger sequences of sedimentary rocks, including limestones, sandstones and clays, were laid down. Although in some parts of Northern Ireland, sediments continued to be deposited relatively constantly, in most areas deposition stopped and instead uplift and erosion took place for tens of millions of years. As a result, when deposition restarted the next layer was laid down on a variety of different older sediments. This situation where younger rocks rest directly on rocks of different older ages because of uplift and erosion is referred to by geologists as an unconformity*.*

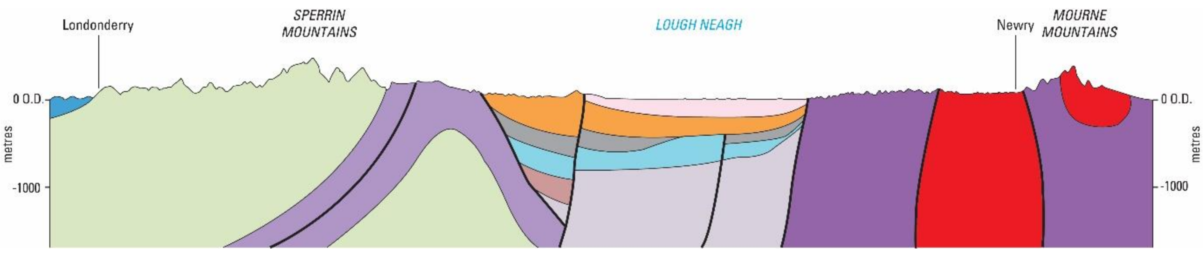


Figure 2: Schematic cross-section through the geology of Northern Ireland. The alignment of the section and key are shown in Figure 1.

The geology of Northern Ireland is also affected by geological faults where the rocks on each side of the fracture have moved relative to one another. The relative movement of the rocks on either side of some of these faults can be very significant resulting in dramatic changes in geology over short distances. These include the Omagh Fault which runs in a northeast to southwest direction from Lower Lough Erne through Omagh to the coast near Ballycastle and the Southern Uplands Fault which runs northeastwards from Armagh to the coast near Belfast. These two major faults continue through Scotland to the edge of the North Sea.

Individual areas

In broad terms Northern Ireland can be divided into four contrasting areas of bedrock and/or basement geology. In the northwest, the Sperrin Mountains in Londonderry and Tyrone are the oldest basement rocks in the Province. The Down-Longford area in the southeast is composed of basement rocks whilst in the Lakelands of the southwest, layers of sedimentary bedrock predominate. The youngest rocks, comprising younger sedimentary bedrock and extensive lava flows are found in the north forming the Antrim Plateau and including the famous columns of the Giant's Causeway. The main geological features of these four areas are as follows:

Sperrin Mountains

The Sperrin Mountains are located in the northwest of Northern Ireland in counties Londonderry and Tyrone. The mountains form northeast to southwest aligned ridges that include the main Sperrin Ridge with the highest peak of Sawel Mountain at 678 m. No sedimentary bedrock lies on top of the basement rocks in this area.

Figure 3: Metamorphic schist from the Sperrin Mountains, County Tyrone.

Basement rocks

The Sperrin Mountains are made of the oldest rocks in the Province comprising metamorphic rocks 650 to 570 million years old resulting from the alteration of sedimentary and volcanic rocks. The sedimentary layers originally accumulated as layers of sandstone, mudstone and some limestone in an ancient ocean. The lavas were erupted onto the ocean floor and form part of the succession of layers. As the ocean closed adjacent continents collided and the oceanic rocks underwent deep burial and contortion under high temperatures and pressures which altered or metamorphosed the entire rock package. This produced schist (Figure 3) and other metamorphic rock types that were then pushed up over younger rocks at the margin of this ocean. The fractured contact between these rock masses is known as the Omagh Fault. The younger rocks, 480 to 465 million years old, are located the southeast of the Omagh Fault and are composed of various igneous rock types such as granite and gabbro. Contained within the metamorphic rocks of the Sperrin Mountains are minerals veins and other deposits rich in gold, silver, copper, lead and zinc.

Down-Longford

This area lies within Down and Armagh and shares a border with the Republic of Ireland. The main settlements in this area are Armagh, Newry and Downpatrick. Again, no sedimentary bedrock lies on top of the basement rocks in this area.

Figure 4: Folded sandstone beds on the Ards Peninsula, County Down.

Basement rocks

In the Down-Longford area basement rocks are found at the surface and extend to depths greater than 6 km. These rocks are mainly sandstones (Figure 4), with mudstones that range in age from 460 to 430 million years old. The rocks have been slightly altered by temperature and pressure (weakly metamorphosed) and have water in the fractures only at shallow depths, deeper the fractures are tightly closed due to the weight of the overlying rocks. The sandstones are used for aggregate, the best of which is used for road surfacing. Gold has also been found associated with these rocks and may become economically important in future years.

There are two generations of molten rock or magma which were intruded into the basement rocks of this area and then cooled and solidified to form granitic igneous rocks. An older group, found in the vicinity of Newry (from Slieve Gullion to Slieve Croob), are about 420 million years old. The younger group are the granites that form the Mourne Mountains, only 55 million years old, and were formed along with the lavas in Antrim as a consequence of the initial opening of the North Atlantic Ocean. The Mourne granites contain sufficient naturally radioactive minerals to produce geothermal heat. They are exposed at the surface but are not thought to extend to much more than 1 km depth. The older granites extend to several kilometres depth.

Lakelands

The Northern Ireland Lakelands occupy much of County Fermanagh, which shares a border with the Republic of Ireland. In addition to the many tranquil lakes there are sheer cliffs and mountains many composed of limestone, and possessing extensive cave systems including Marble Arch. The principal settlement is Enniskillen.

Sedimentary Bedrock

The Lakelands are composed of older sedimentary bedrock compose of layers of limestone, sandstone and mudstone with thin coal beds, which formed between 360 to 300 million years ago in a variety of tropical environments such a warm shallow seas, swamps, rivers and deltas. This rock sequence can be divided into an upper sandstone rich unit (Coal Measures and Millstone Grit) and a lower limestone rich (Carboniferous Limestone) unit; their combined thickness is greater than 7 km.

The upper sandstones and mudstones (Figure 5) contain coal seams and are potential sources for oil and gas. These rocks formed when vast quantities of sediment were transported by large river deltas. Occasionally the tops of these deltas were exposed, which allowed massive swampy forests to develop. After burial the vegetation from these forests was compressed to produce layers of coal.

The limestones formed in shallow tropical seas. Being soluble, the limestones have been dissolved by rainwater percolating through them to form many caves, dry valleys and sinking streams. Landscapes where drainage is underground through caves in this way are called karst landscapes. Such features are especially well developed in the Cuilcagh Mountain area. The limestones form an important source of drinking water for public supply, with the water flowing through the caves and fissures in the rock. The limestones and their associated mudstones also include layers with potential as sources of shale gas.

Figure 5: Carboniferous mudstones in a quarry near Dungannon, County Tyrone.

Basement rocks

In only one place do Basement rocks equivalent to those of the Down-Longford area come to the surface. However, evidence from deep boreholes across the region indicates that these rocks continue below the old sedimentary bedrock layers but over most of the area this is at a depth of several kilometres.

Antrim Plateau

This area is mainly within Antrim but extends westwards into Londonderry. It is largely an upland area, covered by thin glacial superficial deposits formed as a consequence of ice that built up around Lough Neagh. The steep sided river valleys or Glens of Antrim are found on the eastern margin of the plateau. The main settlements are Londonderry, Coleraine, Ballymena, Antrim and Belfast.

Sedimentary Bedrock

The Antrim Plateau is a unique geological area of the UK in that it contains an almost continuous sequence of flat-lying layers from 420 to 30 million years old. The uppermost layer of the plateau is composed of hard, black basalt lava that erupted from deep fissures in the Earth's crust as the North Atlantic Ocean began to open about 60 million years ago. In places as much as 1 km of basalt are known to be present. Below the basalt, is a layer of the Chalk up to a maximum of 120 m thick (Figure 6), which was laid down in an ocean about 80 million years ago. Chalk is a fine grained white rock composed of fragments and microfossils of calcium carbonate; it is a special type of limestone. The Chalk of Northern Ireland is unusual because it is extremely hard. The value of chalk lies in its purity which makes it much sought after as a raw material. Around the margins of the Plateau caves have been formed in the chalk where it has been dissolved by slightly acidic rain and stream waters.

Figure 6: Landslip blocks of black basalt on top of white Chalk, north of Carnlough, County Antrim.

Beneath the Chalk the rocks are 200 million year old mudstones and limestones that are up to 250 m thick, which formed in warm shallow seas that existed at a time when dinosaurs roamed the Earth and Northern Ireland lay south of the Equator. Because of their position below the harder chalk and basalt some of the softer mudstone layers are responsible for often spectacular landslips that are seen around the coast of County Antrim. Deeper still lie red mudstones and sandstones comprising the Mercia Mudstone and Sherwood Sandstone. This sedimentary sequence is known to be up to 3 km thick in the vicinity of Larne and was laid down between 300 to 200 million years ago by rivers, lakes and sand dunes in desert environments. The sandstones contain pores, or spaces between the grains that can hold water, oil or gas. So this layer is an important aquifer, meaning it can be used to supply drinking water, and a potential reservoir for oil and gas resources.

Finally rocks, ranging between 420 to 300 million years old, are also found in places below the Antrim Plateau and indicate that shallow seas and deltaic environments existed here at a time when Northern Ireland lay in tropical latitudes. These rocks are rich in fossil plant material that is most obvious when seen as coal and less so when trapped in black mudstones. These carbon rich rocks, the Coal Measures, are economically vital in that they contain coal seams and are potential sources for oil and gas.

Basement rocks

The basement rocks are deeply buried throughout this area. In northeast Antrim they are known to be metamorphic rocks identical to those of the Sperrin Mountains.

2. The 'Barbour Well' and the Northern Ireland Water Lisburn Groundwater abstraction scheme.
Conor Lydon

Introduction and background

Northern Ireland Water is responsible for supplying the public with clean drinkable water in Northern Ireland. In 2021, 99.9% of all public water supplied is from surface water sources. This is out of kilter with the rest of Ireland, Great Britain and many other countries in Europe. One of the main reasons for the strong reliance on surface water is that Northern Ireland has several large upland sources; including the largest freshwater lake in the British Isles: Lough Neagh; supplying 40% of Northern Ireland's water requirements.

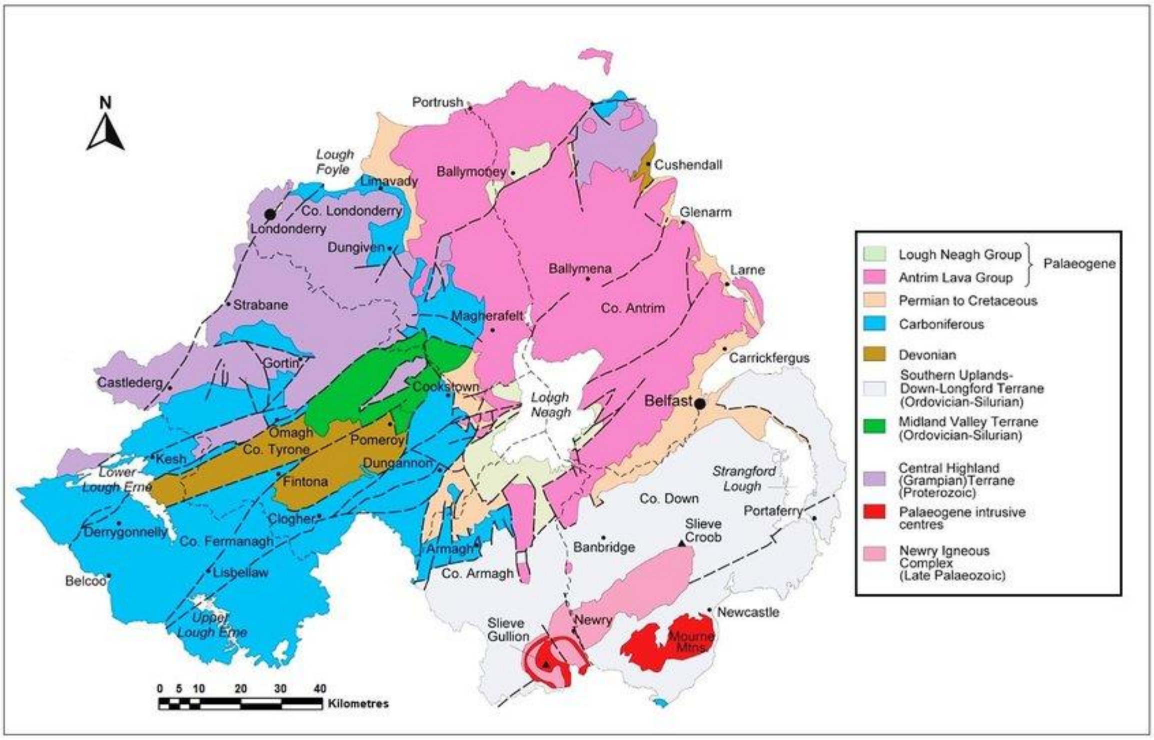


Figure 7: Simplified Geological Map of Northern Ireland, Mitchell (2004).

Those tasked with evaluating Northern Ireland's supply and demand requirements in the 1980's saw "effectively no hydrological limit on the use of Lough Neagh for water supply". Northern Ireland faced a growing demand for water from the early 1970's; a trend which continued throughout the late 1980's and 1990's. In 2002, Northern Ireland Water published their Water Resource Strategy and the strategy saw no future for groundwater. From this point on, NI Water progressively abandoned their seventy strong network of springs and borewells supplies in favour of surface water sources. The financial cost and resource demand associated with the management and operation of such a large network of satellite sites were also factors that led to the abandonment of the groundwater network. This allowed NI Water to concentrate future investment on larger surface water sources, with the view to treating and distributing on mass. By the mid 2000's only two borewells remained in service on Rathlin Island. Some borewells were sold off, but the vast majority were simply re-categorised as 'Out of Service' and the power was disconnected.

The future for drinking water in Northern Ireland

Twenty years on, Northern Ireland Water's outlook is changing. Resilience, climate change, sustainability, carbon reduction, cost saving, and efficiency are all now top of the organisation's agenda. There has also been a recognition that surface water sources often requires more treatment and pumping which increases emissions from fossil fuel generated electricity. The challenges facing Northern Ireland Water have led to a re-think. Groundwater is now firmly back on the agenda in Northern Ireland.

Bringing back the borewells

Due to the growing frequency of high demand incidences, NI Water has been actively looking for a solution. In September 2021, Northern Ireland Water gave the green light to the reintroduction of groundwater sources into its portfolio. Capital funding has been secured to develop, what is hoped to be one of many, new public borewell supply sites in Northern Ireland. NI Water's top priority is the delivery of a long term, resilient water supply to its customers. The solution is expected to involve the use of borewells to access a sustainable water supply. Solar panels will offset electricity usage associated with water abstraction and treatment of the new supply. Overall, the strategic use of borewells is expected to result in significant cost savings, improved resilience against the effects of climate change and reduces chemical use and carbon. A four borewell scheme is proposed for Lisburn and will include the grandfather of borewells – The Barbour Well.

Hydrogeology of the Lagan Valley Aquifer

The Sherwood Sandstone aquifer of the Lagan Valley is Northern Ireland's most important aquifer. It reaches a thickness of 300m at the centre of the valley and dips gently to the north west underneath low permeability sediments of the Mercia Mudstone Group. The system is flanked by high ground to the west and north of Belfast, and the hills of County Down to the south. The aquifer is afforded good protection against anthropogenic sources of contamination. Till thickness varies but covers almost the entire extent of the aquifer; thinning only along the valley margins. The till and overlying sand and gravel deposits confine groundwater within the underlying sandstone, with recharge occurring on higher ground along the valley margins, and discharge occurring at Belfast Lough to the north east. The sandstone aquifer is generally fine to medium grained, thinning towards its base and contains subordinate interbeds of mudstone and siltstone. The aquifers intergranular porosity permits the movement of groundwater, but higher flows are dominated by the presence of fractures. The aquifer is underlain by Permian Marls comprising mudstones and marls.

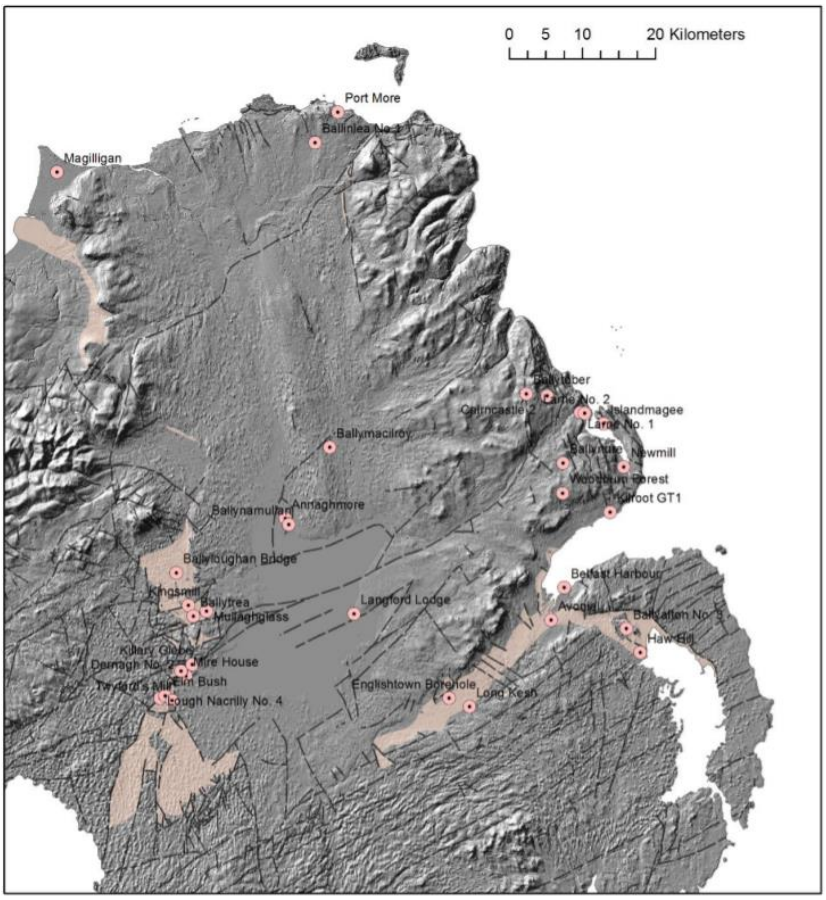


Figure 8: Distribution of the Sherwood Sandstone Group at outcrop. Map reproduced from Raine, R. and Reay, D.M. (2019).

Whilst borewells drilled into the Sherwood sandstone aquifer have been used by private industry for more than 120 years, routine evaluation of the aquifer's hydraulic properties did not begin until the 1970's. Yield varies, but borewells delivering 1MLD are not uncommon. Historical mapping of the aquifer's piezometric surface suggests that groundwater flows are towards the centre of the Lagan Valley, from the northwest side all along the length of the valley and from the southeast side at the top of the valley

Groundwater quality is generally very good achieving a wholesome standard without the need for treatment. Groundwater is moderately mineralised and of calcium magnesium bicarbonate type. It is for this reason that Northern Ireland Water began exploiting this natural resource from the 1960's onwards.

Lisburn Groundwater Abstraction, John D. Barbour Well – The Past

As Belfast and surrounding towns grew throughout the 18th and 19th centuries, largely fuelled by the growth of new industry and economic activity in Belfast and Lisburn, the demand for clean water constantly outpaced the supply. Up to this point, water was sourced from springs in and around the early settlements. With a growing population and demand from industry, the Belfast Water Act (1840) was passed and the newly constituted 'Water Commissioners' became responsible for supply to a population at that time of over 70,000.

Duncan's Reservoir appears on the 1876 historical Ordnance Survey map. Further north, Boomer's Reservoir was constructed in 1880 and in 1894 The Town Commissioners purchased Boomer's Reservoir along with Duncan's Reservoir; providing them the water rights, and ability to meet the growing demand for water in Lisburn.

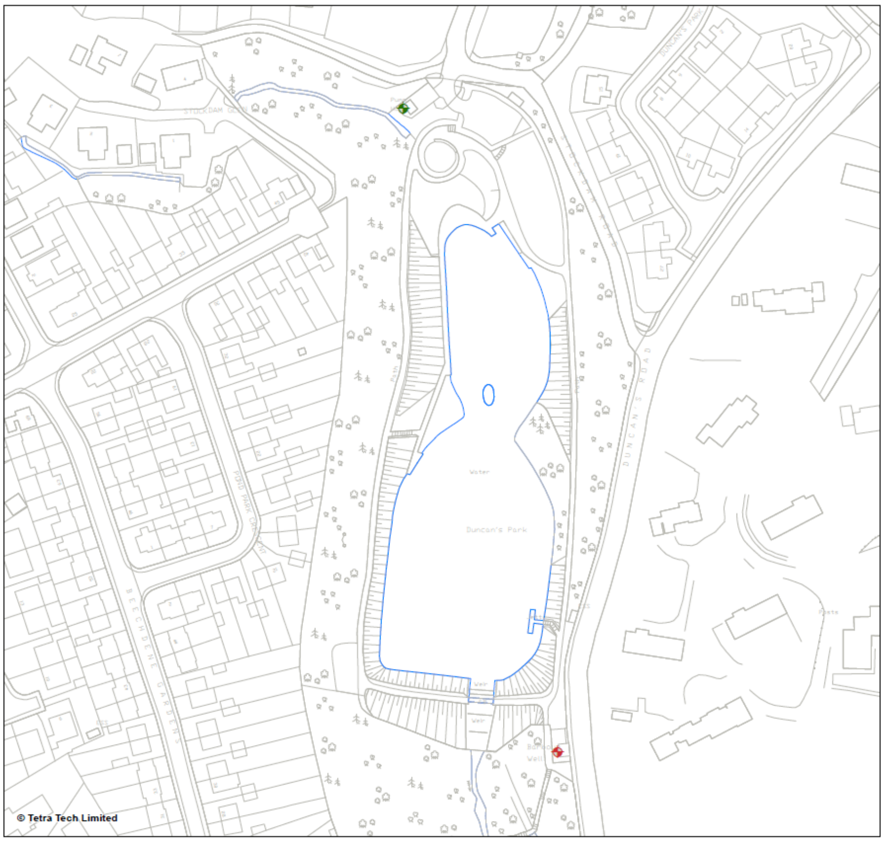


Figure 9: Duncan's Dam with the Barbour well shown to the south east.

Boomer's Reservoir became the primary source of supply. In 1925 a pumping station, equipped with a diesel powered pump, was installed at Duncan's Dam to pump water up to Boomer's. In 1930 an electrically driven centrifugal pump was installed. By 1941 both pumps were reportedly inoperative, and Duncan's Dam ceased to be used as a town water supply. It is reported that since the construction of the John D. Barbour Well in 1935 it "started to pour forth its unending stream of very high quality water to Boomer's Reservoir, it has never run dry". From when it was first commissioned it delivered 1.9MLD (22 litres per second); drawing water from the Sherwood Sandstone aquifer. The well was such a success that a further three borewells were drilled close by and pumped in unison up to Boomers.

Figure 10: Street view of the Barbour Well (Lisburn No.1) well house.

Drilling of the Barbour Well (Lisburn No.1) commenced in 1934. It was drilled to a depth of 122m through 23m of Till before encountering the Sherwood Sandstone aquifer. Drilling was at a diameter which allowed the installation of 12” steel casing to 27m. The piezometric surface sat 8m below ground level. The pumped water level was 21.34m for an output of 1,831m3/day and a calculated transmissivity of 106m^2/day. The original pump could deliver an output of 2.2MLD and it allowed water to be delivered to Boomers, over a kilometre away, without the need for secondary pumping. Lisburn No. 2 and 3, drilled in 1944, also to a depth of 122. Lisburn No. 4 followed in 1945; however, borewell No.4 was eventually capped and abandoned due to poor yield (0.69 MLD) and quality issues.

<u>John D. Barbour Well – The Future</u>

In 2019 Tetra Tech, formally WYG, were commissioned by Northern Ireland Water to assess if groundwater abstraction could provide resilience within the water network at an efficient cost. A shortlist of sites was drawn up by the Geological Survey of Northern Ireland for further evaluation. The Barbour Well was selected for contemporary yield and quality testing. This work took place during 2020 and 2021.

Changing Policy – Challenges & Benefits

In June 2021, the Drinking Water Inspectorate (DWI) of England and Wales wrote to the DWI in Northern Ireland to advise them of the outcome of their review of the arrangements for approval of mild steel products used in borehole construction and components for abstraction from boreholes.

The Inspectorate's Information Letter 03/21 regarding Mild Steel products used in Boreholes seeks to bring a halt to the traditional use of mild steel, without approval, under regulation 31(4)(a) of the Water Supply (Water Quality) Regulations 2016. This raised a question mark over whether the Barbour Well could be re-commissioned, owing to its use of mild steel as part of its construction.

In August, the DWI wrote to Northern Ireland Water to advise that any installations existing prior to 12 June 2021 are unaffected by the Inspectorate's Information Letter, however any future modifications to the borewells or any proposed new boreholes involving the use of mild steel would have to be approved. Whilst significant strides have been made by the drilling industry in Ireland over the last fifteen years, particularly since the publication of The Institute of Geologists of Ireland (IGI) Guidelines for Drilling Wells for Private Water Supplies (2007), and the promotion of uPVC use as an alternative material, we still face many challenges when it comes to borewell construction materials.

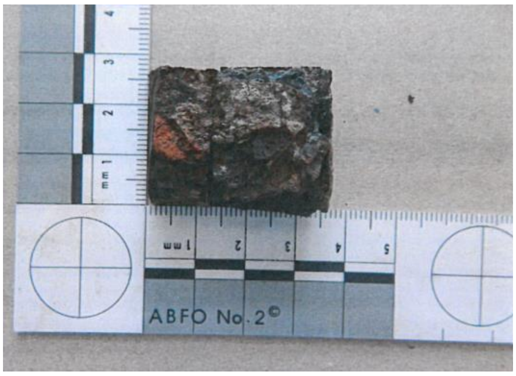


Figure 11: Mild Steel sample sent for analysis, Sept-21

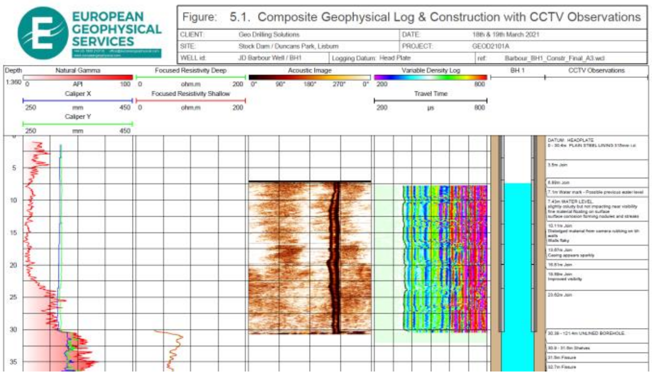


Figure 12: CCTV Survey & Cement (Sonic) Bond Log (VDL, TT). Mar-21.

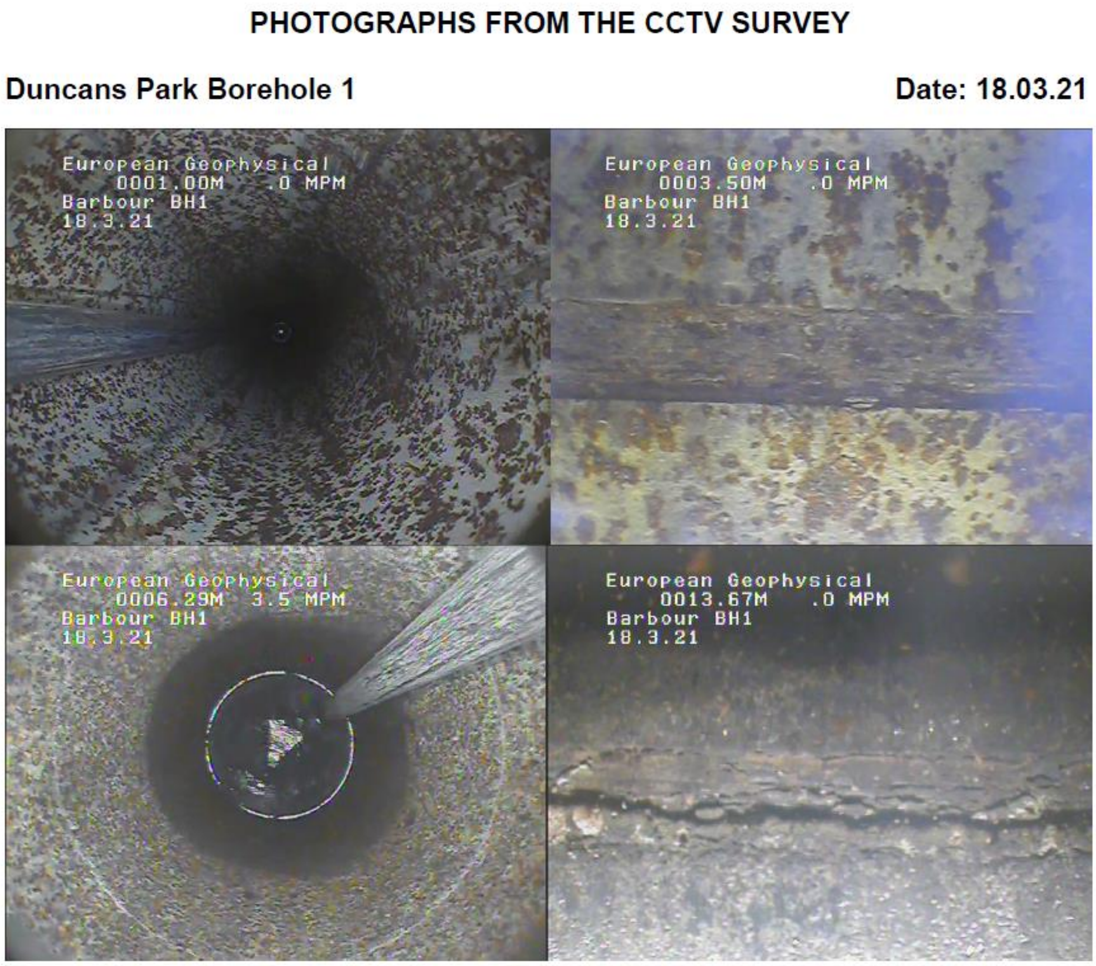


Figure 12: CCTV footage from the Barbour Well Mar-21.

Have we seen the last of the mild steel?

Since June 2021, we have been involved with the construction of several new public supply borewells in Northern Ireland. One of these sites was designed to target a secondary aquifer at depth. Mild steel had been proposed owing to the depth of the target aquifer (120m below ground). The timing of the DWI letter couldn't have been worse for our client and it forced a sudden change on the design team.

120m of mild steel had been ordered, paid for, delivered and loaded onto the drilling contractors trailer ready for mobilisation to site. It couldn't be returned to the supplier. A shortage of stainless steel and increasing steel costs lead to the use of DWI approved uPVC casing as a last-minute alternative. This introduced its own challenges. None of the well-known manufacturers or uPVC casing suppliers would offer surety that the uPVC casing would withstand the weight of grout cement intended for the annular space. This led to a (nervous) multi-stage grouting procedure to minimise the risk of an exothermic reaction causing the casing to fail. Credit must be given to the drilling contractor (Geo Drilling Solutions) who worked closely with our hydrogeologists to mitigate the risks and completed the construction works successfully.

Poly- and Per-fluorinated Alkyl Substances (PFAS)

PFAS (per- and polyfluoroalkyl substances) are a large group of over 9,250 individual compounds with an increasing number being regulated globally. PFAS possess a combination of properties, including extreme persistence, potential to bioaccumulate and mobility (long range transport) that are causing an increased regulatory focus worldwide as more is understood regarding their toxicity. This is leading to the promulgation of extremely low drinking water standards, often in the ng/L range.

There are currently various analytical methods being developed to measure PFAS. Only a few of these methods are accredited as quantified techniques and there is yet no Standing Committee of Analysts (SCA) Blue Book method. In January 2021 the Drinking Water Inspectorate (DWI) published guidance for PFOS and PFOA compounds in drinking water.

On 1 October 2021 the DWI of England and Wales wrote to Water Companies in the UK to advise them of the introduction of additional requirements for sampling, testing and monitoring of PFAS compounds in raw water sources from which abstractions are ultimately used for supplying drinking water. This change could have implications for raw water sources across Northern Ireland. Given the ubiquitous nature of PFAS in the environment, the lack of accredited laboratory methods or treatment options, it is unclear how this change in policy will affect water utility's ability to meet their water demands. Its possible that a flexible approach to sourcing untarnished raw water will be required.

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3. The Garron Plateau, County Antrim.

Raymond Flynn and Francis Mackin

Introduction

Blanket bogs cover approximately 13% of the Island of Ireland, including many areas hosting high status surface water bodies. Despite its widespread occurrence, on-going national surveys under Section 17 of the EU Habitats Directive (HD) reporting requirements, have revealed a significant proportion of Irish blanket bog to be in poor ecological condition, primarily due damage caused by human activity. The HD requires that any loss of priority habitat, including peat accumulating, or active, blanket bog (ABB), requires restoration. However, in the absence of intact sites, establishment of quantifiable restoration targets for this habitat prove challenging.
Studies completed across Western Europe have demonstrated the intimate relationship between water and peatland ecology (including blanket bog ecology). Moreover, a number of studies have also observed that peatland degradation results in a corresponding deterioration in surface water quality, and, more controversially, the generation of flashier

runoff regimes (aka bog as a sponge hypothesis). This degradation has been accompanied by a loss of high status sites (Figure 13). Once again, restoration measures (programmes of measures, POM) are necessary to address these losses. These require an understanding of how hydrological processes influence the abiotic ecological supporting conditions (notably flow and water quality) for undertakings to be effective.

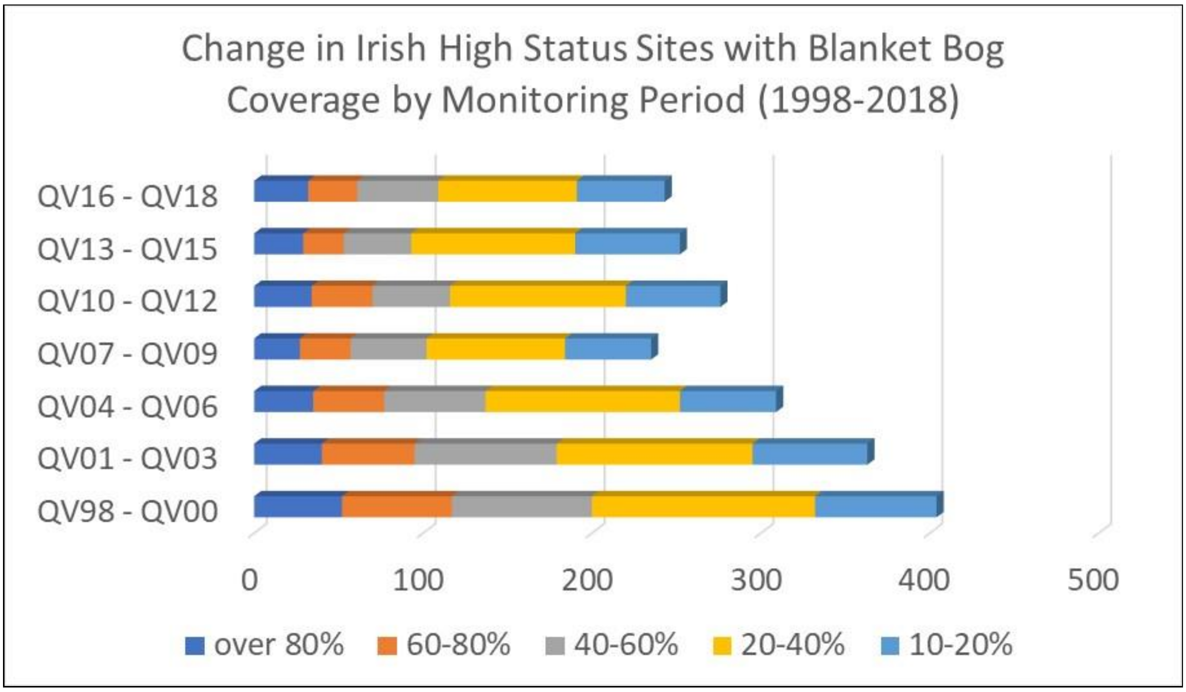


Figure 13: Loss of high status surface water body sites across the Republic of Ireland with peat cover (Flynn et al. 2021).

Study Catchment

The Collin Burn Catchment on the Garron Plateau, Co. Antrim forms one of the best remaining areas, covered in relatively intact blanket bog habitat, on the island of Ireland. In 2017, personnel from Queen's University Belfast, supported through the EPA Research's "Towards the Quantification of Blanket Bog Ecosystem Service to Water (QUBBES)" programme, instrumented the catchment to better understand hydrogeological processes operating in blanket peat, and how these influenced stream flow and water quality.

The Colin Burn Catchment is underlain by Palaeogene Upper Basalt, locally overlain by Pleistocene glacial till containing basalt clasts. Blanket peat covers all but the steepest slopes in an area with roughly stepped topography (Figure 14).

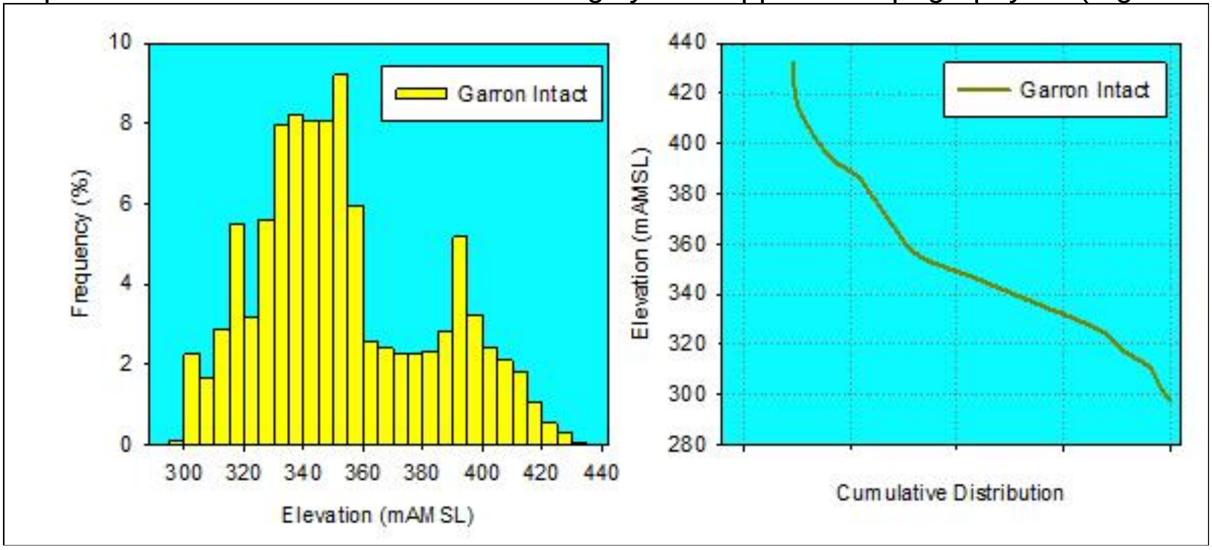


Figure 14: Statistical Summary of Topographic Conditions at the Colin Burn Catchment, Co. Antrim, derive from catchment wide Lidar survey.

Implementation of an integrated programme of hydrological and water quality monitoring consisted of monitoring rainfall, evapotranspiration, groundwater level fluctuations in the peat and runoff at hourly intervals over a three-year period, while complementary water quality monitoring (SEC, major ions, colour and stable isotopes) aimed to shed further light on hydrological processes.

A series of smaller investigations accompanied the main programmes to evaluate specific hydrological and geological influences on stream response. These included ground penetrating radar (GPR) and electrical resistivity tomography (ERT) studies to examine geological influences (Figure 15, Figure 16), while stable isotopic studies allowed investigation of seasonal variations in rainfall-runoff responses.

Results

Groundwater quality monitoring data have revealed limited variations in peat groundwater SEC over the hydrological year (Figure 17), with similar patterns being observed at two other relatively intact QUBBES catchments further west in Cavan (Cuilcagh) and Sligo (Letterunshin). (Dissolved organic carbon in groundwater displayed comparably low variations.) The limited variation contrasted with conditions observed in stream water, where SEC values resembled those encountered in peat during hydrological events. On the other hand, SEC exceeded maximum levels in peat by up to a factor of three during groundwater prolonged dry spells. This gave rise to negative log-linear relationship between SEC (and ions such as Ca). This response has proven consistent at the other research sites (in Cavan and Sligo), albeit with different water quality signatures at low flow. On the other hand, DOC/flow relationships prove to be positive, yet far more irregular during hydrological events. (Figure 18).

Compiling SEC, DOC and major ion data revealed a distinct evolution in water quality during hydrological events (Figure 19), with peak flow in all three catchments proving comparable, yet diverging at lower flows as a function of inorganic substrate geochemistry

(Figure 19). These responses can be simulated by basic mixing models in which stream water consists of variable proportions of peat groundwater and deeper more mineralised water derived from the peat substrate (Figure 20).

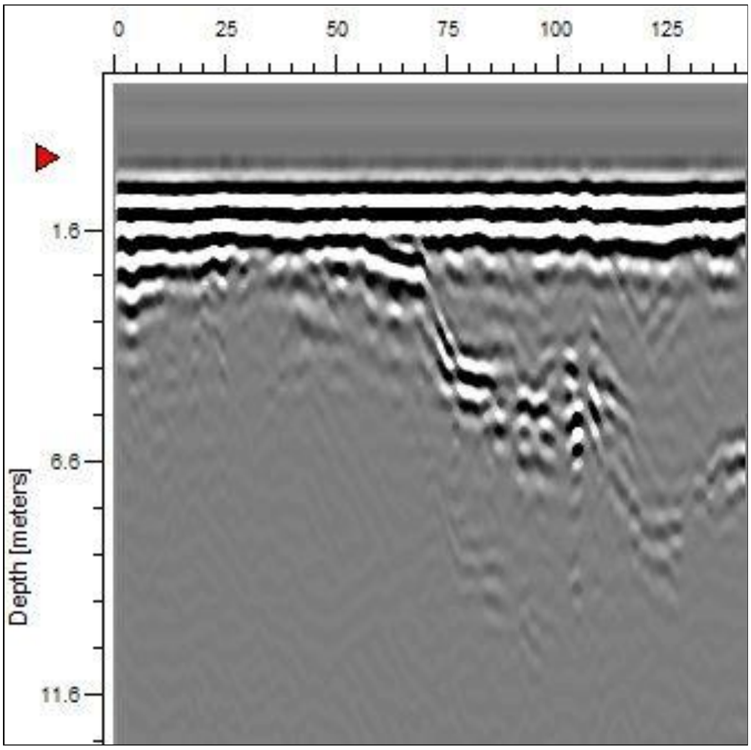


Figure 15: Ground Penetrating Radar profile, Colin Burn, Co. Antrim, reflecting the significant variations in peat thickness (up to 7m) across the catchment. Image: Alastair Ruffel, QUB.

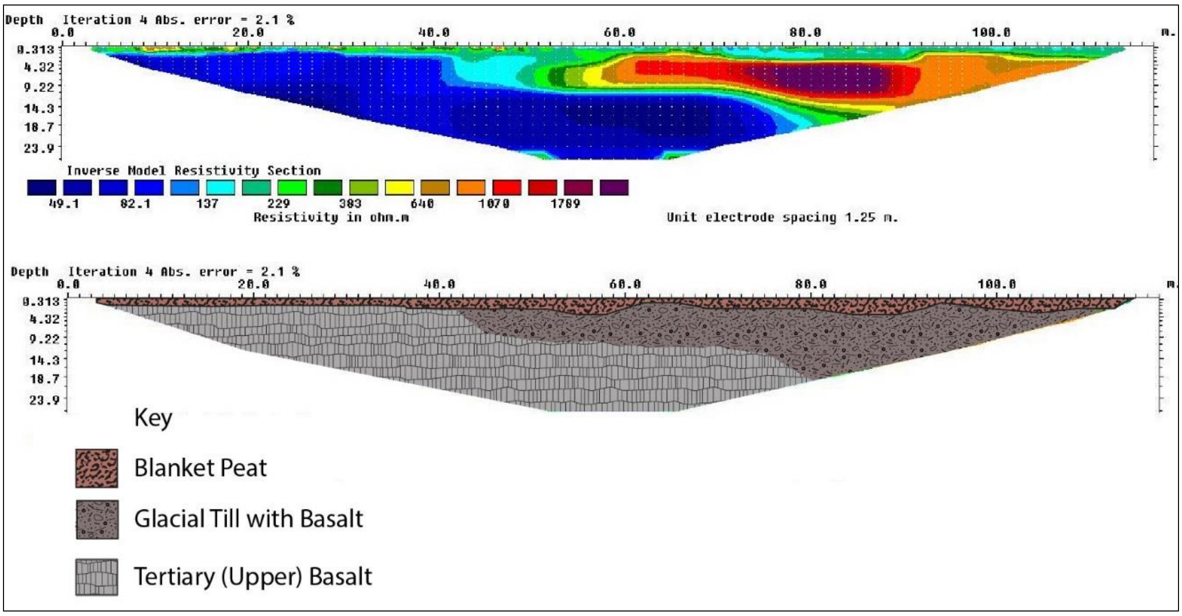


Figure16: Electrical Resistivity Tomography (above) and geological interpretation (below), Garron Plateau, Co. Antrim. Data/Interpretation: Jesus Fernandez-Aguila (QUB), Shane Donohue (UCD)

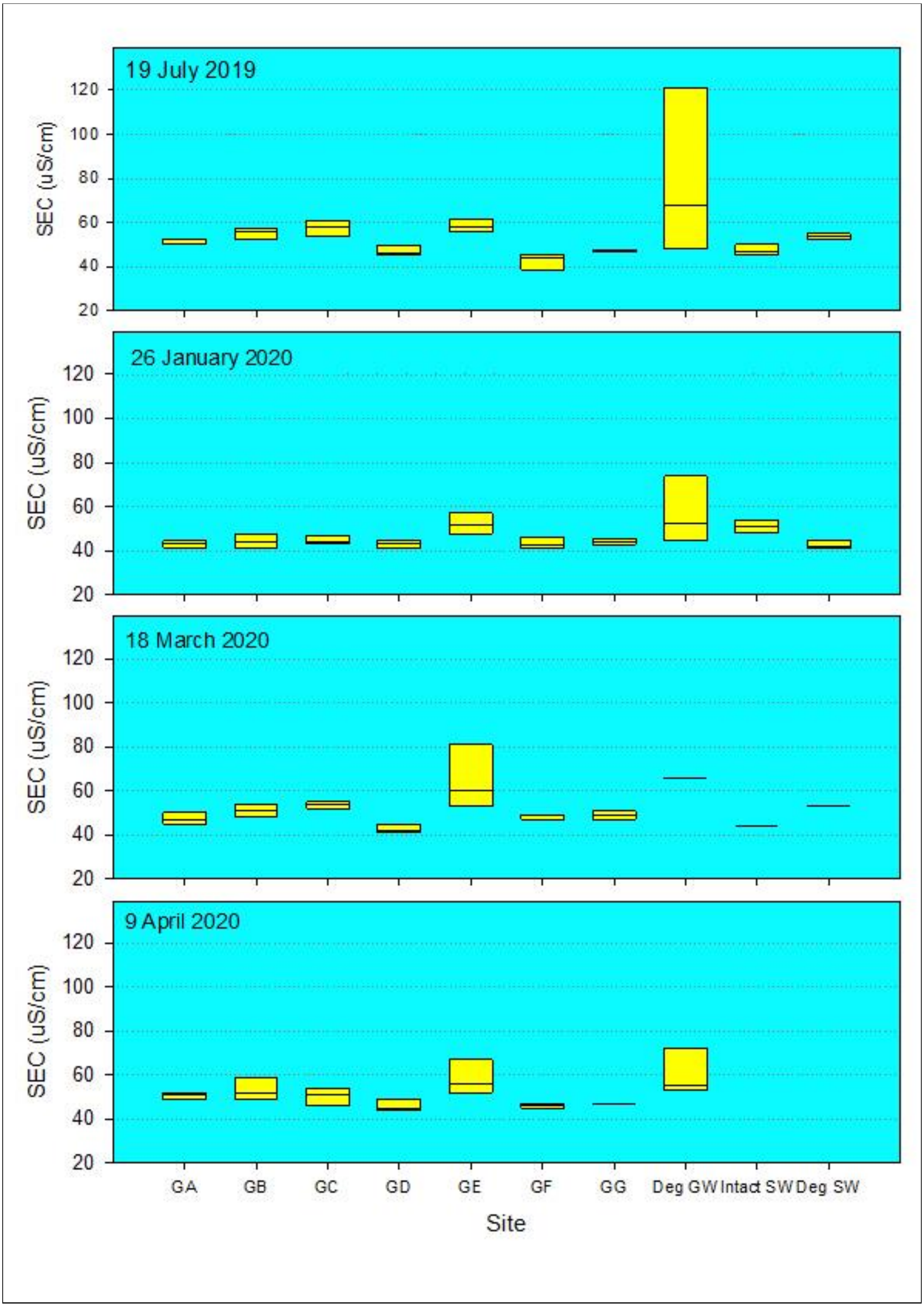


Figure17: Box and whisker plots reflecting variations in peat groundwater quality, Colin Burn, Co. Antrim.

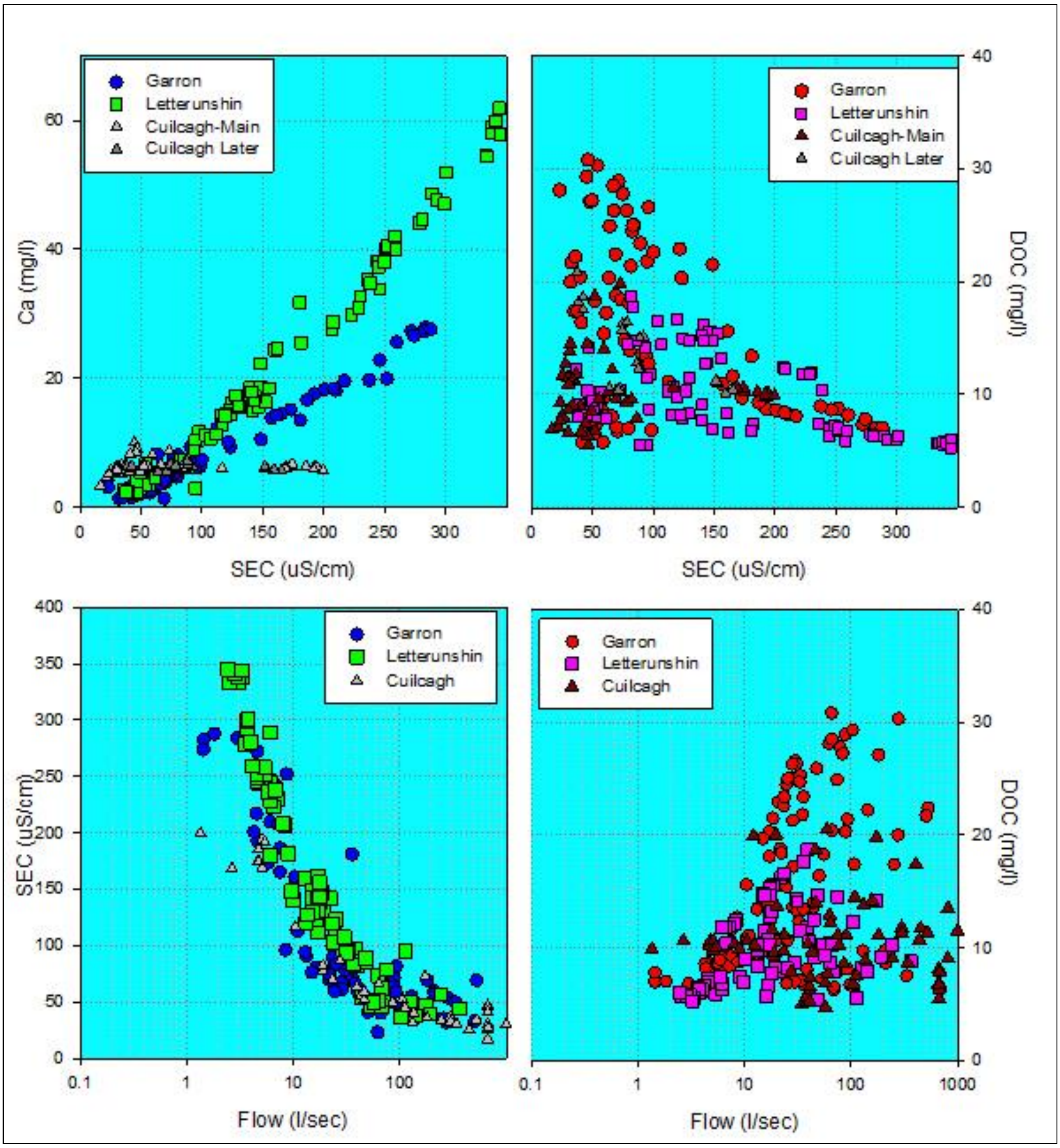


Figure 18: (Above) Plots of water chemistry with specific electrical conductivity (SEC) for (left) calcium and (right) dissolved organic carbon (DOC) for the three test catchments. The poorer correlation between SEC and Ca content at the Cuilcagh site reflects the dominance of sodium and potassium, generated by reactions with underlying clay-rich deposits. (Below –left) Plot of SEC variation with flow; (Below-right) Plot of DOC variation with flow.

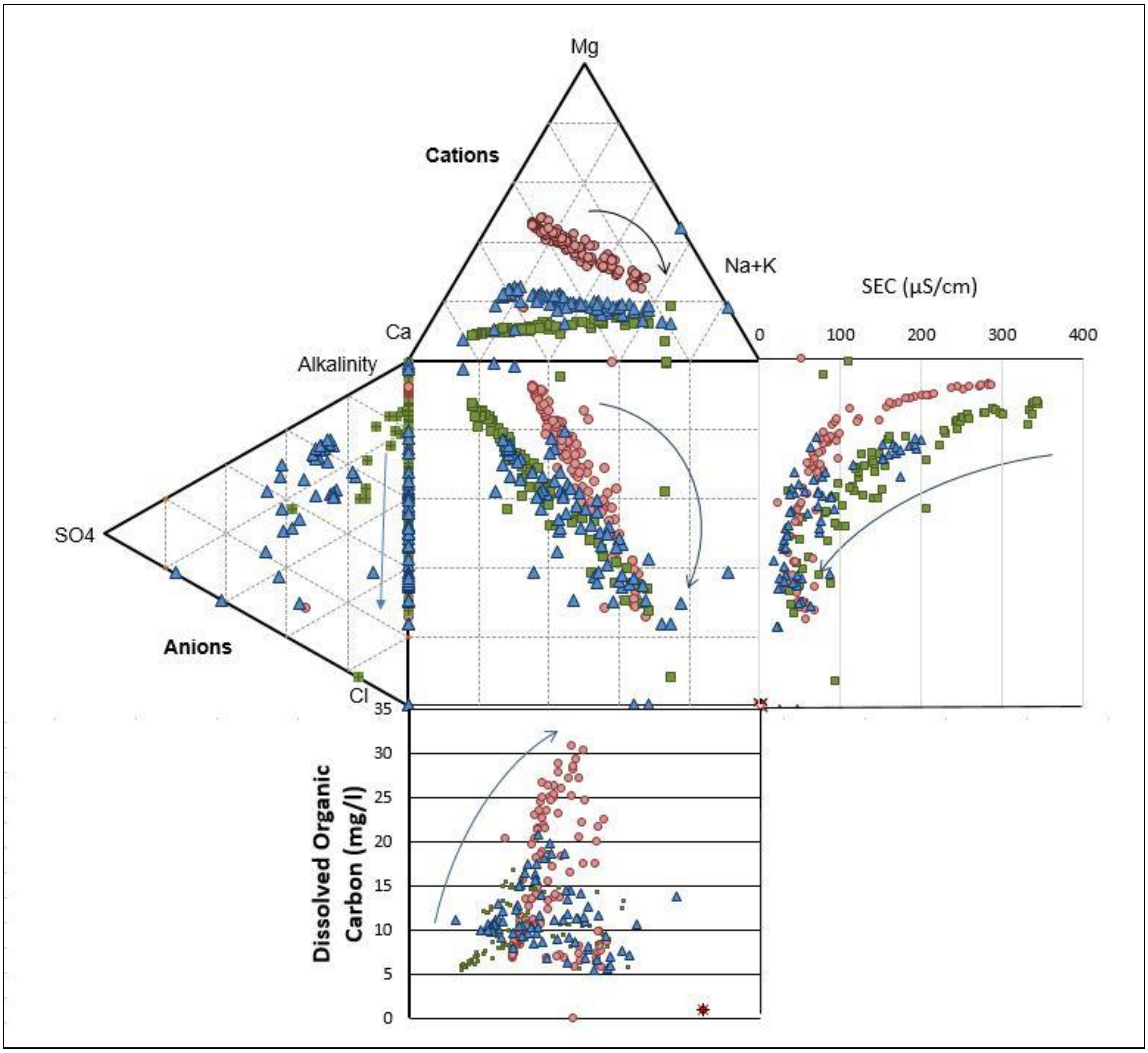


Figure 19: Expanded Durov plot summarising water quality in the streams draining the three test catchments. (Squares-Letterunshin, Circles-Garron, Triangles-Cuilcagh). Arrows reflect the evolution of water quality as flow increases, in which catchment waters with distinct base flow chemistries converge toward a common low SEC Na-Cl water type.

Revised Conceptual Model

The results of the physical and water quality measurements undertaken at Garron, and at other QUBBES blanket bog research sites, suggests that the substrate groundwater makes up a significant contribution to stream flow during drier periods. This becomes diluted by more uniform bog groundwater at higher flows, and has led to the development of a revised conceptual model. The model considers water from peat substrate, hitherto considered negligible, as making an important contribution to dry weather flow in streams draining blanket bog catchments. This water has a chemical signature influenced by substrate geochemistry, which varies between catchments. The finding helps explain the levels of biodiversity observed in blanket peat-covered catchments, despite the ostensibly similar water quality in peat groundwater samples collected from all sites investigated.

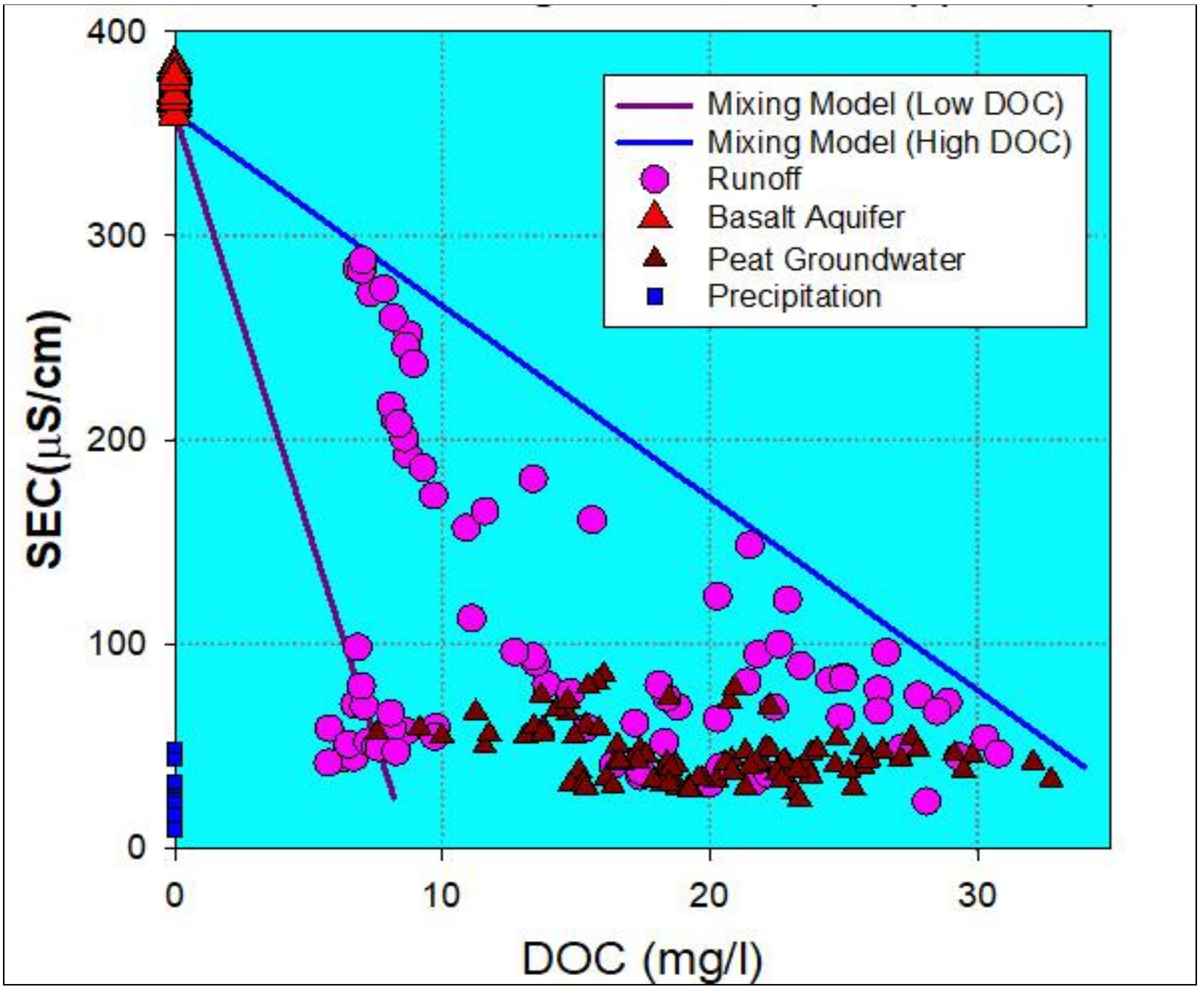


Figure 20: Plot of Specific electrical conductance with dissolved organic carbon content in end members and stream runoff for Garron Test Catchment. The lines reflect mixing models that view all runoff as derived from peat groundwater and from peat substrate, with inorganic substrate groundwater quality resembling that of the basalt aquifer. The model utilises high and low SEC and DOC contents in peat to span the ranges of variation observed in groundwater sampling.

On the other hand, the mixing model reveals that groundwater from peat continues to make a significant contribution to base flow, as reflected by sustained DOC levels. However, comparison with more degraded catchments reveals the more degraded areas to host more mineralised stream water. The findings suggest that flow becomes flashier as more bog water runs off more rapidly. As a consequence, base flow runoff is both reduced and more mineralised where peatland degradation has occurred. This change in hydrological regime changes the aquatic ecosystem abiotic supporting conditions and is suspected to contribute to the degradation in status of many monitoring sites with aquatic biota.

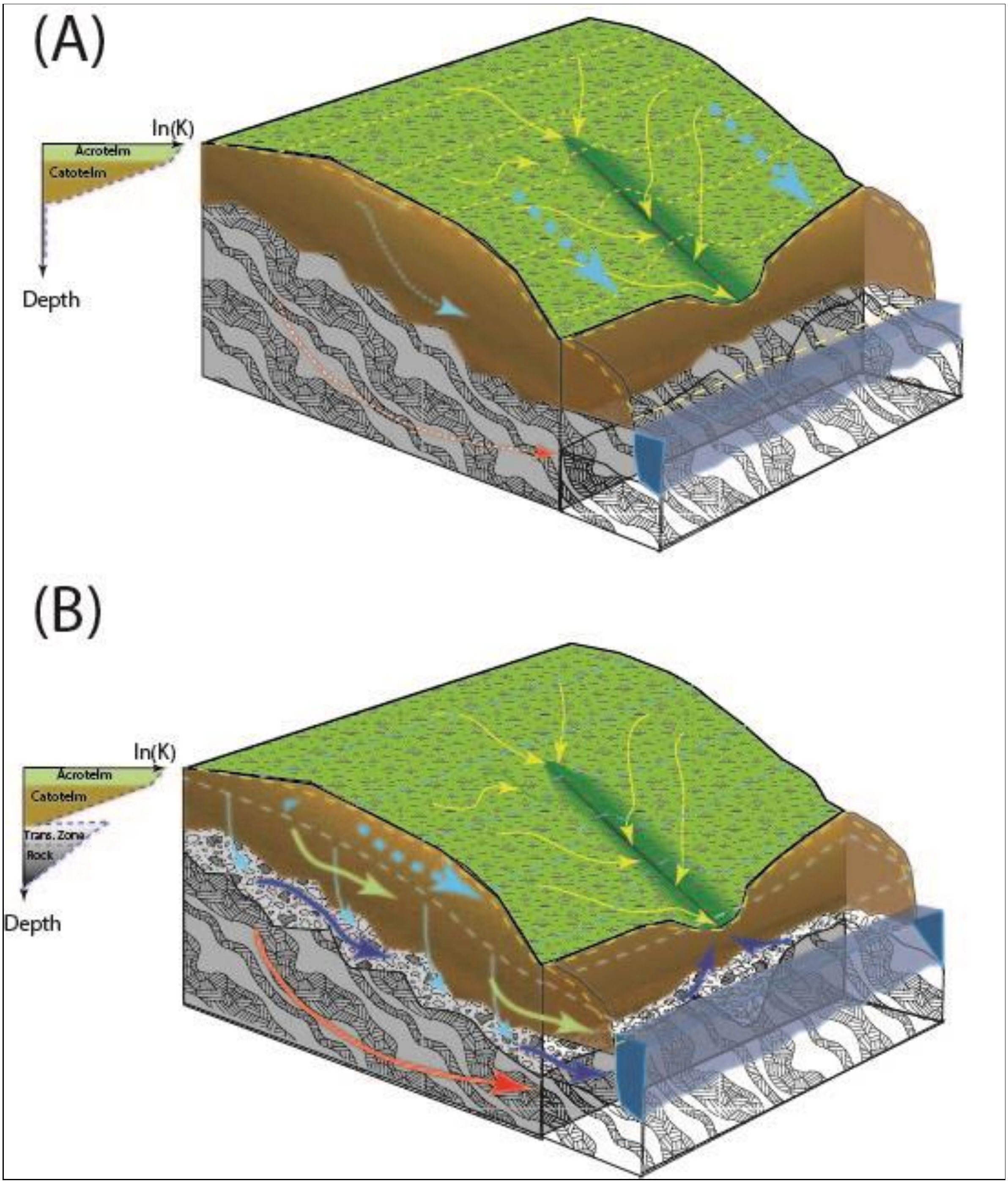


Figure 21: (Above) Conventional model of blanket bog hydrology with substrate contributions to stream flow proving negligible. (Below) Revised conceptual model, with significant substrate contributions.

References

Flynn, R., McVeigh, C., Mackin, F. and Renou Wilson, F., 2021. Sources of stream base flow in blanket peat covered catchments. Journal of Hydrology, Part B, December 2021.

PDF available at **https://authors.elsevier.com/sd/article/S0022-1694(21)01015-5**

4. Karst Geology and Hydrogeology of Loughareema and Murlough Bay, Northeast County Antrim.

Paul Wilson and Mark Cooper

This field guide has been derived from a NIEA commissioned Earth Science Conservation Review (ESCR) report by Dr M. R. Cooper, Dr P. Wilson (GSNI) and Dr. M. Dempster (NIEA). It provides a brief introduction to the 'Karst and Caves' ESCR subject block, and outlines some of the existing Cretaceous Ulster White Limestone Formation ESCR sites and ASSIs in County Antrim. It also includes an introduction to the geology of the NE County Antrim area of interest, as well as its hydrology and hydrogeology. The various karst features at Loughreema and Murlough Bay are described in the Site 1 and 2 accounts.

Introduction to the 'Karst and Caves' ESCR subject block

The ESCR 'Karst and Cave' subject block on Habitas (http://habitas.org.uk/) includes around 140 sites most of which are in County Fermanagh and associated with Carboniferous limestones. Only 8 sites have been reported on in County Antrim where they are linked to the Cretaceous Ulster White Limestone Formation or 'Chalk' as it is known locally. The most significant of these is the Eastern Garron Platea site (ESCR site no. 1169; Galboly ASSI 333) that includes the Black Burn cave which has been explored for about 0.5km (Fogg and Kelly, 1995). Surface water entering the cave system has been shown by dye tracing experiments (Barnes, 1994) to flow some 4km north where it returns to the surface in a small pool and then flows as the Foran River for 70m to the sea at Garron Point. Other County Antrim sites identified include: Cushenilt Burn (ESCR site no. 436) which is a pothole with some cave formations (speleothem); Red Hall Estate (ESCR site no. 434) which features sinks and a rising; Tievebulliagh area (ESCR 435, Tievebulliagh ASSI 082) which has a line of enclosed depressions (dolines) and sinks; Linford (ESCR site no. 1276; Linford ASSI 341) which includes examples of dolines, sinks, a dry valley and a rising; and Larrybane Stalactitie Cave which has examples tufa columns, stalagmites and stalactites (ESCR site no. 520; Carrickarade ASSI 116) (Fogg and Kelly, 1995).

The focus of today are the recently identified and mapped assemblages of karstic features in NE County Antrim (GSI, 2017). Figure 22 from the GSNI GeoIndex shows the distribution karstic features that are located south of Ballycastle on the flanks of Knocklayd, and to the south of Murlough Bay on the flanks of Carneighaneigh, Carnanmore and Cushleake Mountain North. In this area, the very famous 'Vanishing Lake' otherwise known as Loughareema, is found at the end of a prominent glacial meltwater channel.

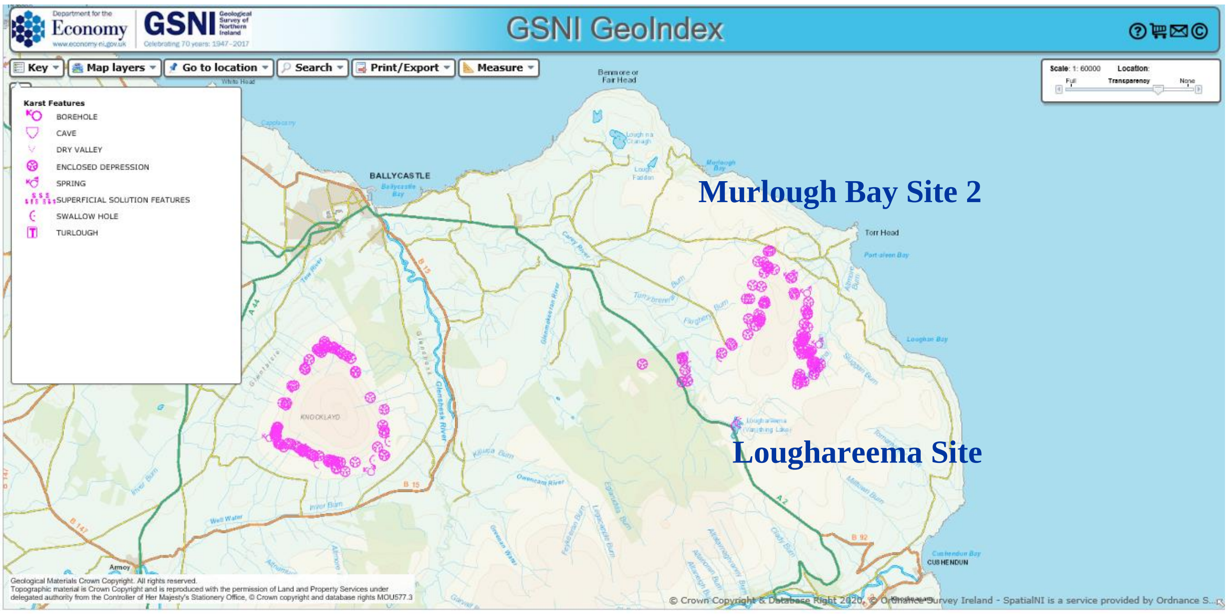


Figure 22: GSNI GeoIndex showing distribution of karstic features mapped as part of the All-Ireland Karst map (GSI, 2017).

Karst Geology, Hydrology and Hydrogeology

Formation of Karst, feature types and their distribution are determined by the interaction of surface water (in streams and rivers) and groundwater with the surface and subsurface geology. Broadly speaking, the bedrock geology of the Antrim Plateau area (Figure 23) is relatively uncomplicated when it comes to the development of Karst. Put simply, all karstic features in the region have formed within the Cretaceous Ulster White Limestone Formation or ‘Chalk’ as it is known locally. However, it is the relationships of the Chalk with overlying (younger) and underlying (older) geology and geological structure that determines what and where features can develop, and their scale. Within the area of interest (Figure 23), the geology (in addition to the Chalk) that is involved in the development of Karst includes the older Neoproterozoic Dalradian Supergroup and Triassic Sherwood Sandstone Group, and the younger Palaeogene Antrim Lava Group and Quaternary superficial deposits.

For Karst to form there needs to be an initial and sustained interaction of water with the Chalk that drives solution and eventually leads to it being captured. Where the Chalk is concealed below other bedrock, for example by basalt of the Antrim Lava Group on Knocklayd (Figure 24), surface water is kept separate from the Chalk and Karst cannot form. However, once surface water has gained access to the Chalk solution can take place and it can with time become captured. Looking at the mapped superficial geology using the GSNI GeoIndex, it would appear that glacial till is not a barrier to karst development as many of the dolines have formed where it is present. It is like therefore that groundwater moving downslope at the base of the till is able to drive dissolution and eventually form a doline. This may explain why many dolines have formed where there is no surface water feature.

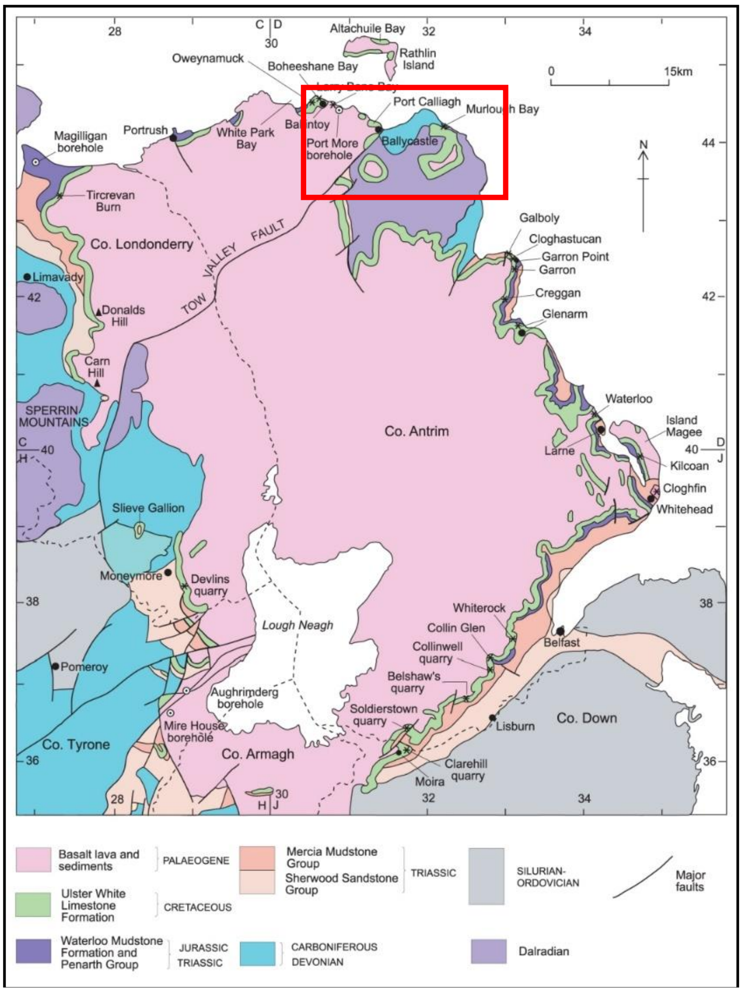


Figure 23: Simplified bedrock geology of the Antrim Plateau area showing distribution of the Cretaceous Ulster White Limestone Formation or 'Chalk' (adapted from Mitchell 2004). The NE County Antrim area of interest shown by red box.

Groundwater moving through Chalk that reaches a contact (unconformity) with impermeable and insoluble Dalradian schists, for example at Knocklayd, is forced to move sideways (or even upwards) until it encounters the ground surface where is can emerge as a spring (Figure 24). Most groundwater entering the Chalk will take the shortest route possible from the top of the formation to its base and out again (Figure 24). It is likely however that some water entering the Chalk will take longer routes depending on the dip of the formation, the occurrence and orientation of faults and the connectivity of Chalk layers across faults.

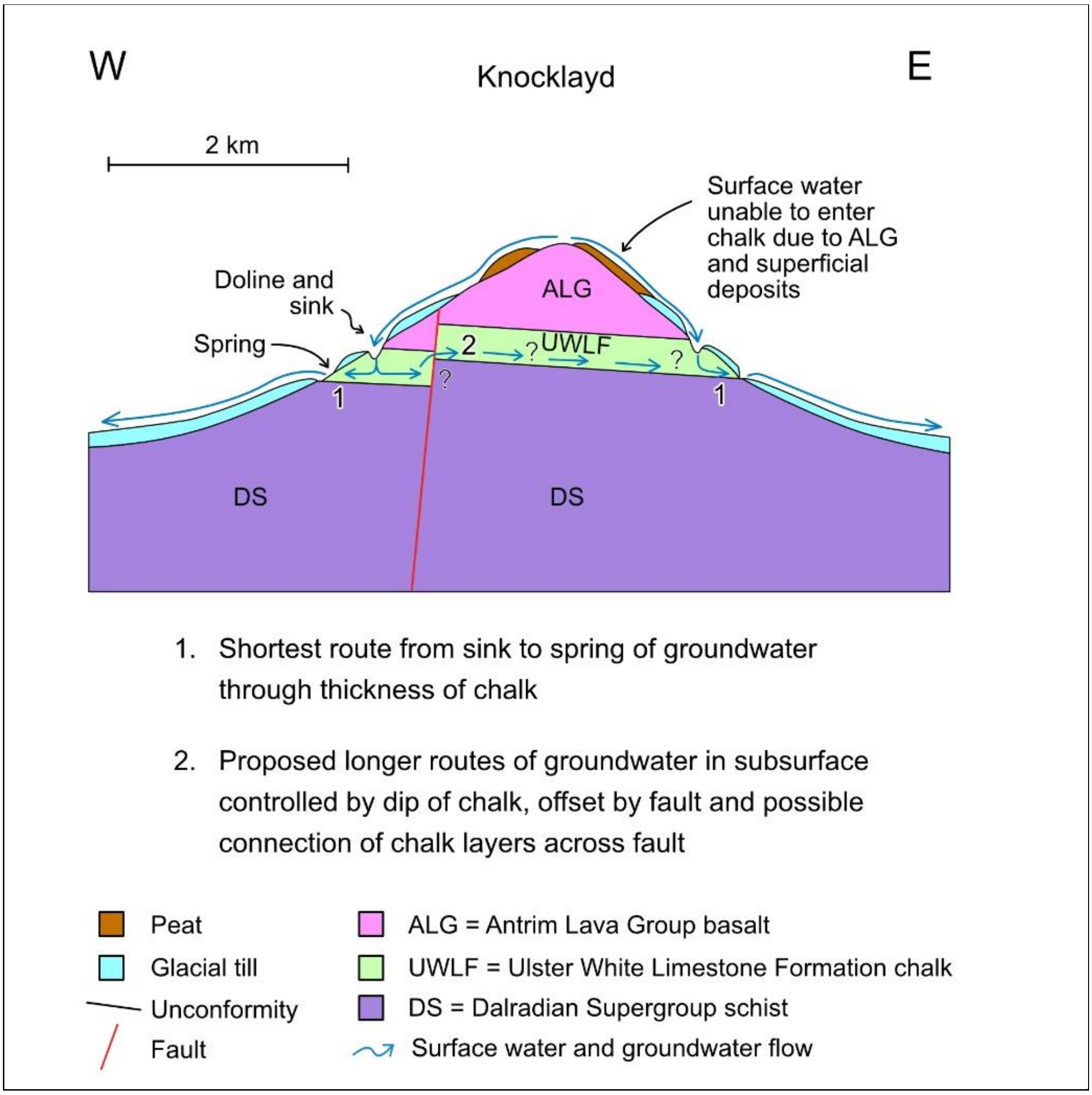


Figure 24: Schematic geological section through Knocklayd geology showing Karstic features and surface and groundwater flow (no vertical scale).

Groundwater in Chalk that encounters an unconformity with the variably permeable Sherwood Sandstone, which at Murlough Bay is a mixed sequence of sandstone, breccia and mudstone, will also be forced to move sideways and out to the surface, though it is likely that at least some of it will be able to enter into intergranular porosity associated with the more permeable parts of this rock unit.

The role of faults in these scenarios depends on what is being moved against what. On the western flank of Knocklayd a NNE-SSW orientated fault brings Chalk down against the Dalradian (Figure 24). It is proposed that some of the surface water entering the Chalk west of the fault is able to move eastwards down dip, then along the fault and possibly even up and through it into the adjacent block and layer of Chalk if connected. The connection of chalk layers across this fault is uncertain but could be tested using water tracing experiments. At Loughareema, NW-SE and NE-SW orientated faults control the flow of groundwater through the Chalk. A cross section (Figure 25) shows that the connectivity of the Chalk layer between fault blocks is maintained. It is also clear from the geological mapping and the cross section, that NW-SE orientated faults provide the focus for conduits (caves) that allow movement of the groundwater from Loughareema in the SE to the main Carey Valley Spring in the NW, and that groundwater is required to move up and across the NE-SW orientated faults. This is consistent with the findings of Barnes (1999) who has recorded, at a regional scale, the dominance of NW-SE and NE-SW faults in the Chalk, and the importance of the NW-SE structures in controlling conduit formation with ten of the twelve traced flow-connections utilising this dominant fracture trend. Quantitative dye tracing by Barnes has also shown that relatively little dispersion occurs within the aquifer, suggesting that flow occurs along discrete conduits rather than a complicated fracture network.

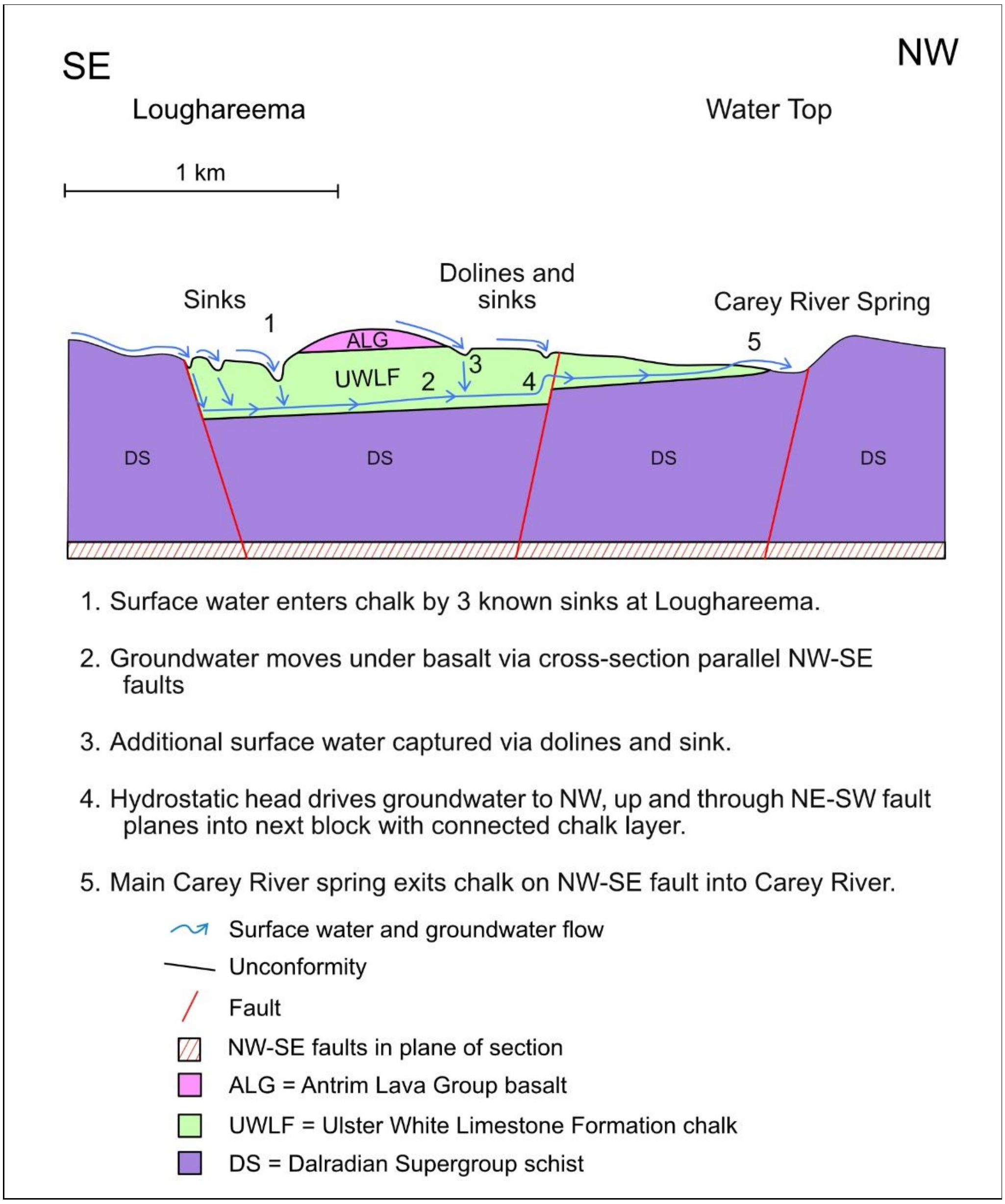


Figure 25: Schematic section through Loughareema and Carey Valley showing karstic features, surface and groundwater flow and relationships with faulting (no vertical scale).

Karst Features and Processes

Figure 26 provides a schematic model of some of the main karstic features found associated with Carboniferous limestones in Ireland and Northern Ireland. The model is applicable to Cretaceous limestone, though no limestone pavement has been identified associated with the Chalk. It shows the relationship between surface water and groundwater, and surface and subsurface karstic features, including sinkholes, dolines and caves.

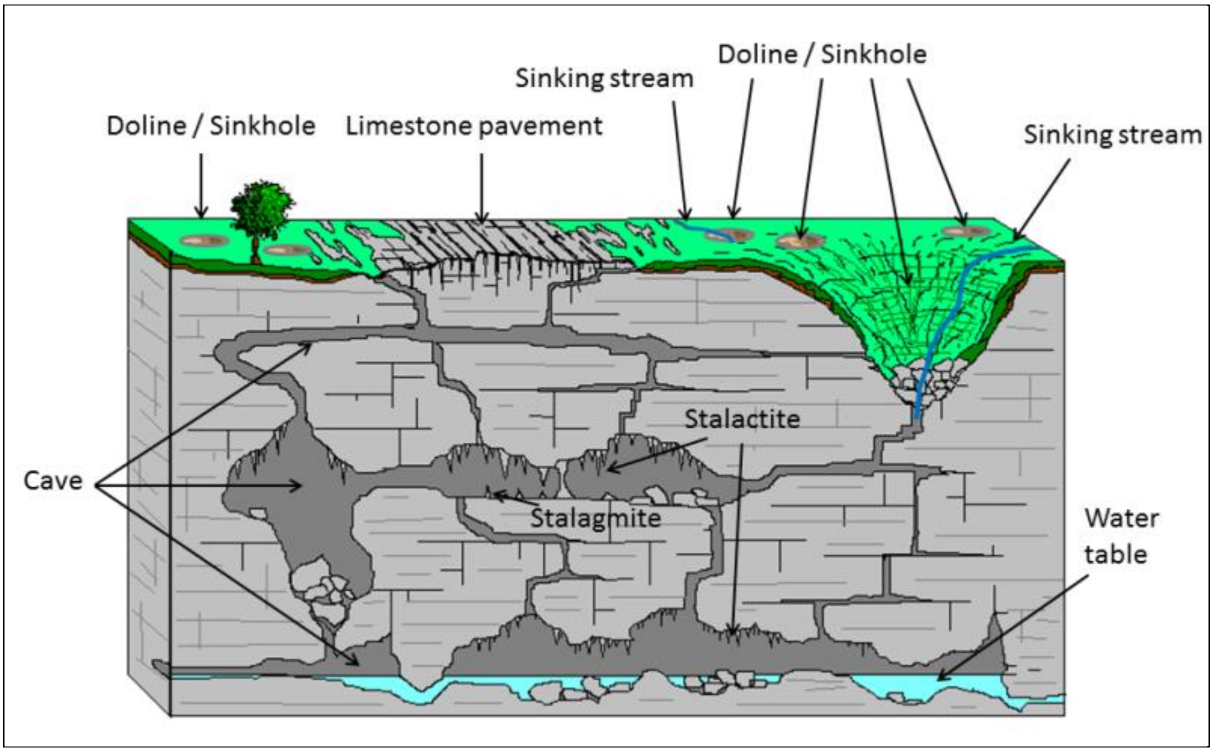


Figure 26: Schematic model showing Carboniferous limestone karstic features (from GSI website https://www.gsi.ie/en-ie/programmes-and-projects/groundwater/activities/understanding-irish-karst/karst-landforms/Pages/default.aspx).

Features identified associated with the Chalk in NE County Antrim include sinkholes (or sinks) into which surface water drains, dolines, dry valleys and springs. At Loughareema (Figure 25), 3 sinks are known to capture surface water entering the lake as streams. The formation of sinks is controlled by dissolution and collapse of the Chalk, and by the washing of superficial deposits, such as soil, peat, alluvium and till, into the resulting depressions. Once captured the surface water becomes groundwater that moves in caves or conduits. It is clear, from the interpretation of Tellus Project magnetics (Young and Donald, 2013), the DTM and orthophotography layers in GIS (Figure 6A and B), that faults play an important role in focusing where the sinks and caves systems have formed in the NE County Antrim area. Chalk that has developed fault planes and damaged rock (breccia) is weakened and more susceptible to being removed, both physically by erosion and chemically by solution. It seems likely that the many repeated periods of glaciation that took place during the Quaternary, will have physically eroded faults and caused the development of

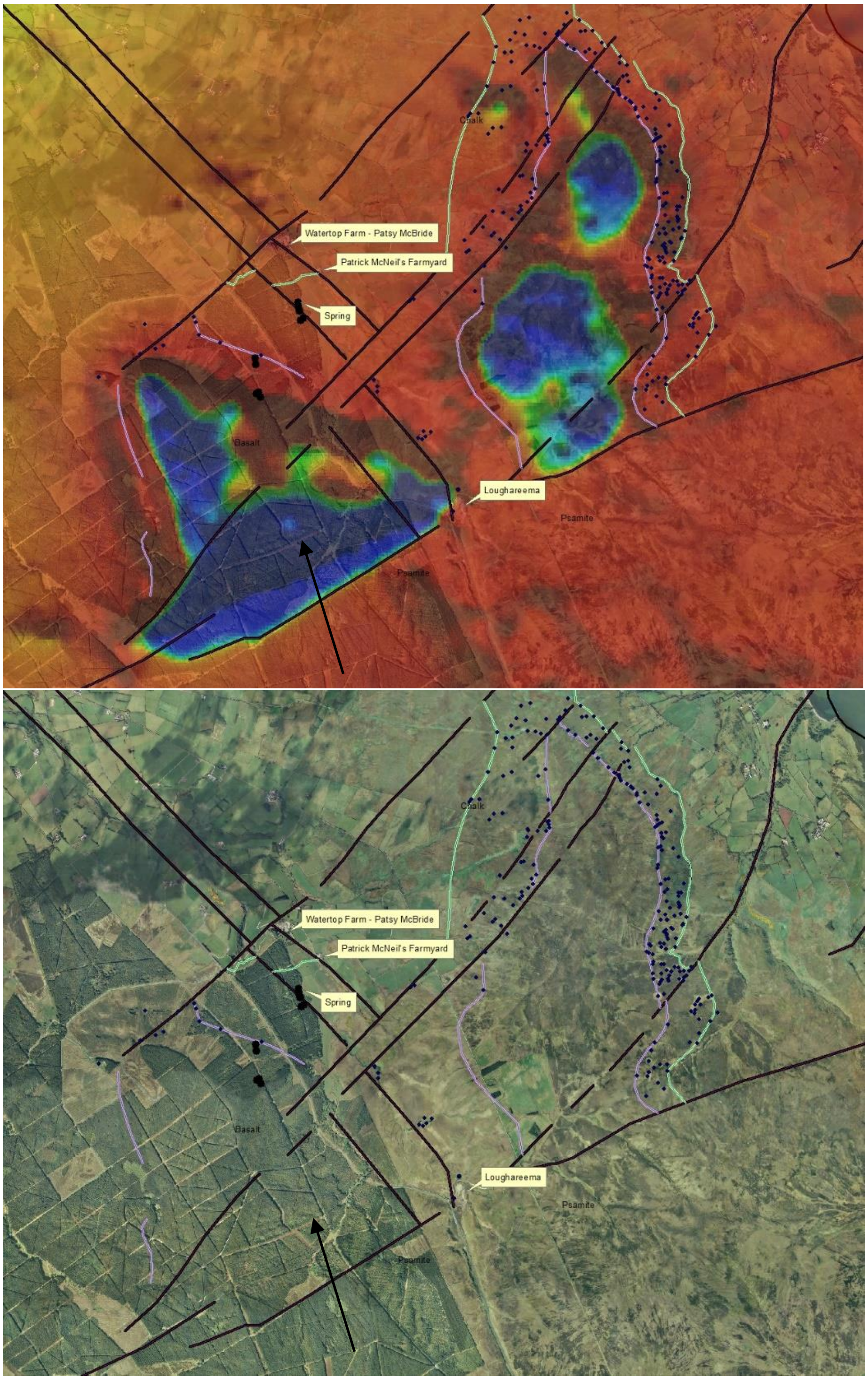


Figure 27A and B - Tellus Project magnetics with interpreted faults (black lines), base of Antrim Lava Group basalt (pink lines) and base of Ulster White Limestone Formation Chalk (green lines). Karstic features shown as points, and meltwater channel by black arrow.

subglacial and proglacial meltwater channels such as the one preserved south of Loughareema (Figure 27B). These glacial drainage channels now form part of the contemporary surface water drainage system and as such focus surface water flow and dissolution. Within the area of interest there are numerous enclosed surface depressions or dolines. Like sinks, their formation is controlled by solution and collapse of the limestone, and by the washing of superficial deposits into the depressions. Many of the dolines identified in the region are found along the upper contact of the Chalk with overlying basalt, where their presence aids mapping of this unconformity (Figure 27A and B). At this upper Chalk contact some dolines clearly capture surface water whilst others appear unrelated. Other dolines appear at various levels within the outcrop/subcrop extent of the Chalk and can even occur close to its basal contact with the underlying Dalradian Supergroup schists where springs are most often located. Straight alignments of dolines are also observed and interpreted to have formed along faults or prominent joint surfaces. Such alignments have been used to aid with fault mapping. Groundwater that returns to the surface does so at springs, for example the main Carey River Spring that links back to Loughareema some 2 km up valley. The connection of Loughareema sinks with the Carey Valley Spring has been confirmed by dye tracing experiments (Barnes 1999).

Site 1: Loughareema and Carey Valley Karst

The Loughareema and Carey Valley area hosts a range of nationally important karst features including sinks, dolines and springs that along with the bedrock geology indicate the presence of a cave system some 2km long that has active groundwater flow through fault controlled conduits (Figure 25). The cross section shows the arrangement of Chalk overlying Dalradian Supergroup schists and overlain by basalt of the Antrim Lava Group.

Loughareema [320608 436055] (Figure 28A), known locally as the 'Vanishing Lake', is fed surface water by three streams, two of which are contained within glacial meltwater channels. Recent monitoring (Wilson pers. Comm., 2020) shows that the presence or absence of the lake is determined by how much surface water enters via the streams and how quickly is can drain through sinks in the Chalk. At Loughareema three sinks have been identified that drain the lake. Figure 29A shows the location of the sinks and springs in the Loughareema-Carey River system, whilst 8B shows sinks and springs in relation to the mapped geology (GSNI, 1963). The main sink (Figure 28B) is located in the base of the lake depression [320526 436043] and can take all the surface water during low flow periods. During wet weather periods when flow through the main sink is exceeded, the lake level rises until it reaches sinks at higher levels [320615 436135 & 320662 436103] (Figure 28C and D) which in turn increase the drainage capacity. At the western limit of the lake, a man-made drainage channel has been constructed to ensure that during very high flow surface water events the lake level is kept below the level of the road and causeway. The location of Loughareema is controlled by the coincidence of NE-SW and NW-SE faults which bring the soluble Chalk against the insoluble and relatively impermeable Dalradian Supergroup schists and Antrim Lava Group basalts (GSNI, 2002).

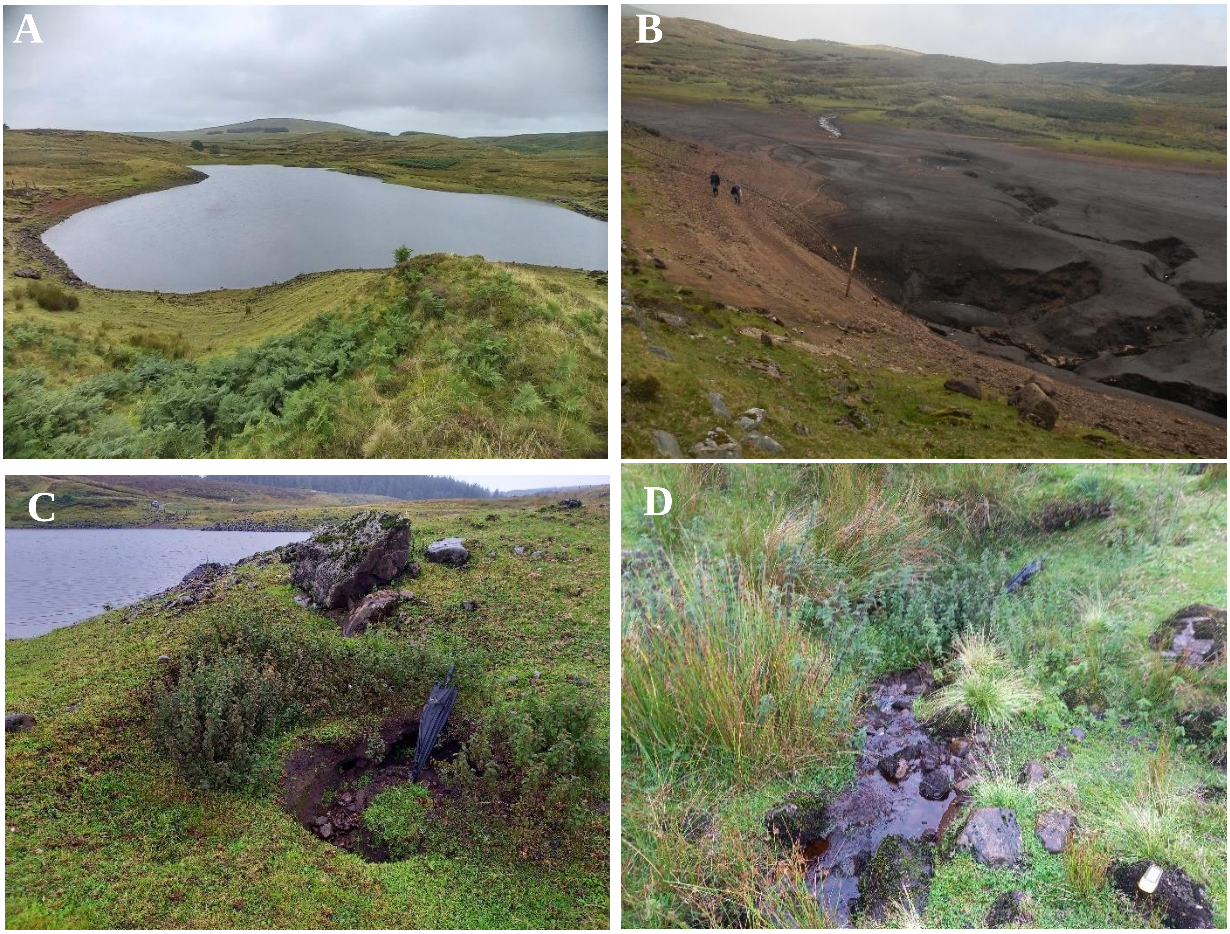


Figure 28: A. Loughareema almost full. B. Lake empty with water draining into main sink. C. Intermediate sink located at NE corner of lake. D. Highest sink located on stream entering NE corner of lake.

Southeast of the main Carey River Spring [319341 437651], two more sinks are known of, one is at the confluence of the Corratavey Burn and Carey River and is known as the Carey River Tributary Sink [319487 437425], and the other is on the Corratavey Burn adjacent to the Ballypatrick caravan park where it is known as the Carey River Upper Sink [319501 437114] (Figure 29).

At the Carey River Tributary Sink surface water sinks into river alluvium and no bedrock is seen, whilst at the Carey River Upper Sink, Chalk is exposed with fault controlled NW-SE orientated conduits into which surface water is captured (Figure 30A). In the ground between the caravan park and the Corratavey Burn, there are numerous enclosed depressions or dolines some of which show signs of active subsidence. At the main Carey River Spring (Figure 30B), Chalk is present in the river bed and groundwater is observed emerging from the western riverbank where there are also dolines. Faults observed cutting the chalk in this area are mainly NE-SW orientated and SE dipping (Figure 27) which may have the effect of forcing groundwater towards the surface.

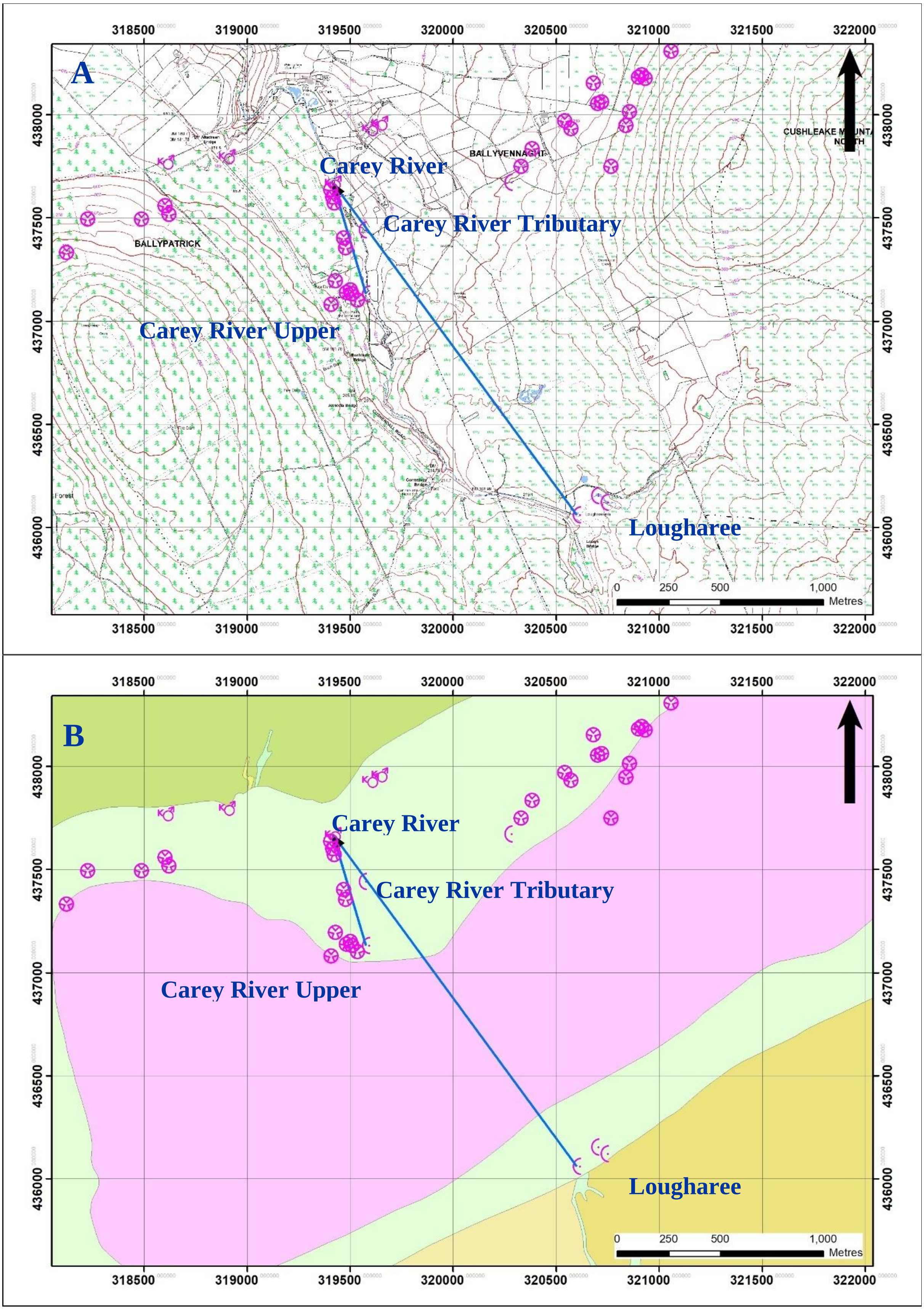


Figure 29: A. Location of the sinks and springs in the Loughareema-Carey River system. B Features in relation to the bedrock geology.

Dye tracing experiments (Barnes, 1999) have shown that water entering the subsurface at Loughareema reappears some 2km to the NW at the main Carey River Spring (Figure 29). This work also confirmed that water entering the subsurface at the Carey River Upper Sink emerges at the Carey River Spring some 0.6km NW.

Figure 30: A. Carey River Upper sink with fault tilted Chalk exposed. B. Carey River Spring.

Site 2: Murlough Karst

The Murlough Karst site hosts a range of nationally important karst features including sinks, dolines, springs, and fault and joint controlled conduits. At this site the Chalk is <60m thick and sits unconformably above the Sherwood Sandstone Group (Figure 10A) (GSNI, 2002). Figure 11 shows the location of karstic features in relation to the bedrock geology and the existing Fair Head and Murlough Bay ASSI (330).

The relationship between the Chalk and underlying Sherwood Sandstone Group rocks is spectacularly exposed in cliffs that extend east-southeast from the upper car park (Figure 31A) [IGR 319095 441790]. In this area the Sherwood Sandstone Group is composed of a mixed sequence of sandstones, breccias and mudstones that are insoluble and relatively impermeable compared to the Chalk. Groundwater moving through the Chalk that encounters these rocks is forced to move sideways and out to the surface as springs, though it is likely that at least some will be able to enter into intergranular porosity associated with the more permeable parts of this rock unit. Springs positioned on this contact are found at IGR 319310 441715 and 319344 441698. Both are associated with minor faults (Figure 31B) and are intermittent in terms of their flow. During periods of wet weather flow is high, reducing to almost no flow in dry periods. The spring at IGR 319344 441698 is associated with a groundwater flush, over Sherwood Sandstone Groups rocks, that hosts a range of plant and animal species including the rare Yellow Saxifrage *Saxifraga aizoides* (Figure 31C), a Schedule 8 species listed in the Wildlife (NI) Order 1985, and the Northern Ireland Priority Species, Yellow-ringed Carpet moth *Entephria flavicinctata*, which has been found associated with this area where its larvae feed on Yellow Saxifrage.

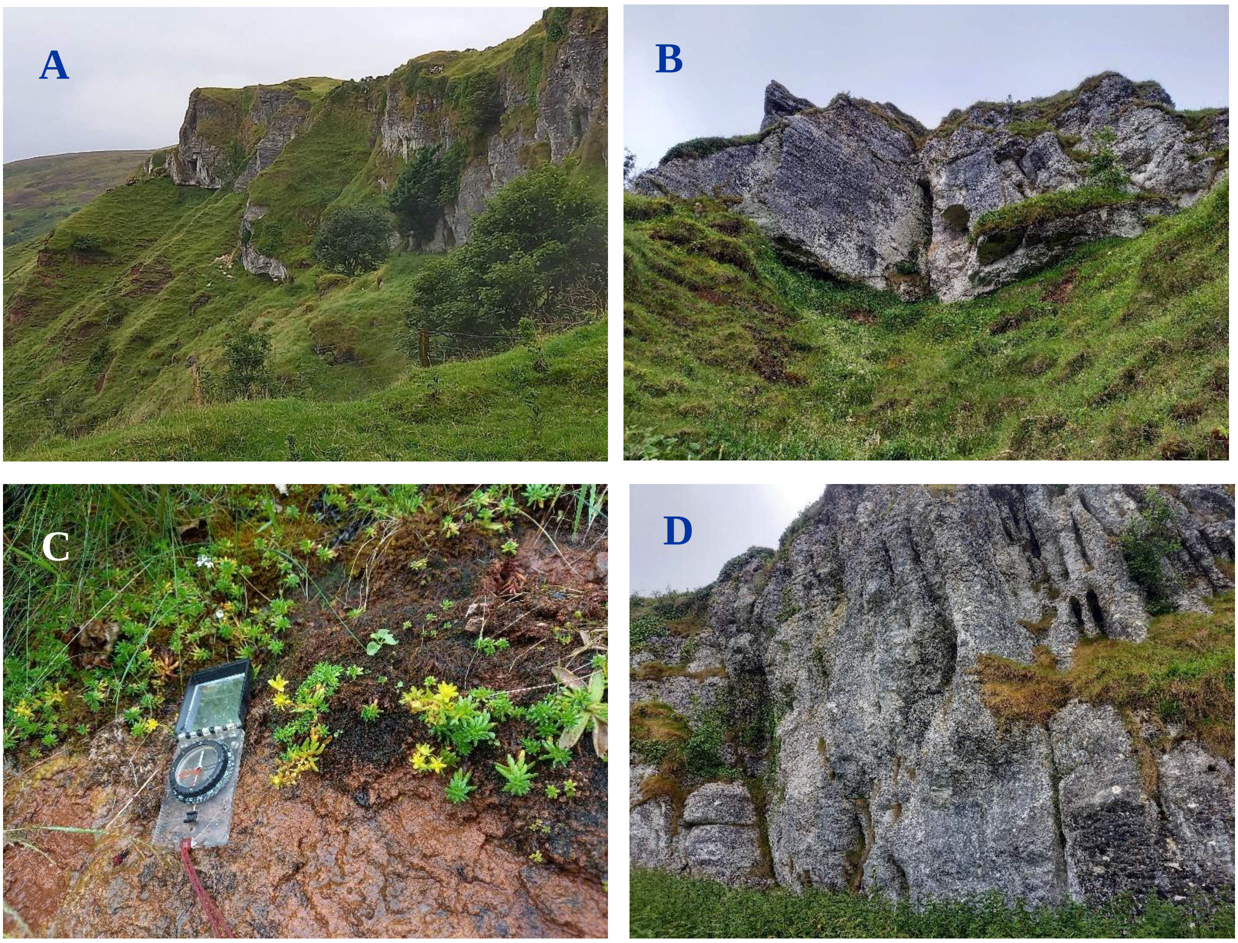
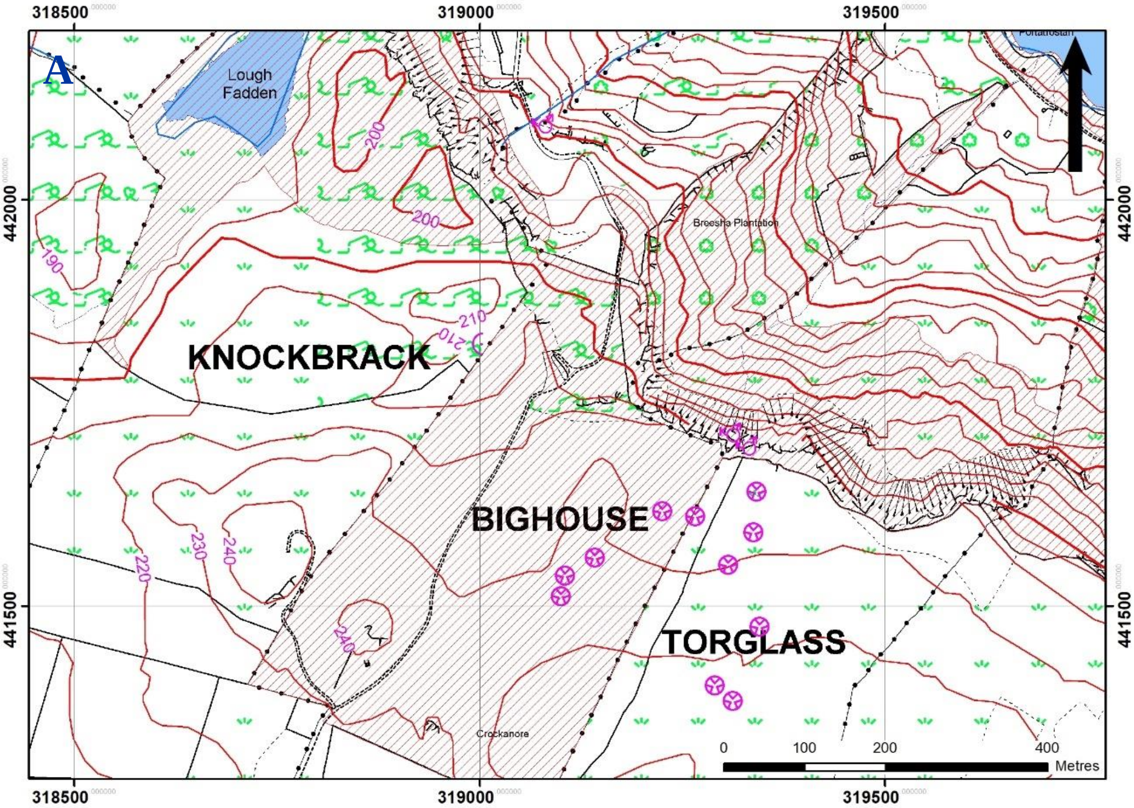


Figure 31: A. Chalk above Sherwood Sandstone Group at Murlough Bay upper car park. B. Example of a steeply dipping strike-slip fault with a spring and flush development. C. Rare Yellow Saxifrage *Saxifraga aizoides* associated with flush below spring at base of Chalk. D. Fault and joint surfaces widened into conduits.

In the Chalk cliffs numerous examples of small faults and joint surfaces that have been widened by solution can be observed (Figure 31D), for example at IGR 319250 441725. In addition, about 100m west of the upper car park a sink is observed at IGR 318996 441822 on a NE-SW feature that is most likely a fault. Flow of surface water into the latter appears to be quite limited and intermittent. Some 300m north of the car park a spring is located close to a NNW-SSE orientated SW dipping normal fault that bring dolerite down against Chalk.

The Chalk area south of the cliff section (Figure 32B) is a flat lying outlier that is uncovered other than by soil and thin patchy peat which fills dolines that interrupt its otherwise smooth surface. The limited extent (about 2km^2) and elevated position of this Chalk precludes the development of surface water steams and as such the sustained recharge of this system is considered to be through diffuse infiltration of rain water into widened fault and joint networks, with more focused input through dolines during periods of rainfall.



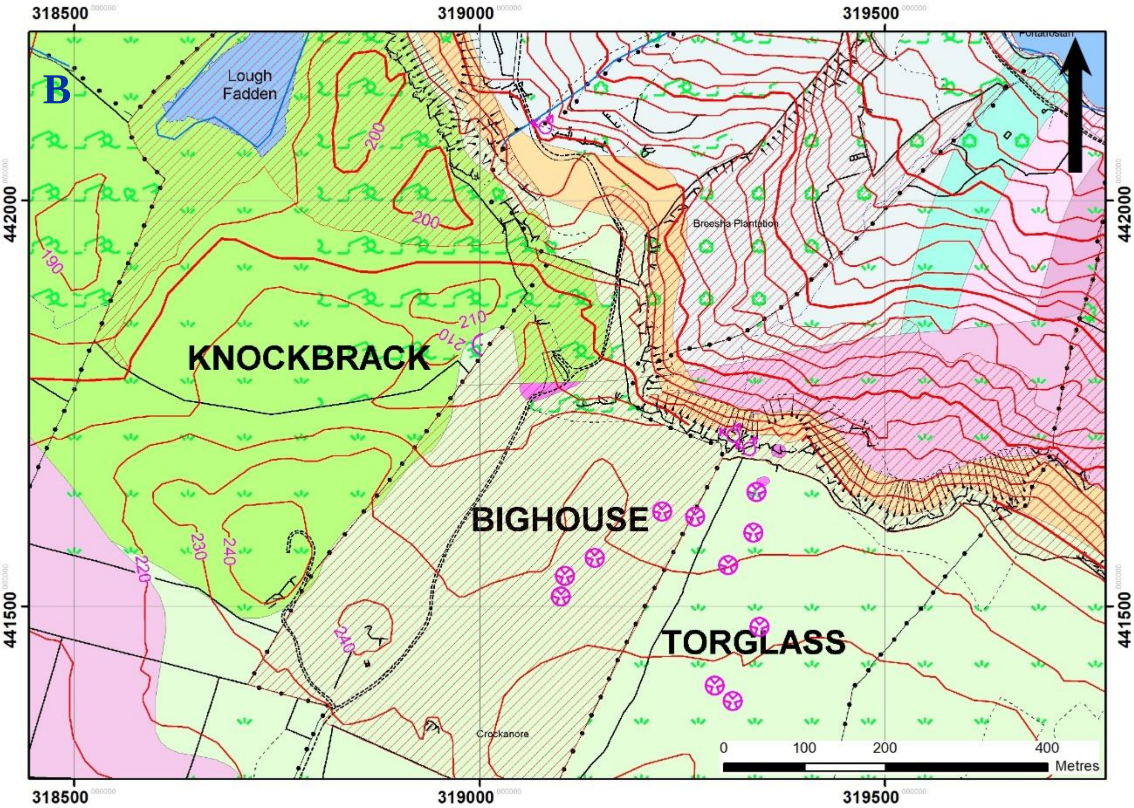


Figure 32: A. Location of karstic features in relation to the existing Fair Head and Murlough Bay ASSI (330). B. Features in relation to bedrock geology.

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5. Magilligan Umbra – Conservation management, Hydrogeological Monitoring.

Andy Crory, Paul Wilson and Kyle Hunter

Umbra Nature Reserve – Context and Ecology

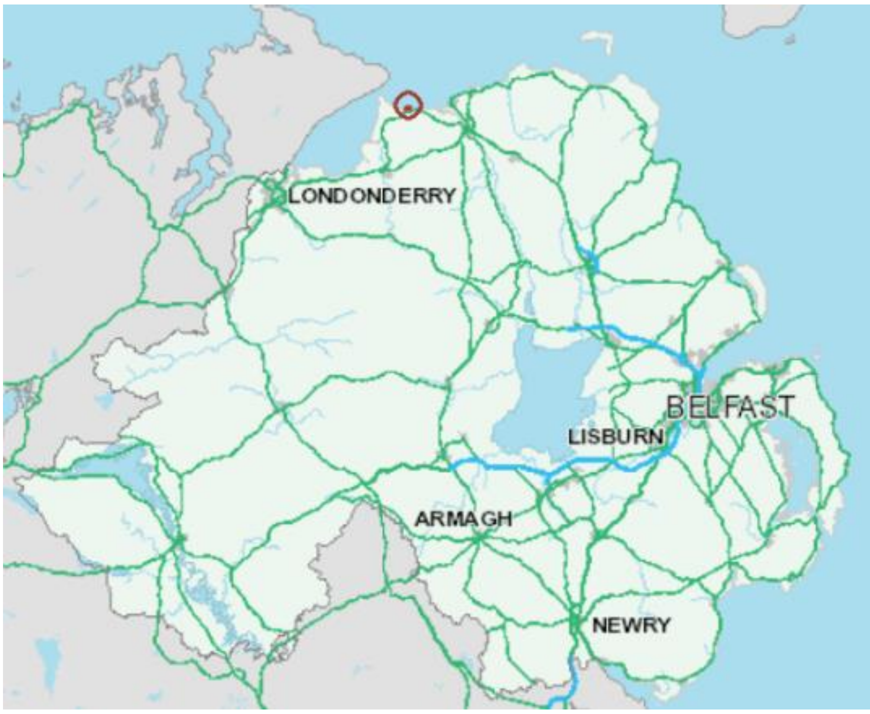

Figure 33: Location in Northern Ireland.

Figure 34: Magilligan SAC (blue), Umbra Nature Reserve (red outline)

Figure 35: Umbra Nature Reserve boundary, all within Magilligan SAC.

Ecology and Conservation Management

Umbra has been managed as a nature reserve by Ulster Wildlife since 1978 under a lease from the Riley family – the site is well-known amongst naturalists in the north of Ireland being particularly notable for its humid dune slacks and associated dune flora and invertebrate assemblages. The site is part of the wider Magilligan Special Area of Conservation (SAC) and is also an Area of Special Scientific Interest (ASSI). The SAC features at Umbra found are:

- Fixed dunes with herbaceous vegetation ("grey dunes")

- Dunes with *Salix repens ssp. argentea (Salicion arenariae*)
- Humid dune slacks
- Embryonic shifting dunes
- *Euphydryas* (*Eurodryas, Hypodryas*) aurinia (Marsh fritillary butterfly – no longer present)
- Shifting dunes along the shoreline with *Ammophila arenaria* (“white dunes”)

Conservation works include the control of scrub, rush and non-native species – the site is also grazed extensively with cattle from mid-August until the end of March at a stocking at a rate of 0.5LU/ha/year.

Regular biological monitoring activities take place, covering a range of Northern Ireland Priority Species, and these are supported through a grant from the NIEA Environment Fund. Support is also provided through inclusion in the Environmental Farming Scheme (EFS) since 2020 – the EFS management agreement will run for five years and has so far subsidised 1.2km of new fencing as well as bird and bat boxes across the site.

Flora
A wide range of plants rare locally, or in an Irish context are found at Umbra – many of these are related to the humid dune slack habitats found here. Typical plants found growing commonly in these dunes include burnet rose (Rosa pimpinelifolia), kidney vetch (Anthyllis vulnaria) and devil’s-bit scabious (Succisa pratensis).

- Grass-of-Parnassus *Parnassia palustris*

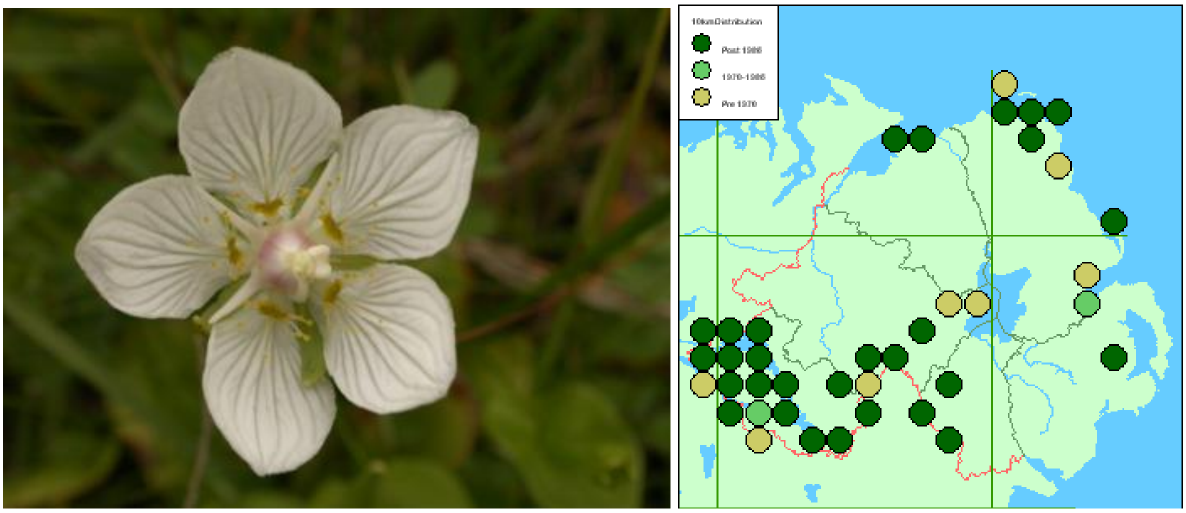

Figure 36: Image: Suffolk Wildlife Trust/ Map © Ulster Museum.

A declining species, found mainly in Ireland and northern Britain – associated with coastal fens and flushes, humid dune slacks on the north coast as well as fens and lakeshores in the south and west of N. Ireland.

- Frog Orchid *Coeloglossum viride*

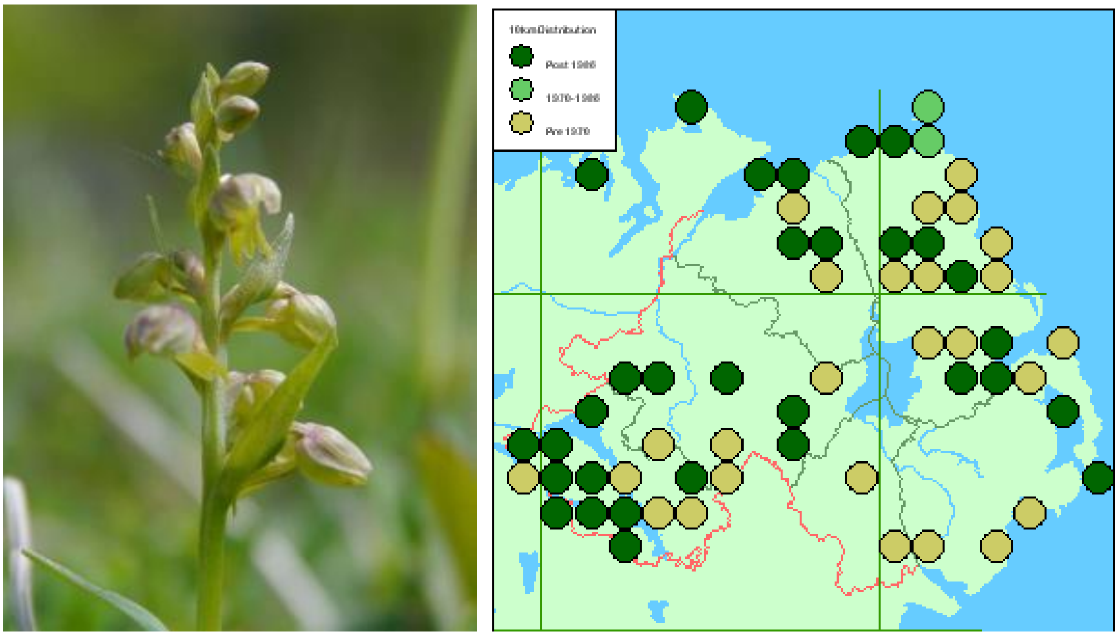

Figure 37: Image: Derbyshire Wildlife Trust / Map © Ulster Museum.

A Northern Ireland Priority Species due to decline and NI being a stronghold for the species – associated with base or lime-rich soils. Flowers from May-August.

- Lesser Tamarisk Moss *Thuidium recognitum* and Wrinkle-leaved Feather-moss *Rhytidium rugosum*

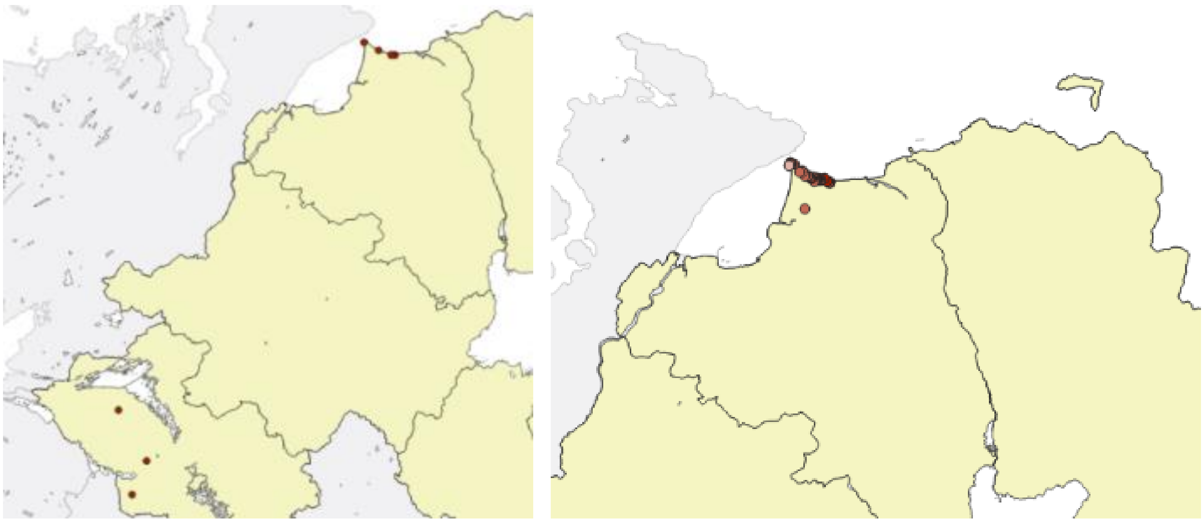

Figure 38: T. recognitum (left) and R. rugosum (right) .Map © Ulster Museum.

Several rare mosses occur on the Magilligan sand dune system including lesser tamarisk-moss and wrinkle-leaved feather-moss, both of which are Northern Ireland Priority Species. The former is known in Northern Ireland at Monawilkin and near Marble Arch and in coastal dunes from Magilligan Pt. to Umbra – this represents around half of the known Irish sites. The latter is restricted to the Magilligan dunes and Umbra, as well as nearby Binevenagh Mountain – it occurs nowhere else in Ireland.

Birds

The most commonly encountered bird species is the meadow pipit Anthus pratensis, also known in English as the ‘cuckoo’s maid’ but perhaps more appropriate is the Ulster-Scots ‘moss-cheeper’. A range of Northern Ireland Priority Species also occur here such as cuckoo (Cuculus canorus), skylark (Alauda arvensis), linnet (Carduelis cannabina) and reed bunting (Emberiza schoeniclus).

Invertebrates

- Grayling *Hipparchia semele*

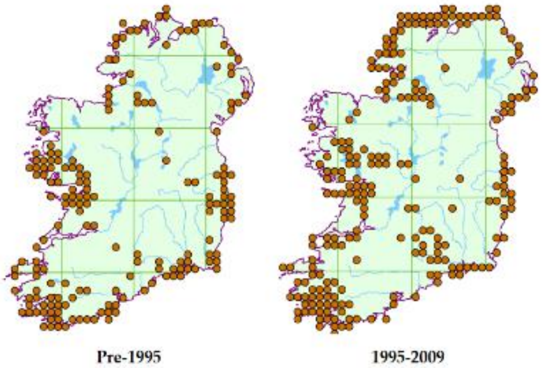

Figure 39: Image: A. Crory / Map © NPWS

Predominantly a coastal species in NI – map is ‘post-1989’, further declines have been observed. Irish Red List Species (NT – Near Threatened)/ NI Priority Species.

- Dark Green Fritillary *Argynnis aglaja*

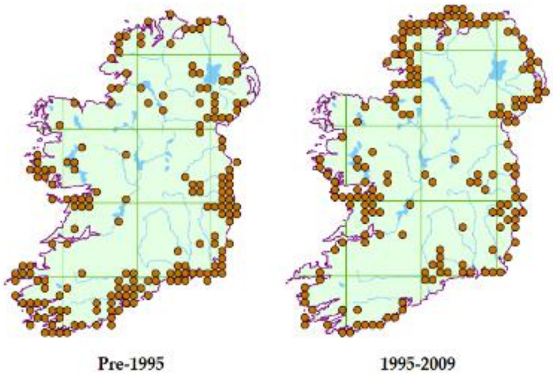

Figure 40: Image: A. Crory / Map © NPWS

Now a coastal species in NI – lost from the majority of inland sites. Irish Red List Species (VU – Vulnerable)/ NI Priority Species.

- *Lampronia pubicornis*

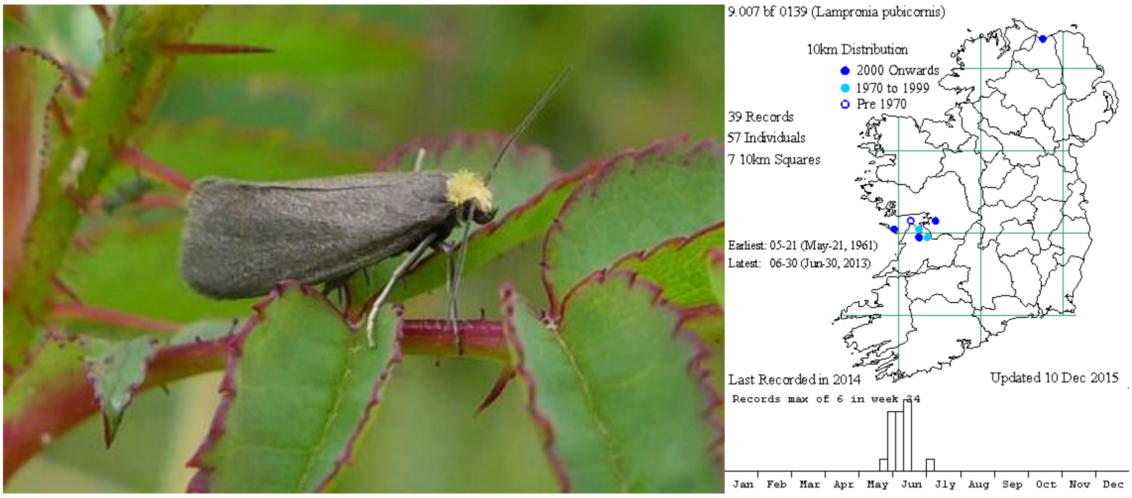

Figure 41: Image: E. McGuiggan/ Map©www.mothsireland.com

Known from only three sites (not illustrated on map, Portstewart dunes and White Park Bay). First recorded in NI in 2012, the larval foodplant is burnet rose (*Rosa pimpinellifolia*) so may be present at other coastal sites in NI. Candidate NI Priority Species.

- Hemp Agrimony Plume *Adaina microdactyla*

Figure 42: Image: A. Crory/ Map ©www.mothsireland.com

Umbra is the only known site for this micro-moth species in Northern Ireland. First recorded in NI in 2014, the larval foodplant is hemp agrimony (Eupatorium cannabinum). The adult has only been seen twice in Northern Ireland – more commonly recorded by searching for larval exit-holes on the foodplant. Candidate NI Priority Species.

- Scarce Crimson & Gold *Pyrausta sanguinalis*

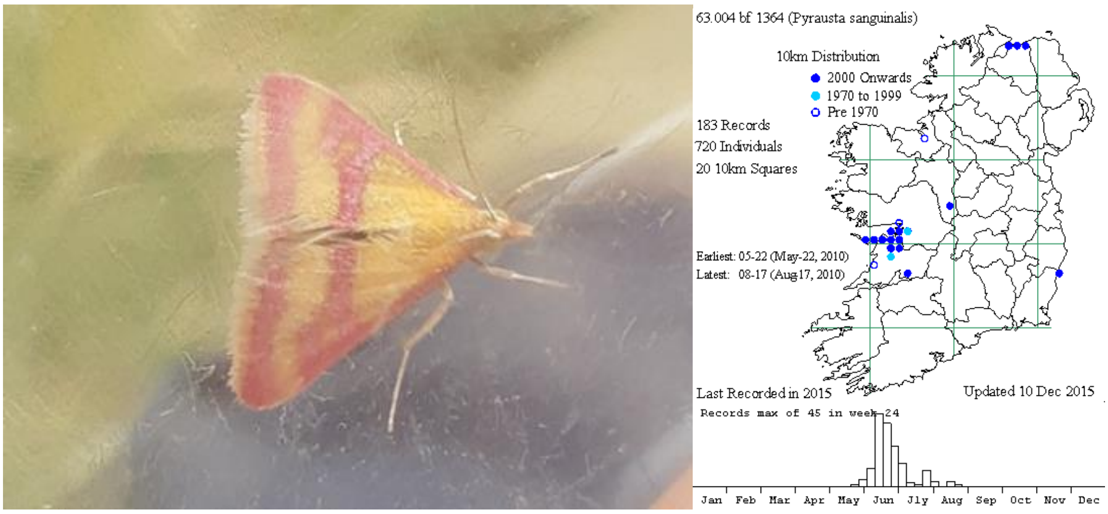

Figure 43: Image: A. Crory/ Map ©www.mothsireland.com

One of the rarest micro-moths in the UK, known only from Magilligan sand dune system, Portstewart Dunes and the northern tip of the Isle of Man. Also known form the Burren in the Republic of Ireland. Presumed foodplant is wild thyme (*Thymus polytrichus*) but the ecology of *P. sanguinalis* is largely unknown – Ulster Wildlife are in partnership with BCNI (Butterfly Conservation Northern Ireland) to progress a student project / PhD to inform best practice conservation management. Northern Ireland Priority Species. Most recent records - 2021.

'When referring to the Cheshire site in Day (1903), HB Prince stated that the habitat and foodplant of the moth had been "destroyed by golf".' Allen & Mellon Environmental Ltd. Note: Conservation management requirements for this species are in direct opposition to those for small eggar (*Eriogaster lanestris*), see below.

- Small Eggar *Eriogaster lanestris*

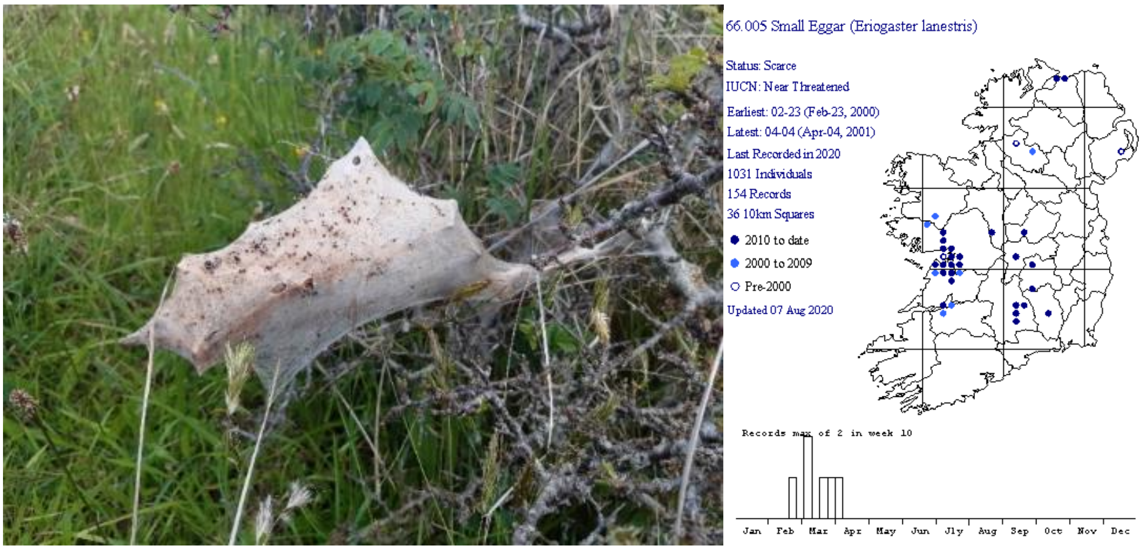

Figure 44: Image: A. Crory/ Map:©www.mothsireland.com

In Northern Ireland this macro-moth is only known from the Magilligan sand dune system. Rarely seen as an adult and populations are best monitored through recording of the conspicuous larval webs on blackthorn (*Prunus spinosa*) and hawthorn (*Crataegus monogyna*). Populations are known to fluctuate, with diapause shown to be proportionate to sunlight hours, which complicates conservation management such as scrub control. Irish Red List Species (NT – Near Threatened)/ NI Priority Species. Most recent records - 2021.

- Northern Colletes *Colletes floralis*

Figure 45: Image: A. Crory/ Map:©www.habitas.org.uk

Found only on sand dunes - in the Atlantic zone, Ireland has 90% of the population. Given the threat to Irish sand dunes, future declines are expected due to habitat loss. Globally Irish populations are extremely important. Known from 29 locations since 1980, of which 10 are within protected sites. Irish Red List Species (VU – Vulnerable)/ NI Priority Species. Most recent records - 2021.

Non-native Species

Non-native species within the nature reserve include, but are not limited to, sea buckthorn (Hippophae rhamnoides), salmonberry (Rubus spectabilis), sycamore (Acer pseudoplatanus), American skunk cabbage (Lysichiton americanus), traveller's joy (Clematis vitalba) and Corsican heath (Erica terminalis).

- Sea buckthorn *H. rhamnoides*

Figure 46: Image: The Wildlife Trusts / Map © Ulster Museum.

A invasive thorny shrub native to the eastern seaboard of Britain and north-west Europe. Planted to ‘stabilise’ dune systems – infestations result in the loss of native biodiversity, increased levels of nitrogen in soils and accelerated erosion. Controlled mechanically (hand-cutting/ removal by digger machinery) or chemical removal using an approved herbicide..

- American skunk cabbage *Lysichiton americanus*

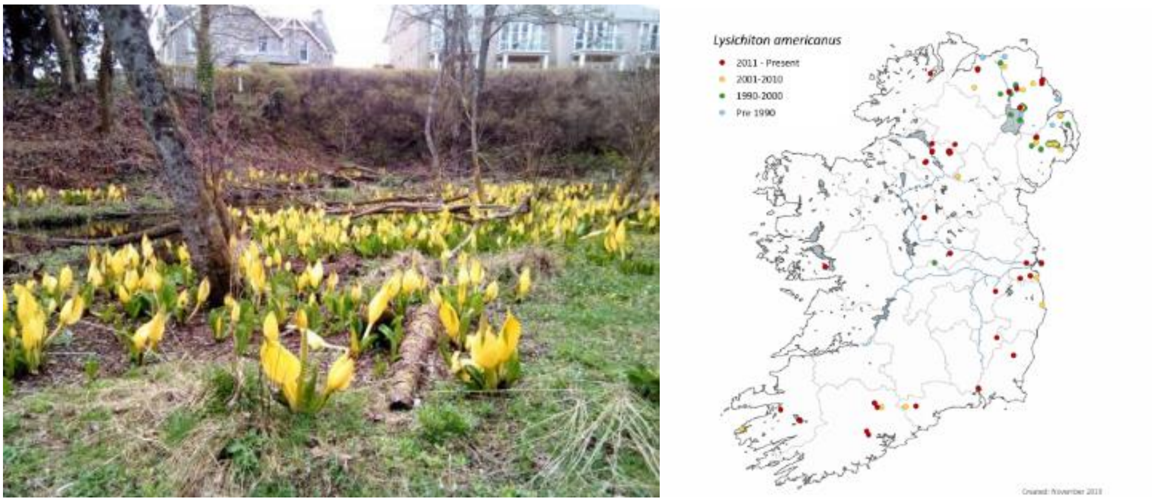

Figure 47: Image: Scottish Invasive Species Initiative/ Map:© invasivespeciesireland

First introduced to Europe in the 1900s as an ornamental plant it has spread to several locations in Ireland inhabiting wet woodland, streams and riverbanks. To add insult to injury, as the name proclaims, it possess an unpleasant smell. Control methods include spraying with approved herbicide, and mechanical removal (digging by hand and disposal of the plant and rhizomes appropriately/ removal of the flower-heads before seeding).

Umbra Nature Reserve – Management of Sensitive Sites (MOSS)

NIEA MOSS project identified to address the failing conservation status of Magilligan SAC/ASSI and project designed to implement intervention in the form of capital works to remove ca. 3.5ha of mature non-native Corsican pine, removed 4,500 tonnes of brash and waste wood post felling, install 1,800m of stock proof fencing to manage conservation grazing, install 4 pasture pumps for animal welfare, install 2 cattle handling facilitates for safe animal husbandry, install site access for forestry operations, remove 1.5ha of invasive Sea Buckthorn.

- Project funding secured at £250,000 and fully funded through DAERA MOSS programme.
- £15,000 generated from private sale of timber to sawmill, revenue paid direct to private land owner.
- Project completed across 2 years as part of holistic site management of the whole Magilligan SAC with additional works taking place on Council and private land to the West and East of the Umbra NR.

Hydrological monitoring programme agreed and GSNI engaged through Dept SLA to determine baseline hydrogeological conditions pre conservation works. Post conservation works hydrogeological and ecological monitoring continuing at Umbra and Portstewart to infer the success of the management works and monitor groundwater level recovery in response to removal of plantations and scrub. Hydrological monitoring ongoing. Site subject to ASSI condition assessment every 6 years, monitored in 2021 however reports are not yet finalised – let's hope it's in better condition than it was in 2014 when grey dunes, dune slacks, white dunes, yellow dunes, embryo dunes all unfavourable.

MOSS disengaged post management works in 2019 and site maintained under effective conservation management by UW as the land managers. Magilligan SAC considered to be under favourable management with all habitat site selection features under effective conservation management by MOD, UW, and Causeway Coast and Glens Borough Council.

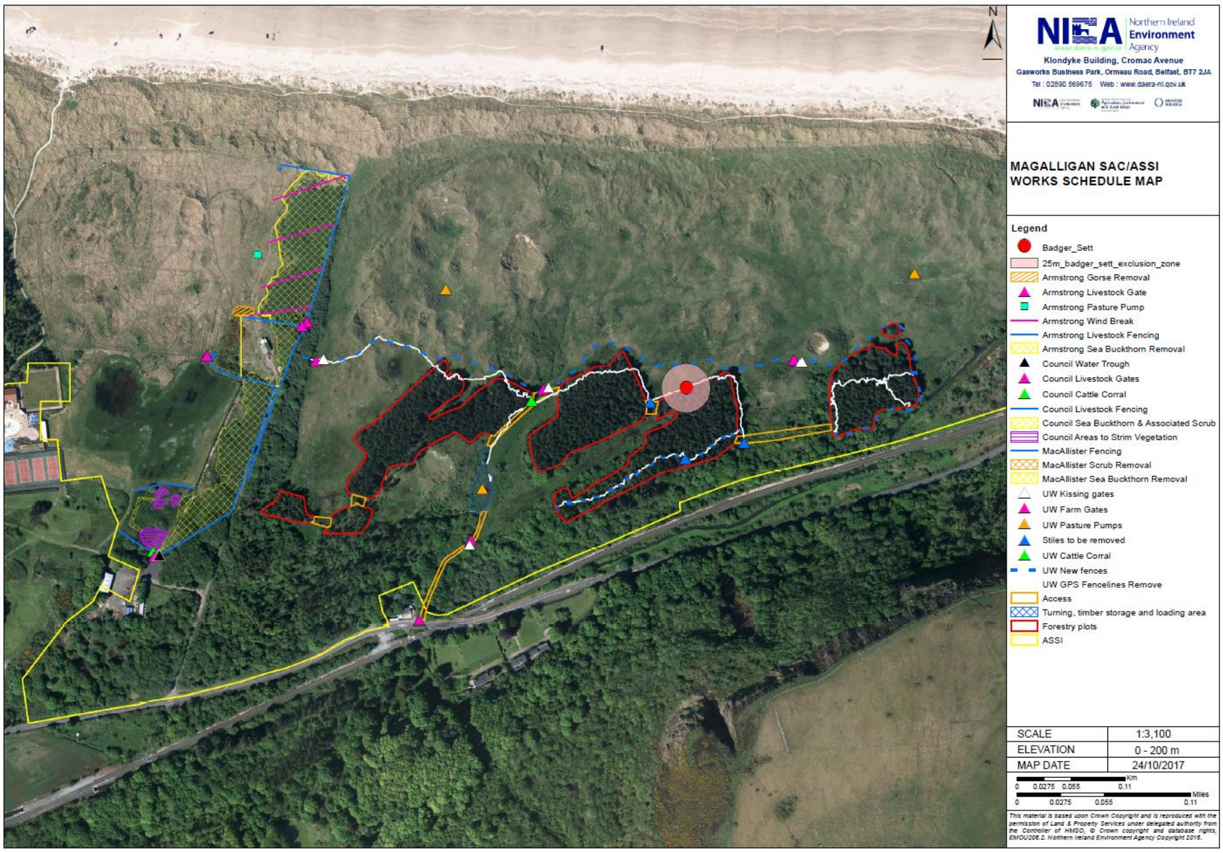

Figure 48: Capital works map.

Figure 49: Site access installation.

Figure 50: Stock proof fencing installation to facilitate conservation grazing.

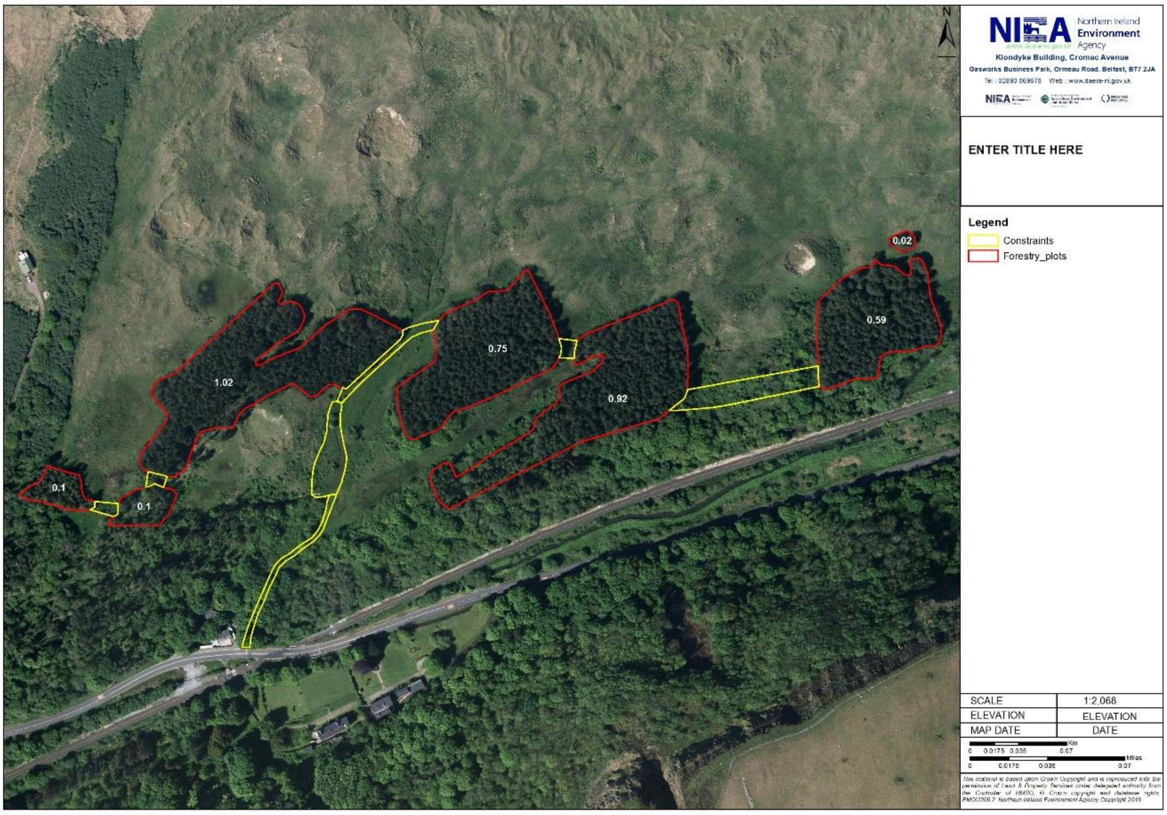

Figure 51: 3.5 ha of Corsican pine removed, plus access clearance between plots.

Figure 52: December 2017 - Toy delivery. Drenagh Sawmills Komatsu 931, 22 tonne harvester.

Figure 53: The business end.

Figure 54: Lets get to work!

Figure 55: Tight lines for the forwarder, sawmill has not completed operations on sand dunes before.

Figure 56: Timber storage area preparation.

Figure 57: Access completed.

Figure 58: Central plot felled, dune slacks naturalised.

Figure 59: Drenagh sawmills Komatsu 865 8WD 19 tonne forwarder onsite, harvester off site after 15 day shift.

Figure 60: Timber stored and hauled to sawmill for processing ca. 20km west.

Figure 61: Site cleared ca 15 days. Note brash and waste wood remain on site. Next phase of site clearance commences.

Figure 62: 'Tub grinder' on site processing 5,000 tonnes of brash and waste wood to wood chip for Edenderry power station.

Figure 63:

Figure 64: Preclearance plots.

Figure 65: Preclearance, harvester on site.

Figure 66: Pasture pump – one of 4 across the site, utilising groundwater for cattle. Access Umbra burn closed.

Umbra Nature Reserve – Hydrogeological Monitoring

Summary Details:

- Project Aim: Observe hydrogeological changes as a result of the vegetation clearance at Magilligan Umbra
- 16 shallow hand installed piezometers across the site, designed along transects and constructed close to slacks
- Groundwater level monitoring, both spot measurements to generate groundwater flow maps, and continuous logging to monitor temporal changes, especially regarding the effects of removal of trees and scrub affecting groundwater recharge
- Up to three chemistry sampling rounds throughout the year since 2017. Groundwater age-dating. Observations – Groundwater level increase and reduction in Nitrate since vegetation clearance.

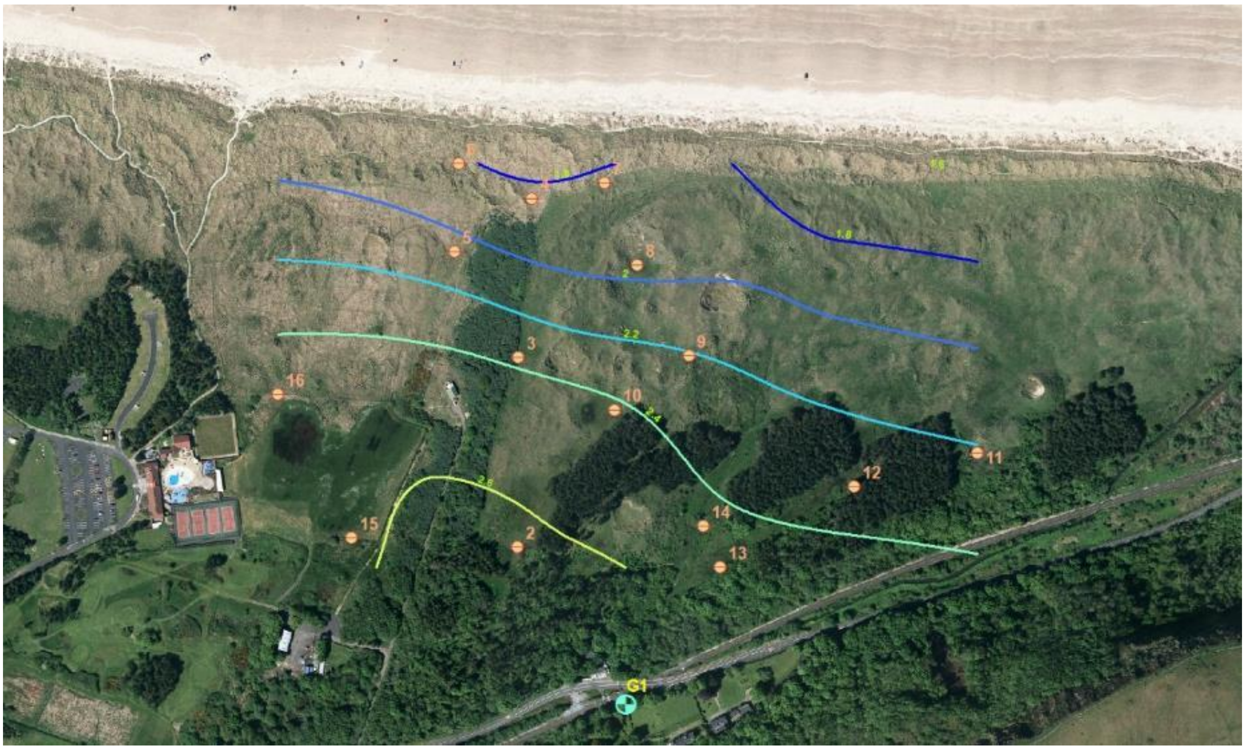

Figure 67: Piezometer locations and groundwater flow map, Winter 2017.

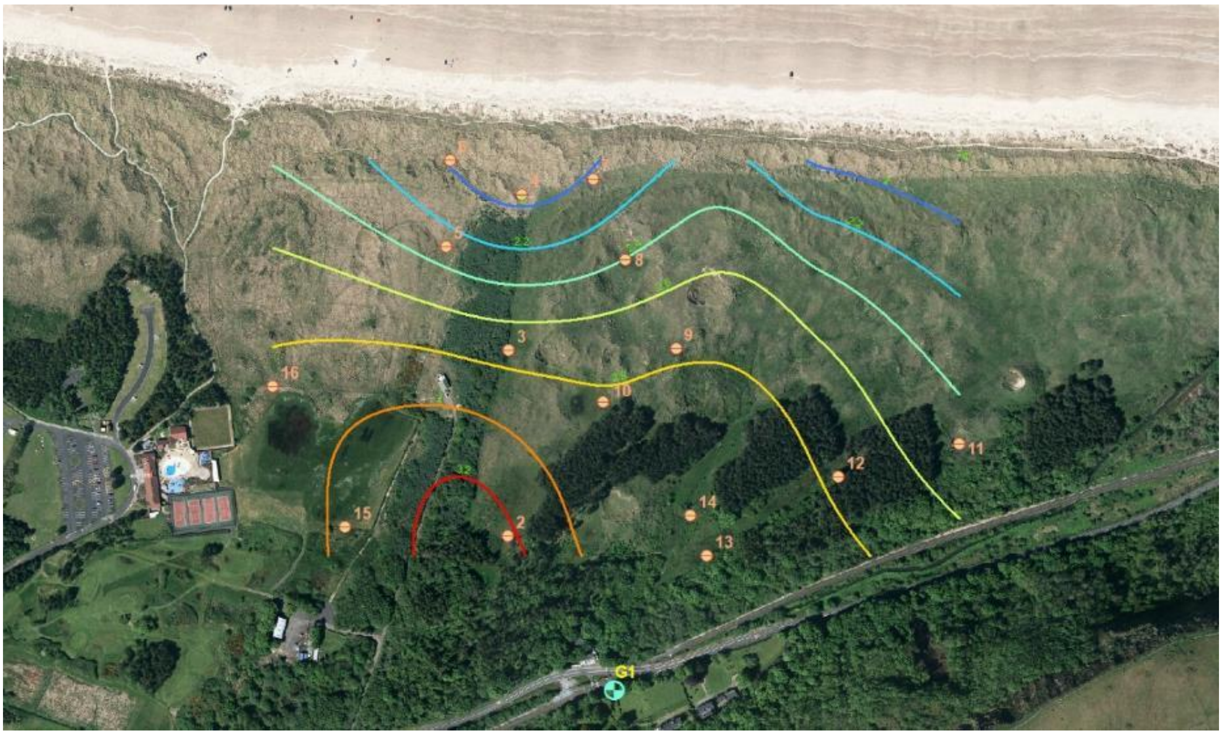

Figure 68: Piezometer locations and groundwater flow map, Winter 2021.

Figure 69: Hand installed Casagrande piezometer point.

Figure 70: Piezometer Installation.

Figure 71: Completed Piezometer.

Figure 72: GSNI/NIEA construction team.

Figure 73: Groundwater Sampling.

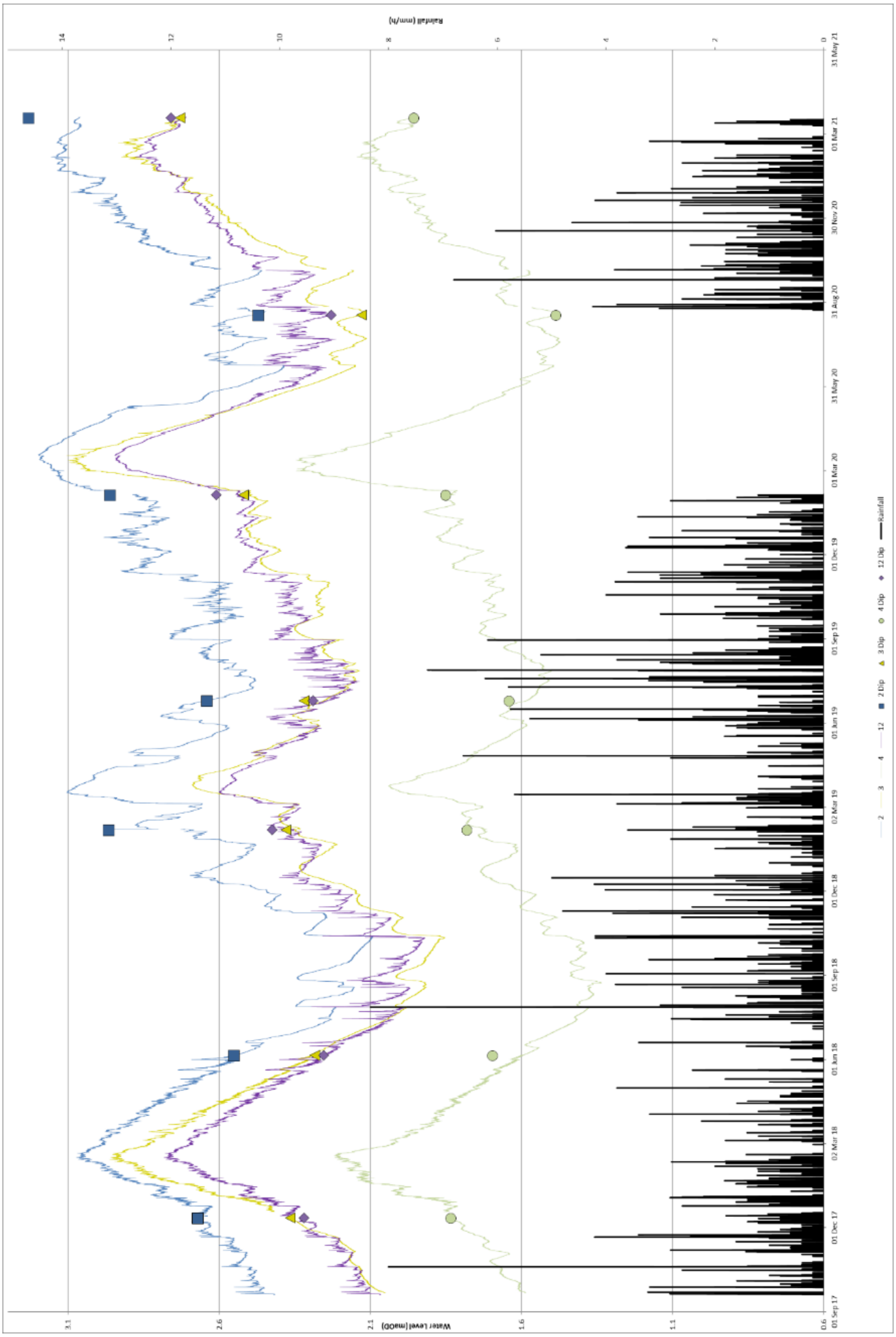

Figure 74: Groundwater Hydrographs and Rainfall 2017 – 2021.

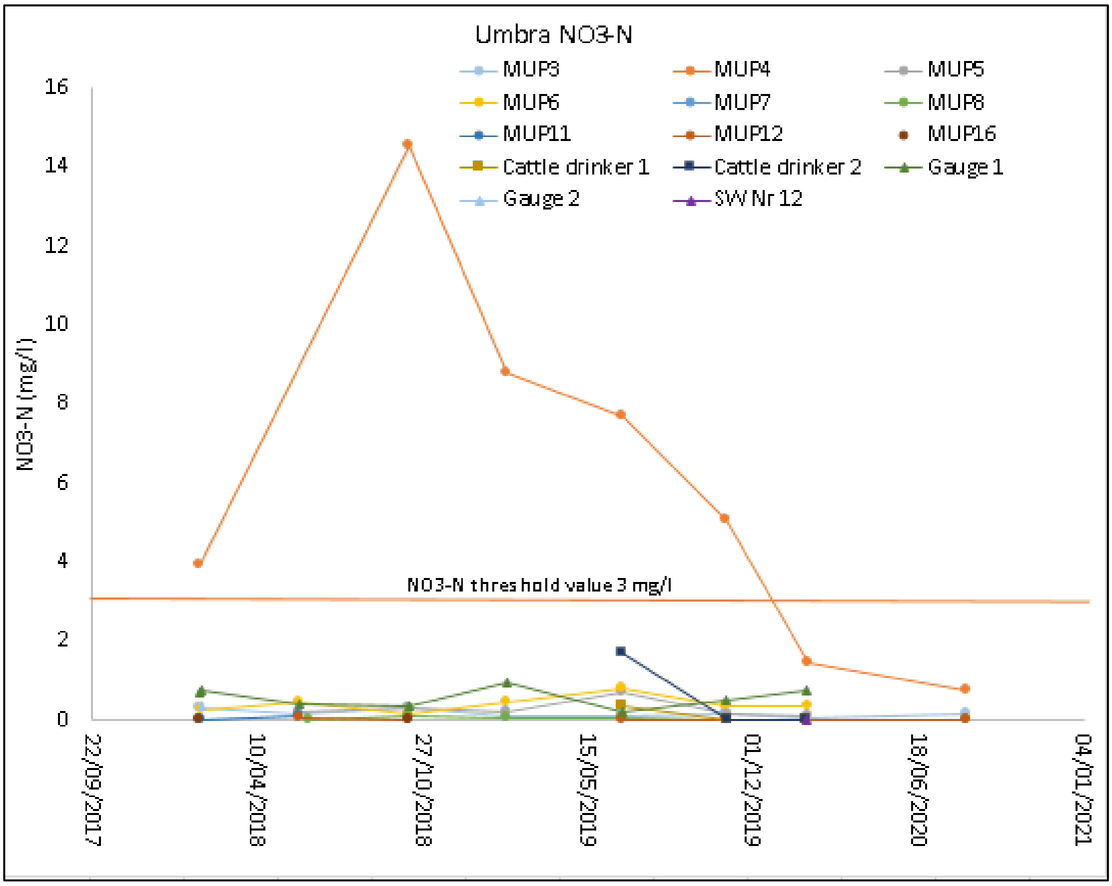

Figure 75: Groundwater NO3-N concentrations temporal changes.

Sample	Sample date	CFC-12 (pmol/L)	CFC-11 (pmol/L)	SF_6 (fmol/L)	Year of Recharge		
					CFC-12	CFC-11	SF_6
Magillian Umbra							
MUP12	05/02/2020	0.51	3.84	0.021	1968	1983	1960
MUP4	06/02/2020	1.92	5.40	21.612	1983	1995	>modern

Figure 76: Groundwater dissolved gases - Year of Recharge.

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6. Magilligan Test Site, County Derry.
Jesus Aguila Fernandez, Mark McDonnell and Ray Flynn

Introduction

Projected growth in the world's population over the next 50 years will occur disproportionately in coastal areas, placing further stress on local aquifers. The widespread occurrence of saline intrusion (SI) bears testament to current over exploitation of many of these units, while also highlighting the need to better understand how sea water enters natural deposits. Although the fundamental processes underpinning SI have been understood for some time, field studies, where the drivers leading to SI have been confidently demonstrated in natural deposits, remain rare in the literature.

Examination of the spatial distribution of SI-related issues around the world indicates that few easily accessible yet pristine areas now remain where coastal aquifers display negligible evidence of human interference, including areas in more temperate settings. Ireland is one area where this problem is largely absent. However, although aquifers around the Irish coast remain largely unexploited, many of bedrock units display high levels of heterogeneity, making definitive data interpretation challenging. By contrast Holocene unconsolidated beach deposits typically have lower levels of variability.

Conditions in the beach sands at the Magilligan Test Site have allowed researchers at Queen's University Belfast and Imperial College London to study SI at the field scale through the RCUK-funded SALINA programme. Test results have been compared to responses observed in laboratory-scale experiments and numerical modelling simulations. This includes pumping tests carried out to induce saline intrusion into the beach sands. During these tests, repeated generation of electrical resistivity profiles permitted investigation of the utility of geophysics to provide a more complete picture of intrusion into coastal groundwater systems experiencing tidal fluctuations.

Laboratory Experimentation

Laboratory investigations permit investigation of processes giving rise to SI, with levels of control not possible at the field scale. Test completed at the QUB SALINA laboratory facility have employed artificial intelligence routines for image analysis to quantify fundamental processes occurring during SI in uniform saturated porous media. (Figure 77). This has included examining fundamental processes giving rise to spontaneous potential responses observed in advance of salt water intrusion into water supply wells. (Figure 78).

Figure 77: Image of laboratory apparatus employed to simulate salt water (red) intrusion into a saturated porous medium (glass beads) containing freshwater. The black points are ports employed to measure spontaneous potential while intrusion occurs. (Image: Georgios Etsias, QUB)

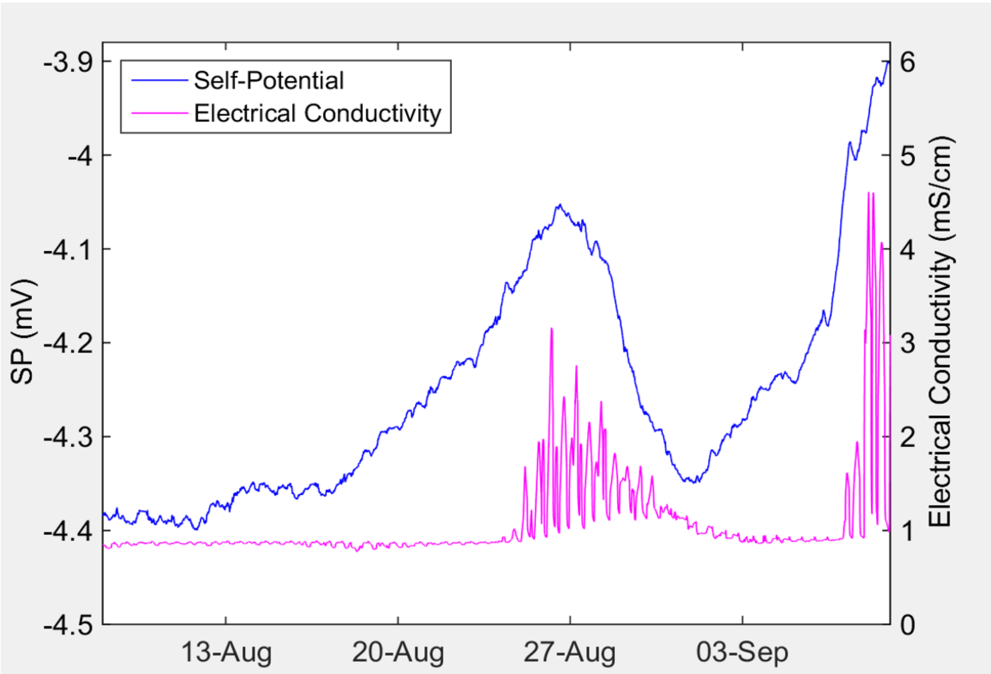

Figure 78: Spontaneous potential response in a chalk aquifer, occurring in advance of the intrusion of salt water. A significant time between the two parameter responses difference provides a basis for alerting of the danger of salt water contamination of drinking water supplies. (Figure: Prof. Adrian Butler, ICL)

Magilligan Site Description

The Magilligan Test Site is located approximately 10m south of the mean high water mark (HWM) on Benone Beach, Co. Derry, Northern Ireland (Figure 79). A belt of coastal sand dunes lies immediately to the south of the site; this forms a hydrogeological continuum with the underlying beach deposits. Preliminary electrical resistivity surveying, undertaken prior to site instrumentation, indicated that a sequence of approximately 20m of sands rests on the northerly sloping Lr. Jurassic bedrock interface, dipping at approximately 1 degree. Magilligan experiences an Atlantic tidal cycle with a mean tidal range of 1.19 m (National Oceanography Centre, 2021). The regular change in sea level gives rise to an intertidal recirculation cell (IRC), in which the uppermost parts of the beach sands become intruded by sea water from above, before partially flushing with freshwater. The capacity of the IRC to affect water quality, compared to salt water wedges, typically encountered at the base of an aquifer, had not been quantified at the outset of SALINA, and formed one of its fundamental goals.

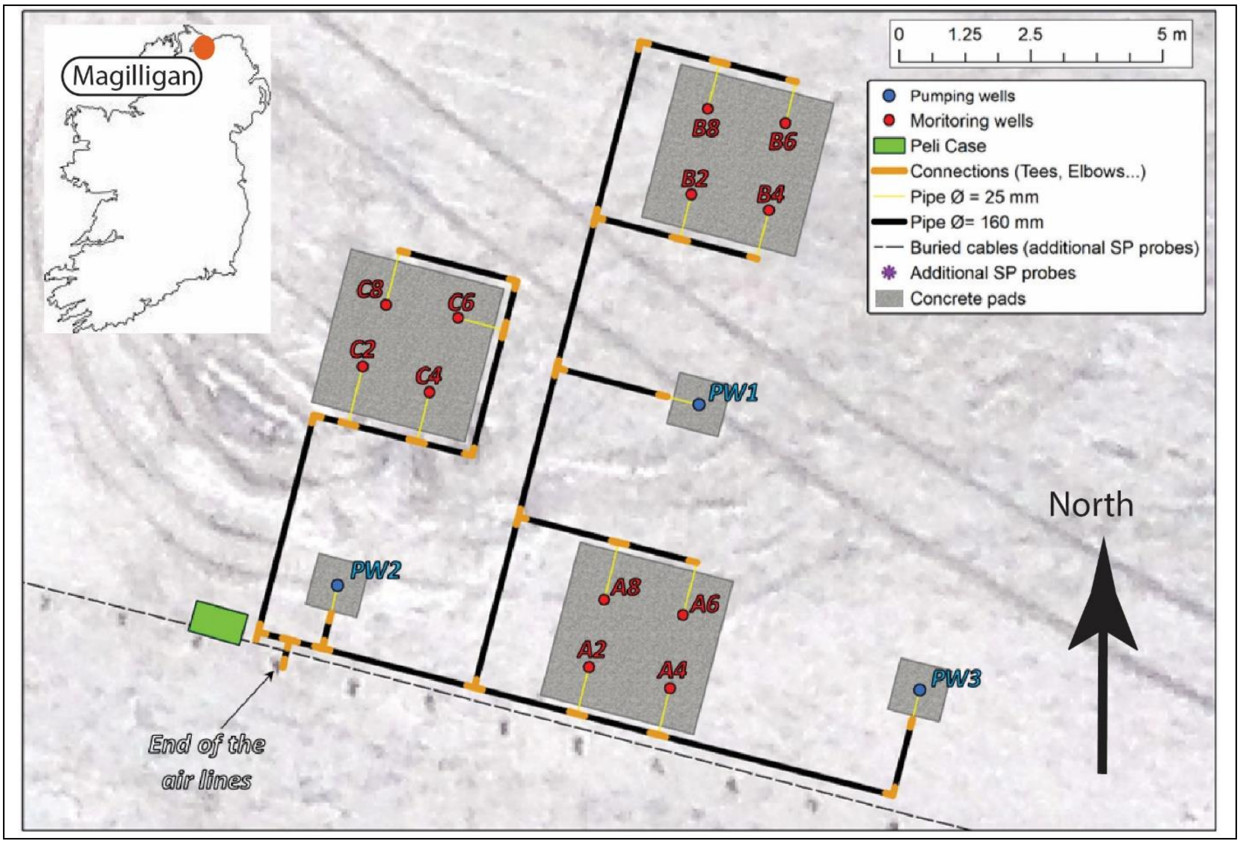

Figure 79: Location of Magilligan Test Site with positions of pumping and observation well clusters.

At Magilligan, visual observations suggested that the IRC restricts freshwater discharge from the underlying sand aquifer to an interval within the intertidal zone. Groundwater level monitoring of the deposits underlying the dunes, carried out prior to experiments, revealed the influence of tidal cycles on groundwater head rapidly dissipates landward and is not apparent in monitoring wells 100m south of the HWM. Furthermore, groundwater head data collected between 01/09/2018 and 30/08/2019 revealed site levels fluctuated over a range of approximately 0.85 m/year, reflecting recharge arising from high year-round precipitation of approximately 1100mm/year, falling over between 240 and 260 rain days (rainfall >0.2mm). Annual average actual evapotranspiration of approximately 550 mm/yr occurs predominantly between the and April (Werner, 2016). Water level data from both Magilligan and the adjacent dunes display no influence from external pumping, which is consistent with the absence of records for significant abstractions (>100m^3/day) in the area. Application of in-situ geotechnical (cone penetrometer) technology, revealed the sand underlying the site to reach thicknesses predicted by ERT.

Experimentally Induced Saline Intrusion

The absence of interference from pumping on Magilligan's groundwater regime, coupled with the relatively homogenous nature of the deposits underlying the main test site make Magilligan an ideal location for experimentally investigating saline intrusion under undisturbed conditions. With this objective in mind, three pumping wells and three clusters of four observation wells, screened at discrete intervals in the uppermost 10m of the aquifer, were installed to examine the capacity of experimental pumping to induce salt water intrusion into the aquifer. Figure 4 and Figure 81 summarise well construction. Groundwater level monitoring has also revealed a consistent north easterly hydraulic gradient, of between 0.005 and 0.0085, reflecting the flow of fresh groundwater from the dunes toward the sea.

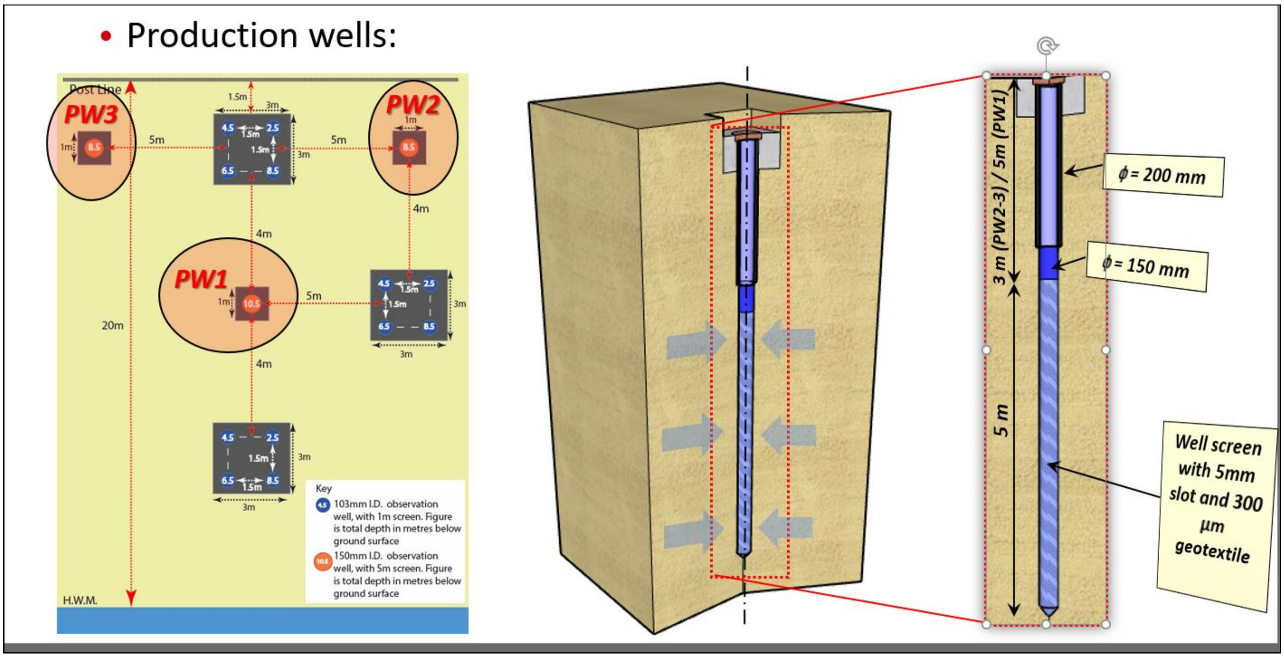

Figure 80: Pumping well design for the Magilligan Test Site. Wells PW2 and PW3 were pumped to intercept seaward-flowing fresh groundwater to enhance the possibility of drawing in salt water at PW-1. Well head water quality was measured with flow through cells at all three wells during pumping.

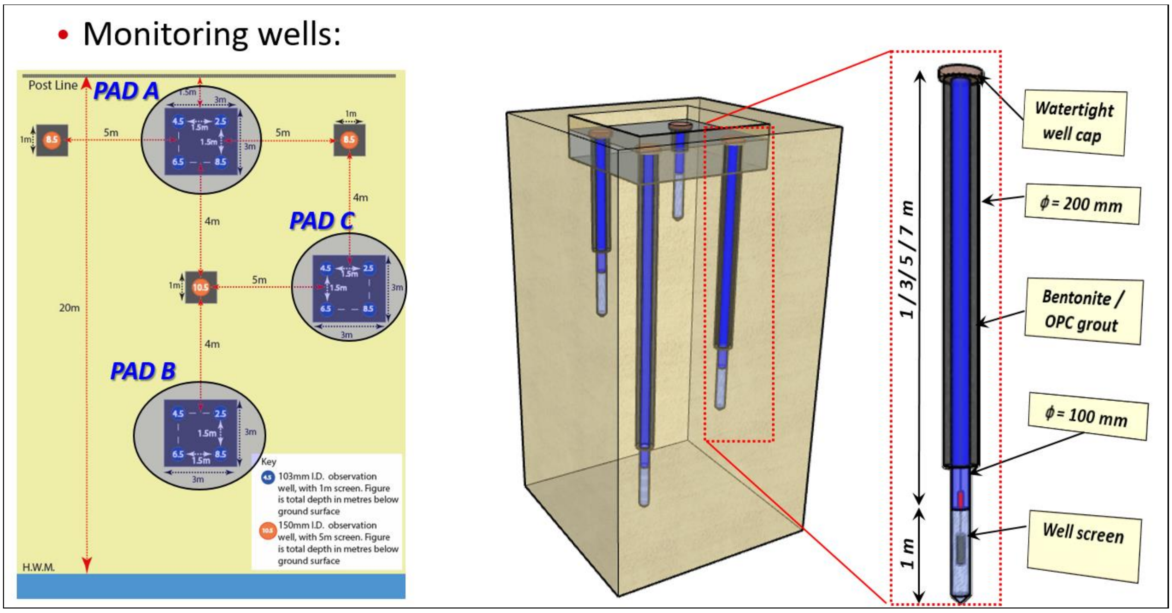

Figure 81: Observation well design for the Magilligan Test Site. Each pad has four 4" observation wells screened up to 8.5m below ground. All wells monitored water level temperature, electrical conductivity and spontaneous potential during pumping.

A 69-hour constant discharge pumping test took place between 11th and 14th of August 2020 with the aim of inducing salt water intrusion into pumping well PW-1. Simultaneous pumping of PW-2 and PW-3 aimed to enhance drawdown, while intercepting freshwater flow from the dunes. Water quality samples collected during the test from pumping wells aimed to evaluate the influence of water quality on SEC and SP signals observed.

Prior to pumping, background monitoring of water levels and groundwater SEC took place over a three-month period to evaluate the impact of tidal cycles on the hydrogeological regime. A more detailed programme of geophysical monitoring took place at roughly three hour intervals during the day, immediately prior to pumping, to characterise the influence of tidal cycles on larger volumes of aquifer.

Electrical resistivity measurements taken, before and during the test aimed to track the migration of salt water through the sands during and after pumping. A Syscal Pro resistivity system (IRIS Instruments), with 36 stainless steel electrodes, connected using multicore optic fibre cable, collected resistivity readings at approximately three hour intervals along two lines. These were located parallel and perpendicular to the HWM, crossing immediately to the north of Observation Well Cluster B; electrode spacing parallel to the shoreline was at 3m intervals, while that perpendicular to the shore had 1m spacings.

Results and Conclusions

The limited levels of heterogeneity observed in the Magilligan aquifer meant that numerical modelling of the pumping test response allowed for confident determination of aquifer parameters. Findings revealed the aquifer to have transmissivity values ranging between 98 and 140m^2/day, and suggesting seaward freshwater discharge rates between 0.6 and 1m^3/m/day, when results were combined with hydraulic gradient data.

Water quality monitoring results revealed a sustained rise in SEC in pumping well discharge. This was accompanied by a change in the ionic makeup of the water sampled from all three pumping wells, from a Ca-HCO3-dominanted system, to system more dominated by Na-Cl (Figure 82)

End member mixing analysis of freshwater, sampled from landward monitoring wells, and sea water suggested an increase in salt water content in discharge from 1.4% sea water to 4.1% as the test progressed despite sea level variations linked with tidal cycles. (Figure 83A).

Intermittent time domain ERT monitoring, collected at low tide at consistent locations in the months prior to pumping, revealed a consistent pattern of resistivity declining to the north (seawards), in a wedge-shaped configuration. This overlay a body with higher resistivity, which declined with depth. The pattern is consistent with presence of saline water into the upper layers of the saturated sand, overlying a layer of fresher groundwater (Figure 83B).

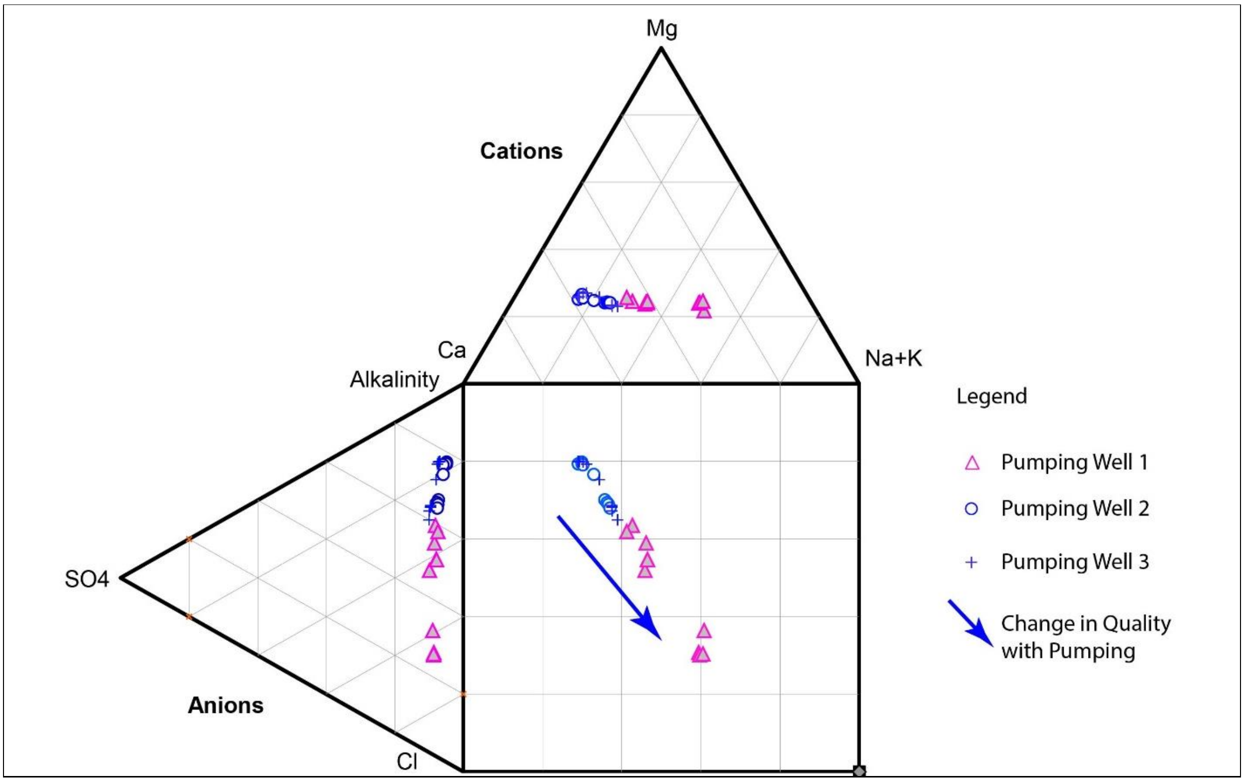

Figure 82: Durov plot illustrating changes in major ion content with pumping as additional saltwater was induced into pumping wells.

ERT responses observed under natural gradient conditions contrasted with those observed during pumping, where the pattern of a lower resistivity overlying higher resistivity inverts to reveal a tongue of lower resistivity ground at between 2m and 4m below surface, which progressively extends toward PW-1 as pumping proceeds. The findings reflect the dewatering of the upper part of the aquifer and migration of

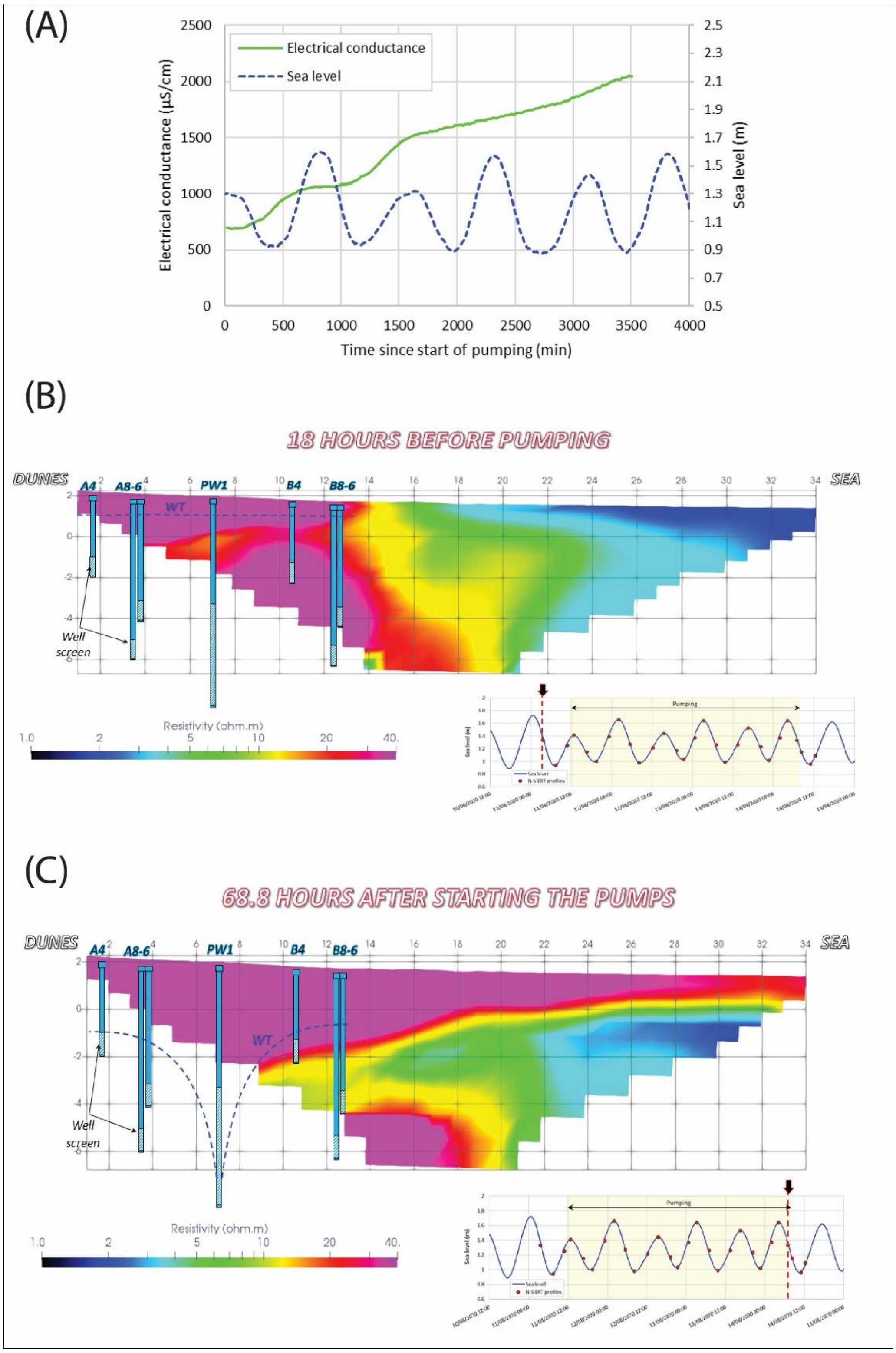

Figure 83: (A) Increase in electrical conductance of discharge water during pumping test, superimposed upon tidal cycles (B) Electrical resistivity profile extending from land to sea, prior to pumping. (C) Electrical resistivity profile observed at same position in tidal cycle towards the end of pumping. The greens and yellows in the tomography reflect the intrusion of brackish water. The dotted line reflects the position of the water table.

saline water at the water table toward the wells, leading to the entry of a higher proportion of saline water into the pumping well. Overall, time domain data indicate that the additional saltwater derived from the IRC rather than depth. This has led to a revised conceptual model of how saline intrusion occurs at Magilligan (Figure 84).

Findings of this investigation further highlight the utility of ERT for characterising saline intrusion. At the same time the data gathered further underscore the value of multidisciplinary methods, using hydrogeology, hydrochemistry and geophysics to better characterise the processes, particularly in environments where intertidal recirculation cells operate. However, uncertainties remain concerning the impact of tidal cycles on groundwater flow and resistivity signals, notably during conditions at high tide / tidal surge. This is currently being addressed by permanent on-site geophysical infrastructure to facilitate the semi continuous (hourly) monitoring of resistivity profiles in the vicinity of the test site. Results promise to shed further light on the impacts of shallow salt water intrusion on both groundwater flow patterns and the capabilities of geophysical tools to characterise them.

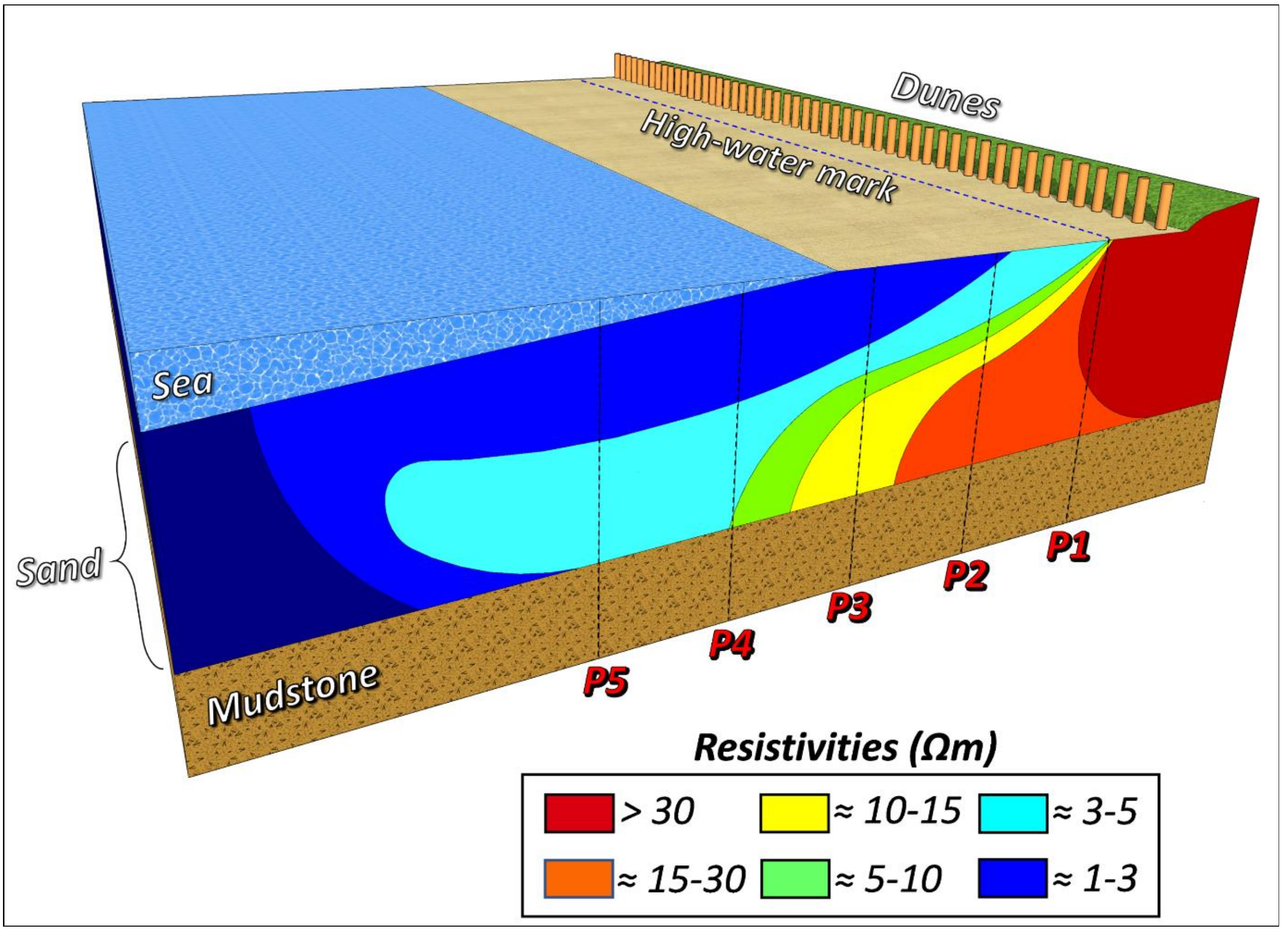

Figure 84: Revised conceptual model of saline intrusion at the Magilligan Test Site. In contrast to the classical basal wedge observed in more widespread studies, salt water induced into pumping wells derives from saline groundwater derived from the inter tidal recirculation cell, with high recharge rates generating an inverted freshwater wedge which extends below the low tide mark.

7. Anney's Well (sometimes referred to as Blacksprings).
Conor Lydon and Paul Wilson

Introduction and Background

Longer and drier summers coupled with elevated temperatures are leading to periods of exceptionally high water demand. During high demand periods, water treatment works are operating at maximum capacity and distribution networks are strained. In 2021, Northern Ireland experienced its third warmest summer on record; second only to the summers in 2006 and 1995. Northern Ireland Water were unable to push water into the areas that needed it. As such they had to resort to tankering water from areas of surplus to areas of need. Lough Fea, was one of those areas that required additional water tankered to it.

This site is one of several new water sources under investigation by Northern Ireland Water, owing to the water shortages they have been experiencing during high demand periods.

Geology and Hydrogeology

The bedrock geology of the area is Ordovician in age and comprises of the Tyrone Igneous Complex, Slieve Gallion Granite with a diorite based igneous intrusion nearby (Figure 85). The area is overlain by a complex of glaciofluvial ice contact deposits (Figure 86). These form a superficial aquifer made up of sand and gravel.

Site Visit

During the field visit Paul Wilson and Conor Lydon will detail the sites water supply history, detail the main water features, the hydrogeological conceptual site model, abstraction constraints and the approach being taken to secure a sustainable water supply for Northern Ireland Water in this area.

Figures

The figures below will be used to inform discussions during the field trip.

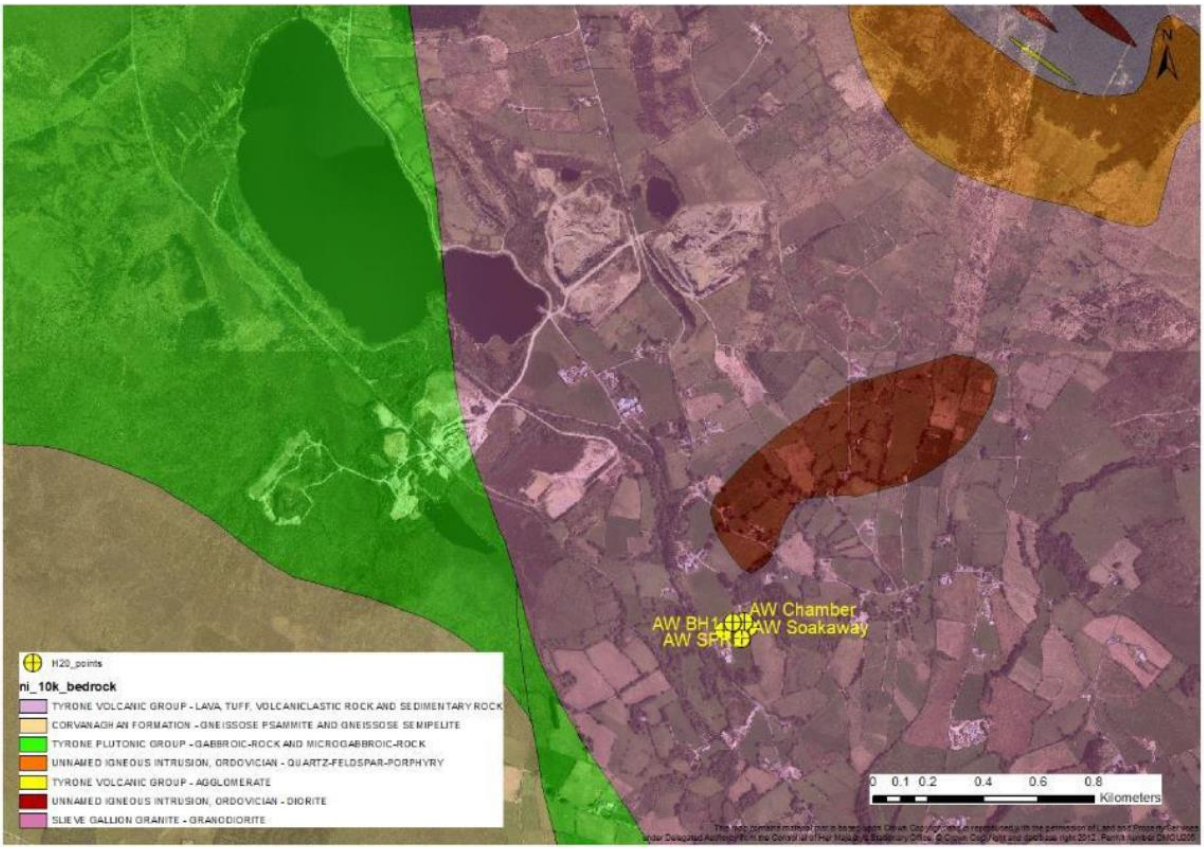

Figure 85: Bedrock Geology of the Lough Fea area (prepared by GSNI, 2021).

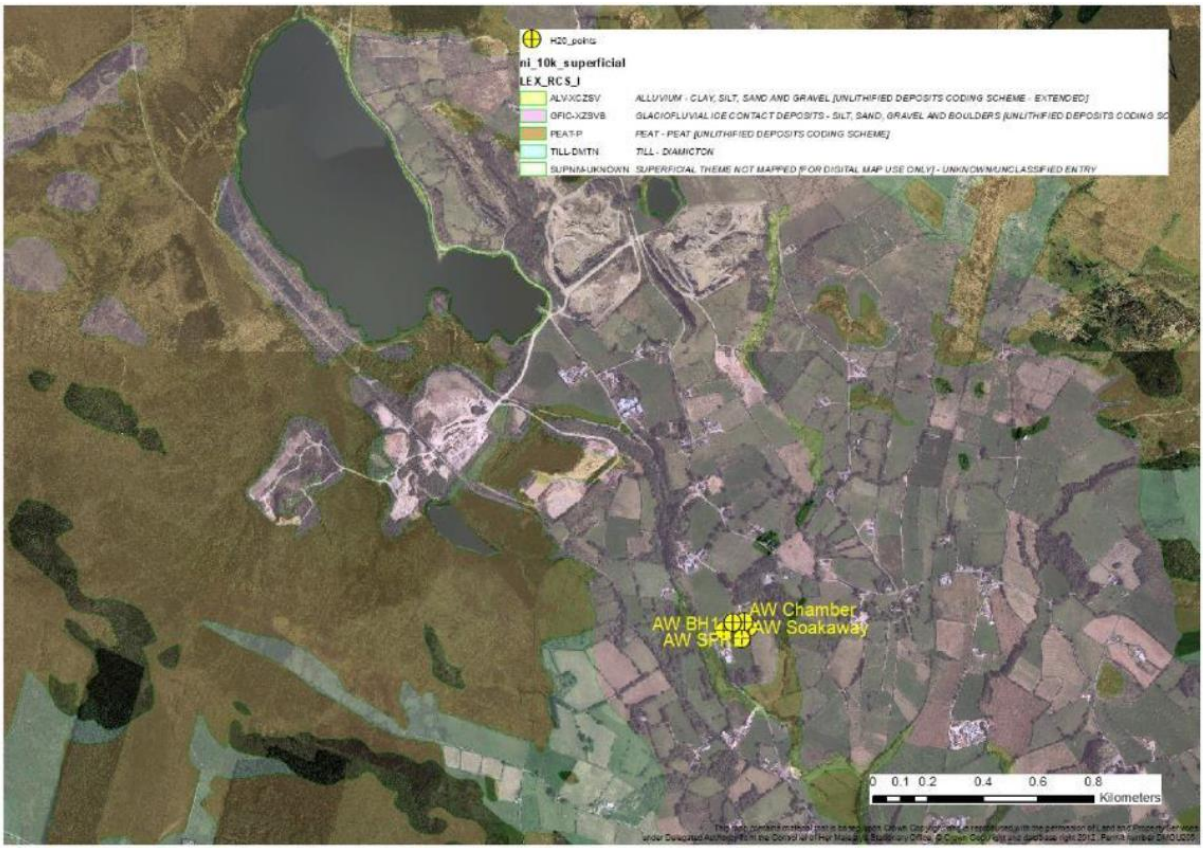

Figure 86: Superficial Geology of the Lough Fea area (prepared by GSNI, 2021).

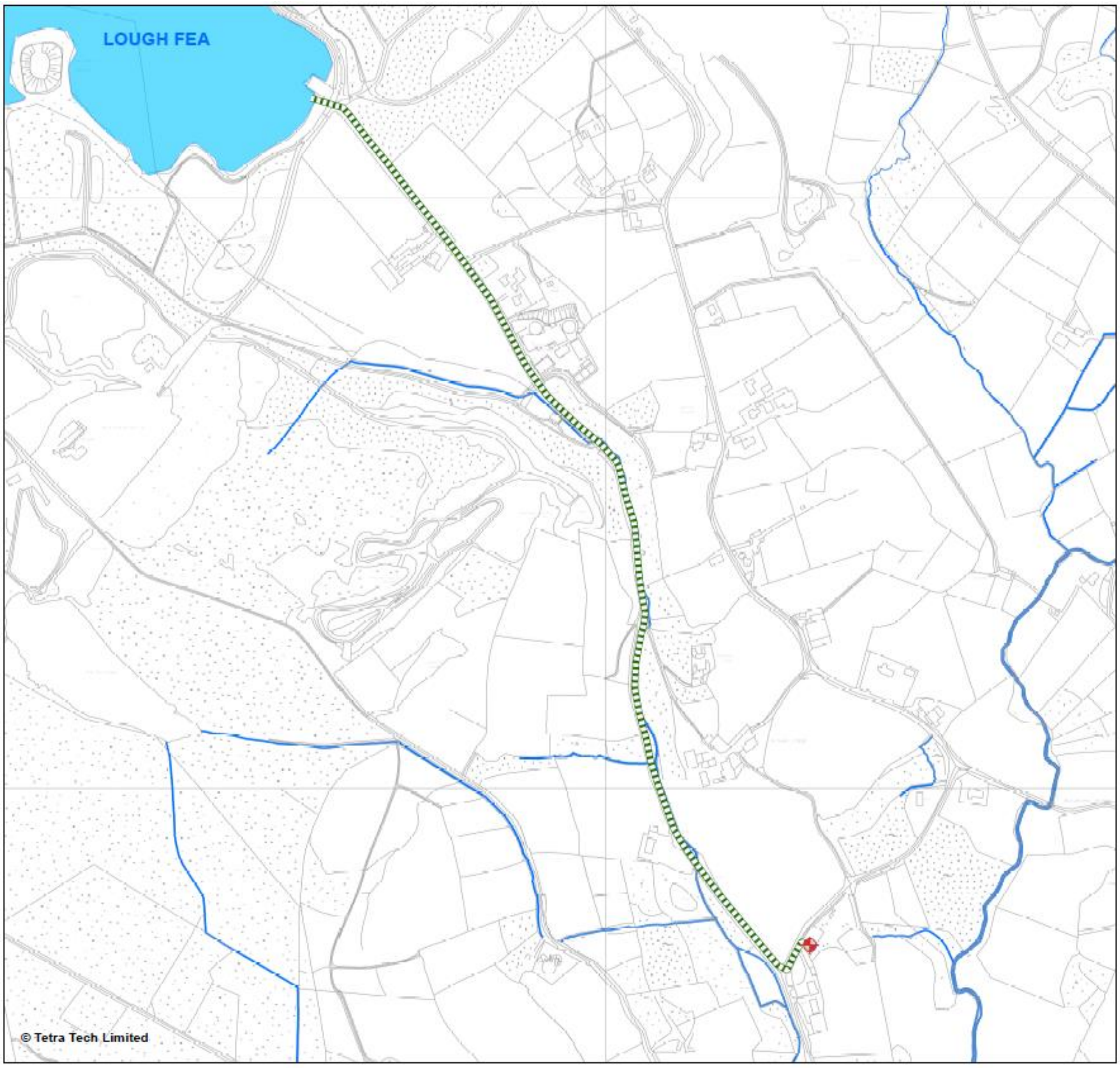

Figure 87: Anney's Borewell Location and Discharge Route to Lough Fea (Tetra Tech, 2021).

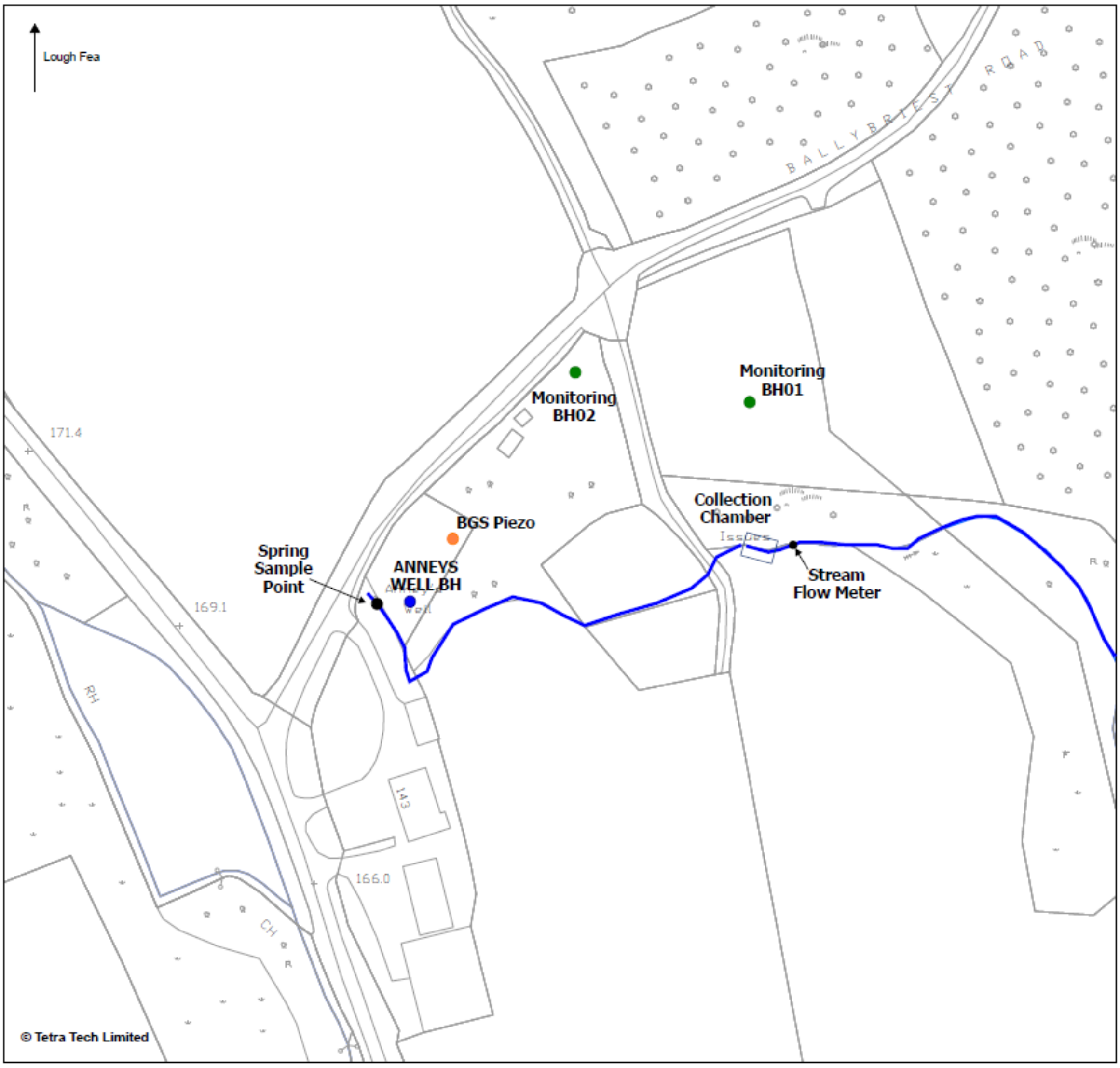

Figure 88: Anney's Borewell Site Layout and associated points of interest (Tetra Tech, 2021).

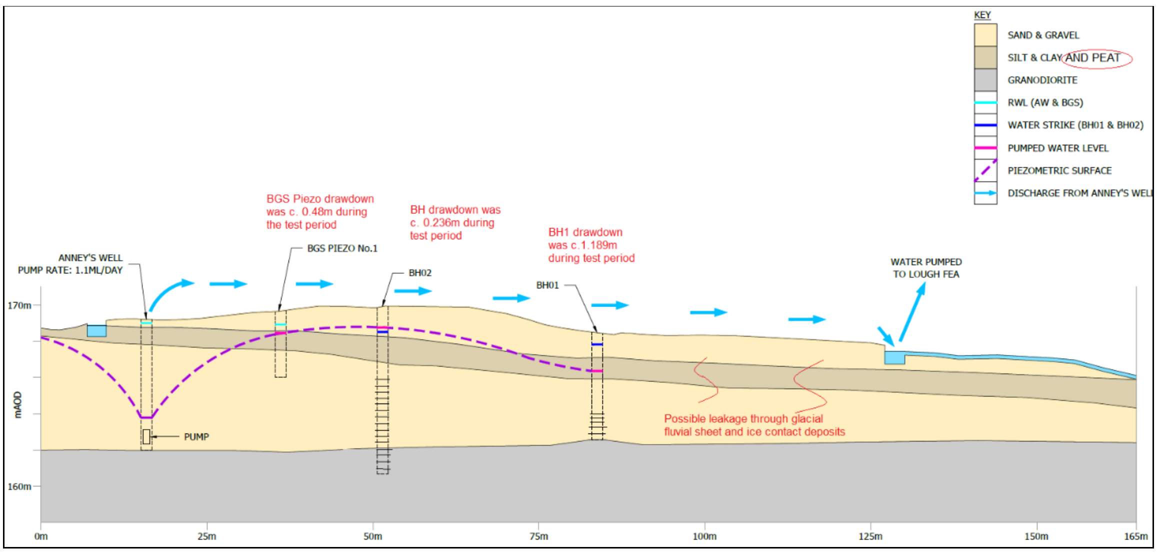

Figure 89: Preliminary Conceptual Site Model

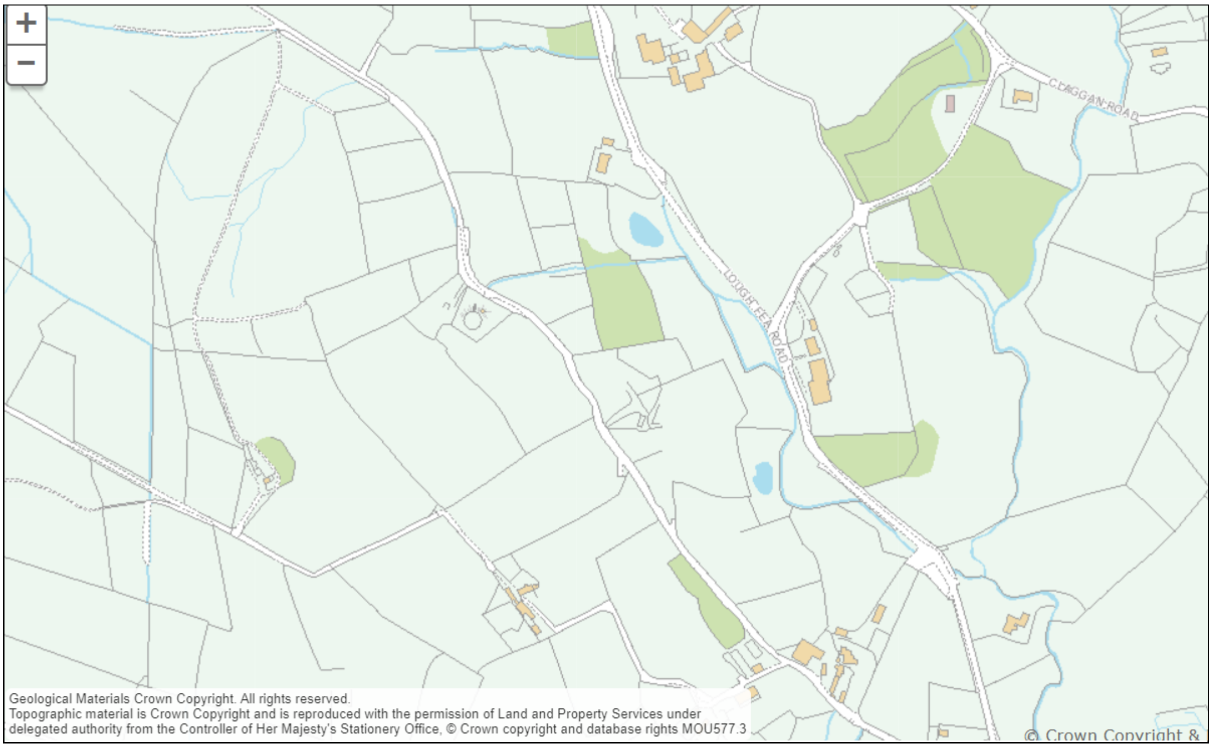

Figure 90: OS Map from GSNI GeoIndex website, Oct-21.

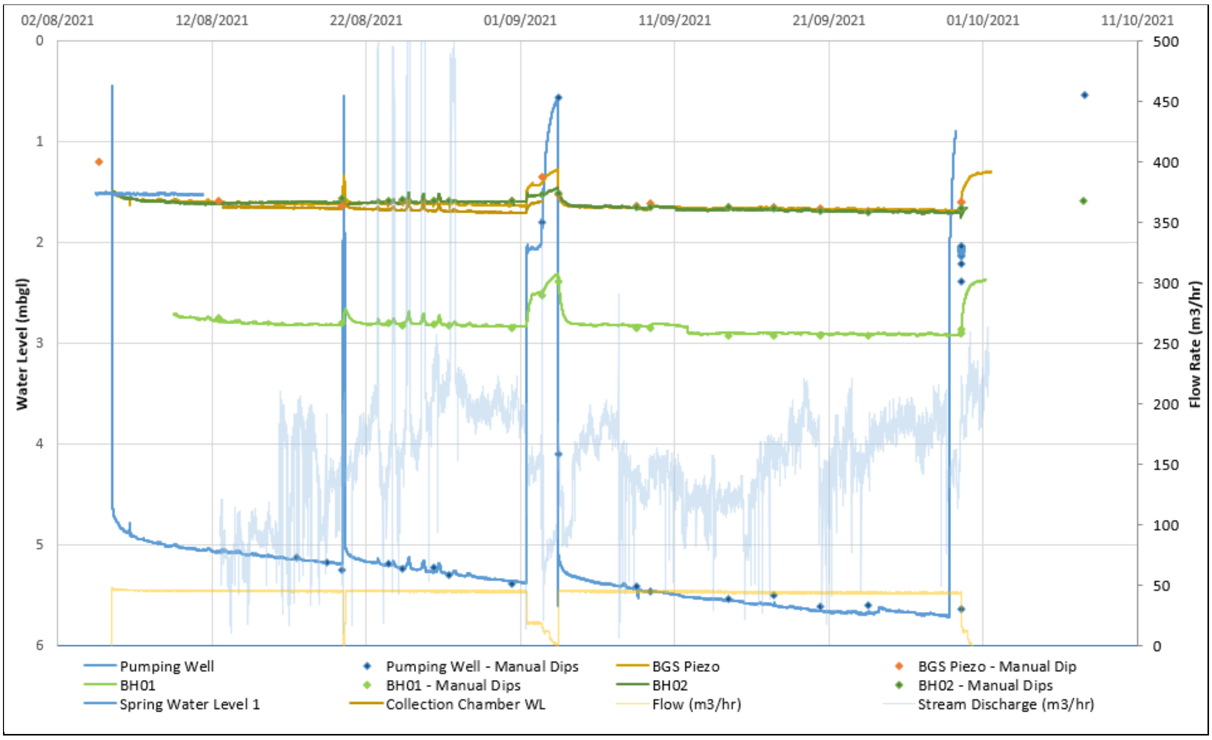

Figure 91: Preliminary Hydrograph

References

Wilson, P. May 2020. Geological Survey of Northern Ireland, Lough Carn and Anney's Well Preliminary Hydrogeology Scoping Report.