7A KARST HYDROGEOLOGY ASSESSMENT

7A.1 INTRODUCTION

A hydrogeological assessment of the River Deel was commissioned by OPW in December 2015 during the options assessment stage for the River Deel Flood Relief Scheme. The initial purpose of the assessment was to assess the potential for a diversion channel between the River Deel and Lough Conn to impact on low flows in the River Deel.

In 2015, there was a deficit of documented evidence of karst activity in North Mayo, including the catchment of the River Deel. Anecdotal evidence suggested a connection between the River Deel and the 'pond' labelled on Ordnance Survey Maps at Mullenmore.

A key consideration in December 2015 was the potential for a diversion channel to affect low flow conditions in the river, which forms part of the River Moy SAC and is home to a range of protected species such as White Clawed Crayfish, Atlantic Salmon and Lamprey Species, all of which are among the qualifying interests of the River Moy SAC and Freshwater Pearl Mussel, a species listed on Annex II of the EU Habitats Directive that is not among the qualifying interests of the site.

Karst flows are unpredictable and site-specific in character. Karst groundwater behaviour can vary in time and space so it is essential that an understanding be developed of where water goes underground, its underground routes and the possibilities of a new channel adversely affecting these karst flows, or intersecting underground conduits. In order to understand the nature of the local karst hydrogeology, its relationship with low flows in the River Deel, and to assess impacts from a flow diversion channel for Crossmolina in sufficient detail, it was deemed necessary to carry out a further hydrogeological investigation. The main objective of the investigation was to establish where water sinks underground, in what quantities, and to determine if all of it emerged at the Mullenmore Springs, and if not, then where.

The karst hydrogeological assessment which culminated in the preparation of this report was led by Dr David Drew with assistance from Jonathan Reid, Ryan Hanley consulting engineers.

The first version of the report was issued in May 2018 to coincide with the public exhibition for the River Deel (Crossmolina) Drainage Scheme. Further investigations were carried out in 2019 in relation to a collapse (drop-out) doline at Pollnacross. Details of these investigations are provided at Section 7A.4 of this report.

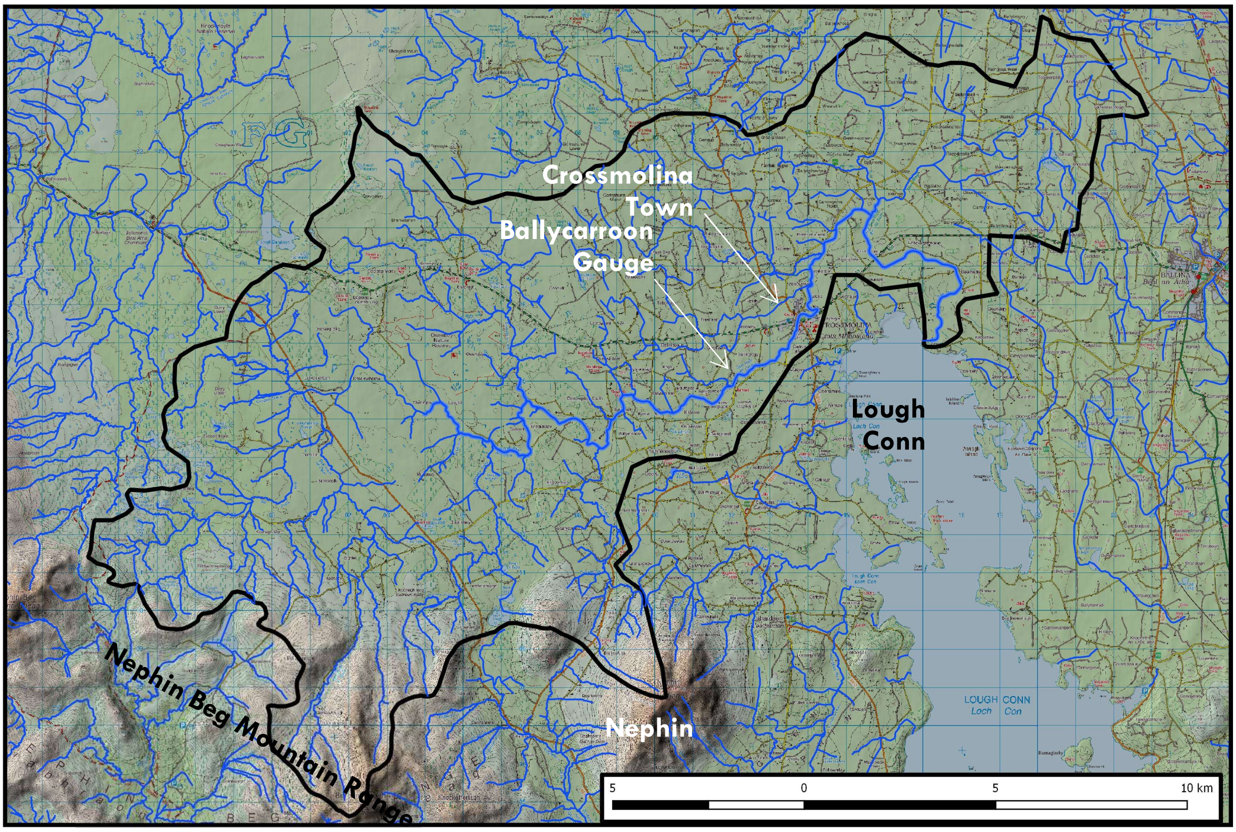

Figure 7A.1: Catchment of River Deel (Outlined in black, source EPA)

7A.2 Assessment Methodology

7A.2.1 Requirement for Further Investigations

Further Investigation required as part of the assessment was initially identified in the following areas:

- Preliminary site investigation to help determine the extent of karstification in the catchment,
- Catchment walkover and collecting anecdotal evidence of the presence of karst,
- Flow measurement along the River Deel to determine the location and quantities of sinking water, and at the Mullenmore Springs and other potential outlets for groundwater,
- Analysis of historic mapping and relevant topographical features, and
- Identification of sinkholes along the River Deel, dye tracing and tracer analysis.

7A.2.2 Assessment Staging

The hydrogeological assessment of the River Deel was carried out in two stages as follows:

- **Stage 1:** An initial assessment of the extent of karstification (open conduits), using the location and measurement of springs in the wider River Deel catchment and the location of other karst features.
    - This work could be undertaken under winter conditions (to greatest benefit in combination with some preliminary site investigation).
    - Tasks involved in Stage 1 were to include catchment walkover, information gathering, flow measurement, analysis of historic mapping and low flow data and preliminary geotechnical investigation.
    - The output from Stage 1 is an assessment of the catchment of the River Deel under static hydrogeological conditions. Static conditions in the case of the River Deel include periods of medium to high flows, which preclude a more detailed analysis of interaction between river flows and the karst groundwater system requires lower flows. The more detailed analysis takes place at Stage 2.
- **Stage 2:** The second stage was to be carried out during low flow conditions using the information obtained at Stage 1 to investigate the dynamics of the groundwater hydrology of the area, for example where water sinks underground and where it reappears, flow rates, variations with stage, etc.
    - This assessment was to be undertaken under low water conditions when the groundwater system was not overwhelmed by medium to high river flows.
    - Tasks involved in Stage 2 were to include catchment walkover during low flow conditions, dye tracing, tracer analysis, flow measurement, bathymetric surveys, and preliminary geotechnical investigations along the banks of the River Deel, the Mullenmore Springs and in the vicinity of the diversion channel.
    - The output from Stage 2 is an assessment of the catchment of the River Deel under dynamic hydrogeological conditions.

Stage 1 will provide a basic understanding of the karst hydrogeology under static conditions, but not sufficient detail to enable a hydrogeologist to understand the nature of the local karst hydrogeology and its relationship with low flows in the River Deel. This can only be understood following Stage 2, an assessment of the catchment of the River Deel under dynamic hydrogeological conditions.

7A.2.3 Study Area

The study area for the investigation encompassed the karst region in the catchment of the River Deel upstream of Crossmolina. The precise extent of the study area was refined as key pieces of information were obtained during Stage 1 and the initial phase of the Stage 2 assessment.

Pure bedded limstone underlies c40% of the catchment fo the River Deel but only 13% of the catchment of the River Deel upstream of Jack Garrett Bridge in Crossmolina Town.

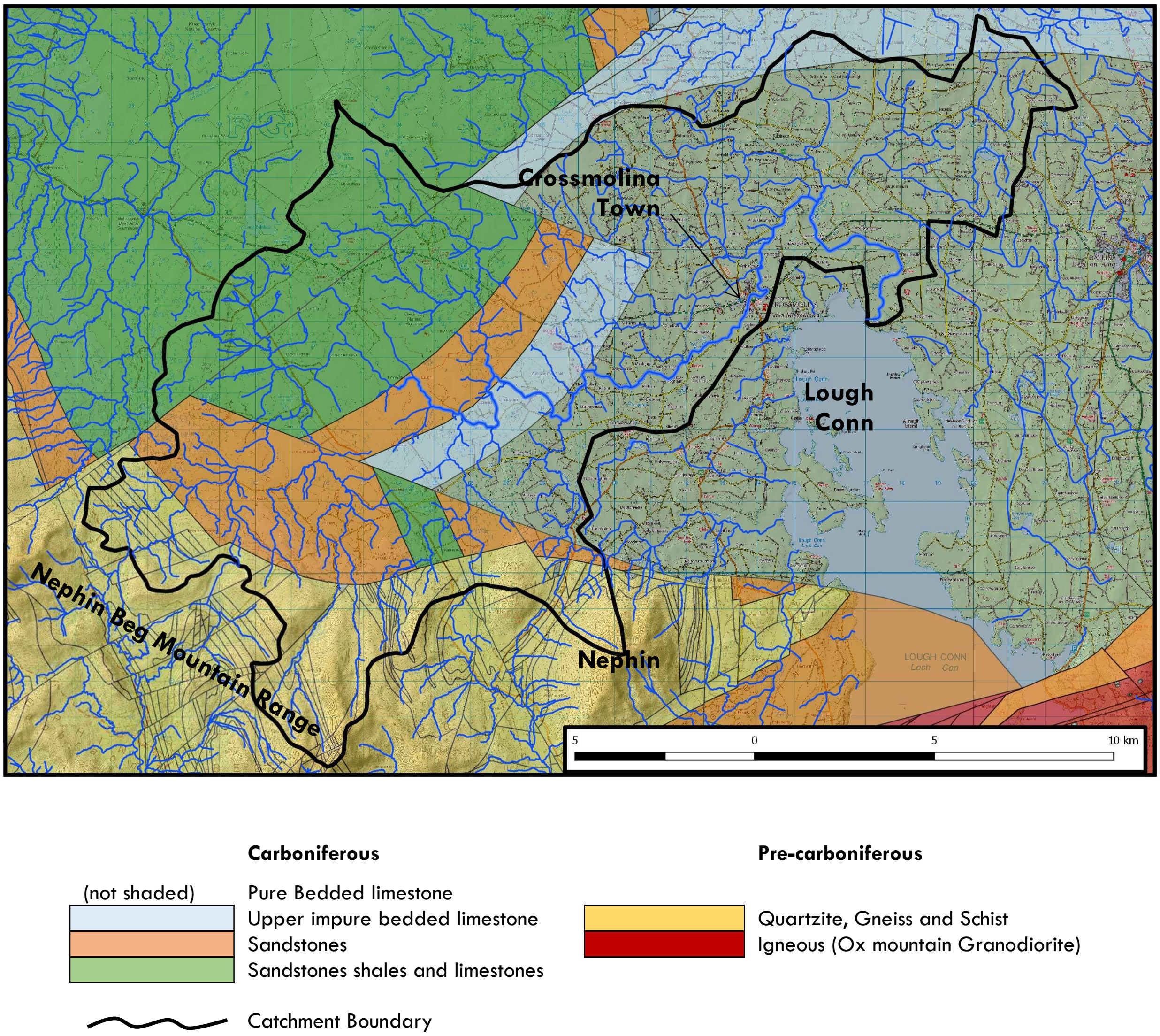

Figure 7A.2: Bedrock Geology of River Deel Catchment (Outlined in black, source GSI)

7A.3 Stage 1 Assessment

7A.3.1 Stage 1 Investigations

The Stage 1 Assessment involved walkover surveys, inspection of karst features, review of mapping, plotting of karst features, on site conductivity mapping and flow estimating.

Flow measurement along the River Deel consisted of monitoring flows in the river, which remained at normal to high levels following the December 2015 flood event and a relatively wet start to 2016. It was not anticipated that low flow measurement would be possible until Stage 2. Flows were also estimated but not measured at the Mullenmore Springs.

Due to the timeframes involved and procurement restrictions, it was not possible to mobilise a geotechnical contractor to site in time to provide input to the Stage 1 Hydrogeological Assessment.

The outcome of the Stage 1 Assessment is set out below, followed by further investigation and information gaps which were identified at the conclusion of the Stage 1 Assessment.

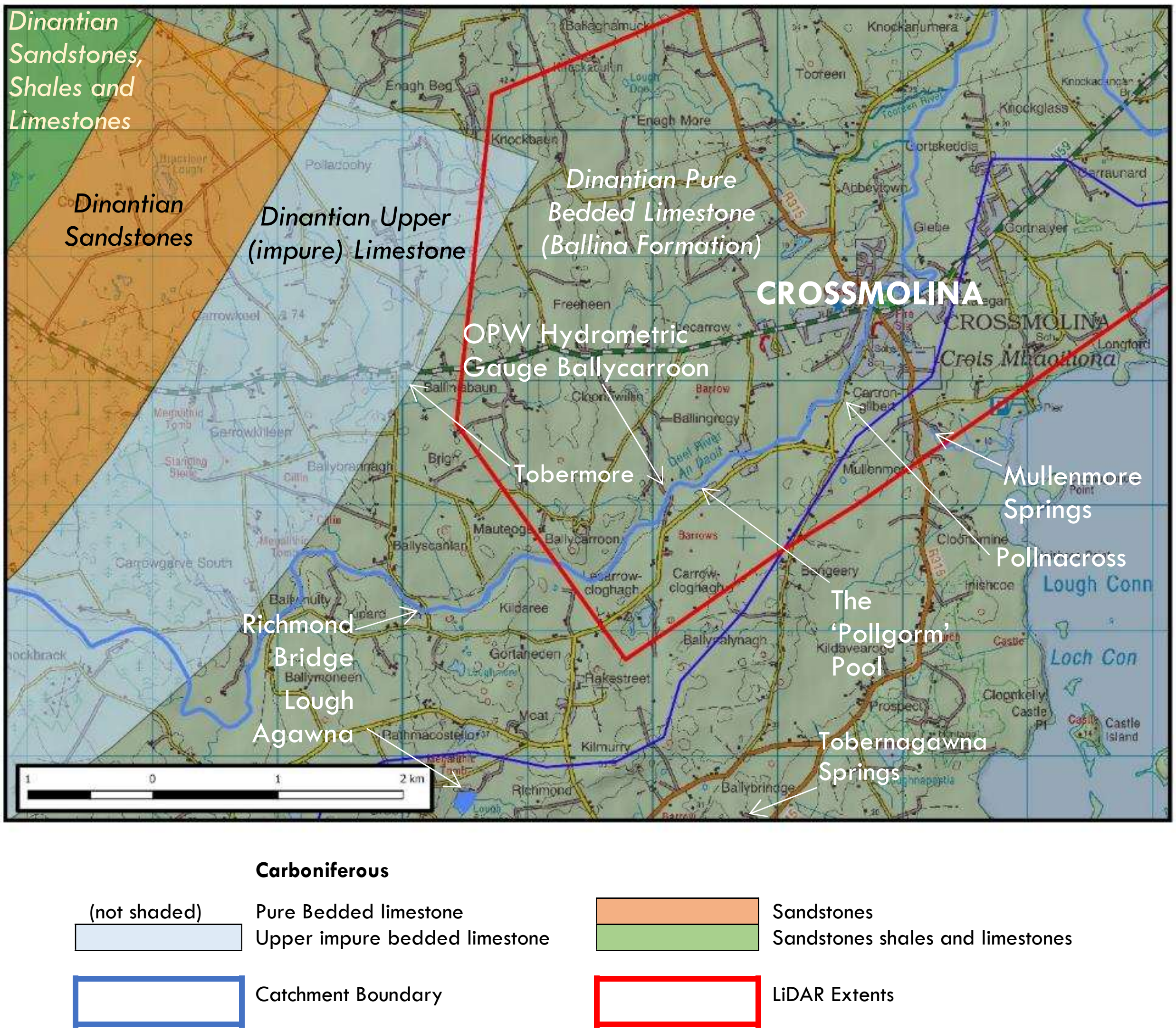

Figure 7A.3: Refined Study Area, showing extent of available LiDAR mapping

7A.3.2 Mullenmore Springs

As noted above, prior to the study, there was a deficit of documented evidence of karst activity in North Mayo, including the catchment of the River Deel. Anecdotal evidence suggested a connection between the River Deel and the 'ponds' labelled on modern Ordnance Survey Maps at Mullenmore. In fact, the townland name Mullenmore is recorded in the 1604 Calendar of Patent Rolls of James I and it is therefore likely that a mill was operating in the locality from at least that time. The ponds labelled on the modern Ordnance Survey maps, and which were not identified as a karst features on historical Ordnance Survey mapping are in fact springs, referred to in this report as the Mullenmore Springs.

An iron mill is believed to have been located at this site as early as the mid-18th century. This ceased production when the timber in the vicinity was exhausted and was in a state of ruin by 1800. Griffith's Valuation (1848-1864) records that an iron mill had formerly been located within the townland. The soils in the townland are described as heavy clays and the tenants were recorded as being of middling circumstances and residing in stone houses. The 6-inch OS map of 1840 (Figure 7A.4) shows a corn mill, with two corn kilns to the north. The 25-inch OS map of 1900 (Figure 7A.5) shows a number of unnamed buildings at this location and, while a lime kiln is indicated to the southeast, there are no traces of the two corn kilns previously indicated in the area to the north.

The history of the area is closely connected to the Mullenmore Springs and the steady water supply that they provided to the various milling activities (as an iron mill and a corn mill) that have been undertaken at this location over the centuries.

Comparison of the 1840 and 1900 maps shows that the shape of the surface water body in the vicinity of the springs has changed. The springs are represented on the maps as a single waterbody in 1840 but as two separate water bodies in 1900. This change is almost certainly due to drainage works that have been carried out at the outlet to the southern spring in the second half of the 19th Century. At times of high flow, the area between the two springs can still become inundated with water overflowing the northern spring, which has a higher top water level.

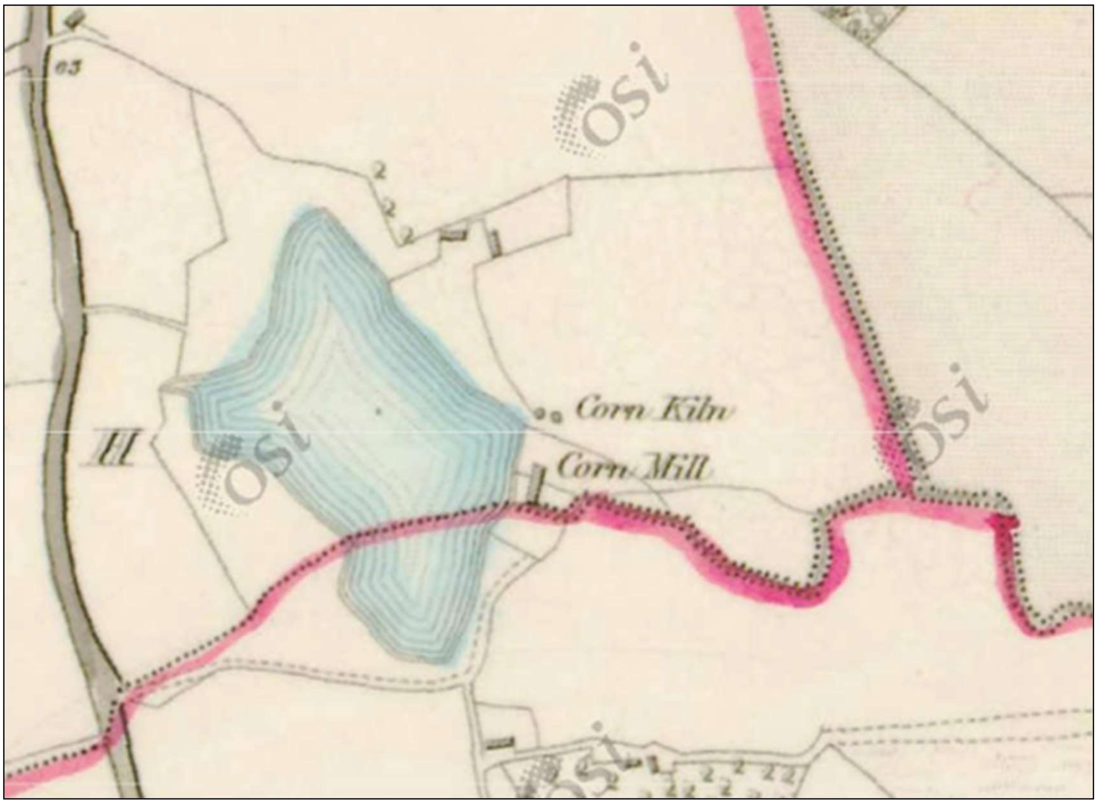

Figure 7A.4: Mullenmore Springs: Extract from 1st edition OS map (survey date 1840) [OSi Licence SU 0003318]

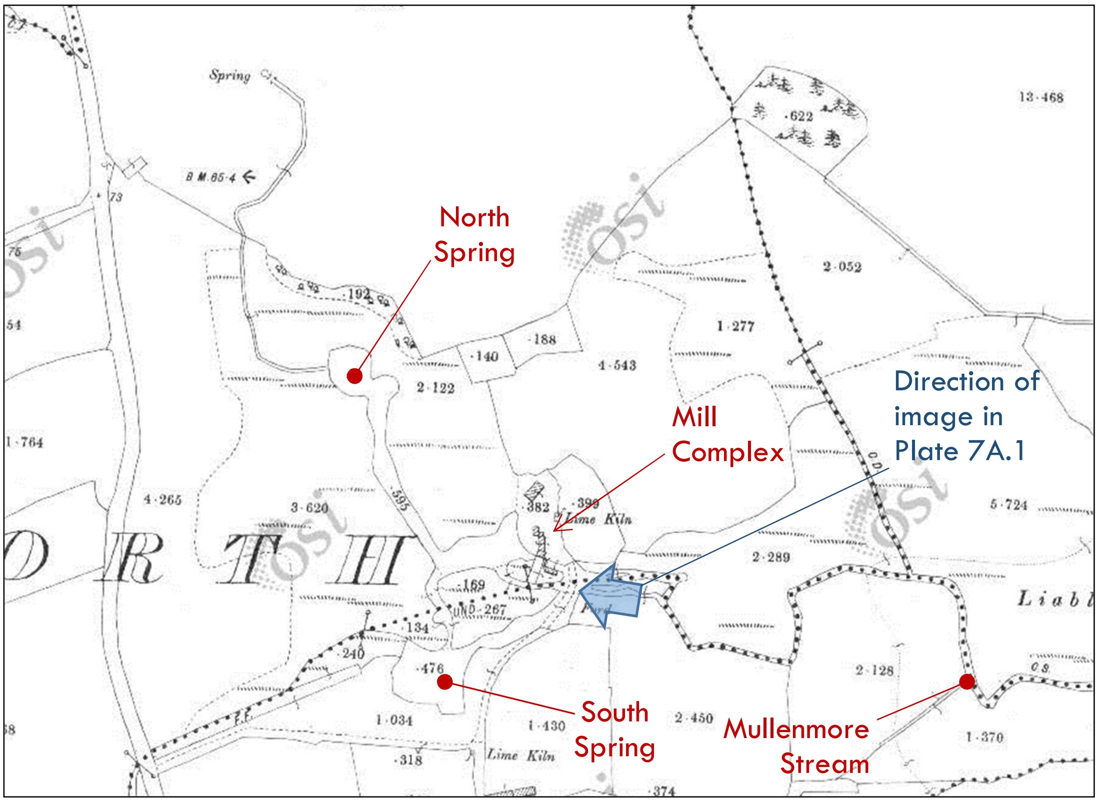

Figure 7A.5: Mullenmore Springs: Extract from 25-inch edition OS map (survey date 1900) [OSi Licence SU 0003318]

Plate 7A.1: Extract from drone footage of Mullenmore Mills

7A.3.3 Dolines

As part of the desktop assessment and walkover surveys, several dolines were identified in the study area. A doline is an enclosed hollow in a limestone area which contains a point recharge to groundwater. Many enclosed hollows are located within the study area, including dolines and kettle holes. This section deals with enclosed depressions which have been positively identified as dolines, i.e. there is confidence in their karstic genesis. The larger dolines identified from LiDAR mapping are shown on Figure 7A.6. These dolines are typically funnel shaped, are actively subsiding and are therefore hydrologically linked with voids/groundwater flow routes. Some dolines are elongated on a N-S or E-W axis, often aligned on north-south or east-west orientations corresponding to the major joint systems in the limestone bedrock, while others are approximately symmetrical on plan. In many instances, dolines are located along the same apparent N-S or E-W axis as can see seen on Figure 7A.7. The dolines are generally filled with trees and have been mistaken for archaeological features or enclosures in the past. The largest of these dolines, labelled No.3 in the figures and tables below, is named Polldotia (presumably translates as the 'burnt hole') on the 25-inch edition OS map (survey date 1900).

The absence of dolines from a particular area does not necessarily mean that karst flow channels are not present.

Collapse dolines (also referred to as 'drop-out') commonly form as catastrophic slumping of overlying strata/deposits into a pre-existing void in bedrock or overlying deposits, often in response to high groundwater flows. The initial form is often cylindrical with vertical walls but then, over time the walls decay to generate o bowl or saucer shape. A collapse doline was located at Pollnacross in 2019 following completion of Stage 1 of the investigation. Refer to Stage 2 Investigations for further discussion. Collapse dolines have been known to form in the general area based on anecdotal information, however they are often filled in by landowners soon after forming.

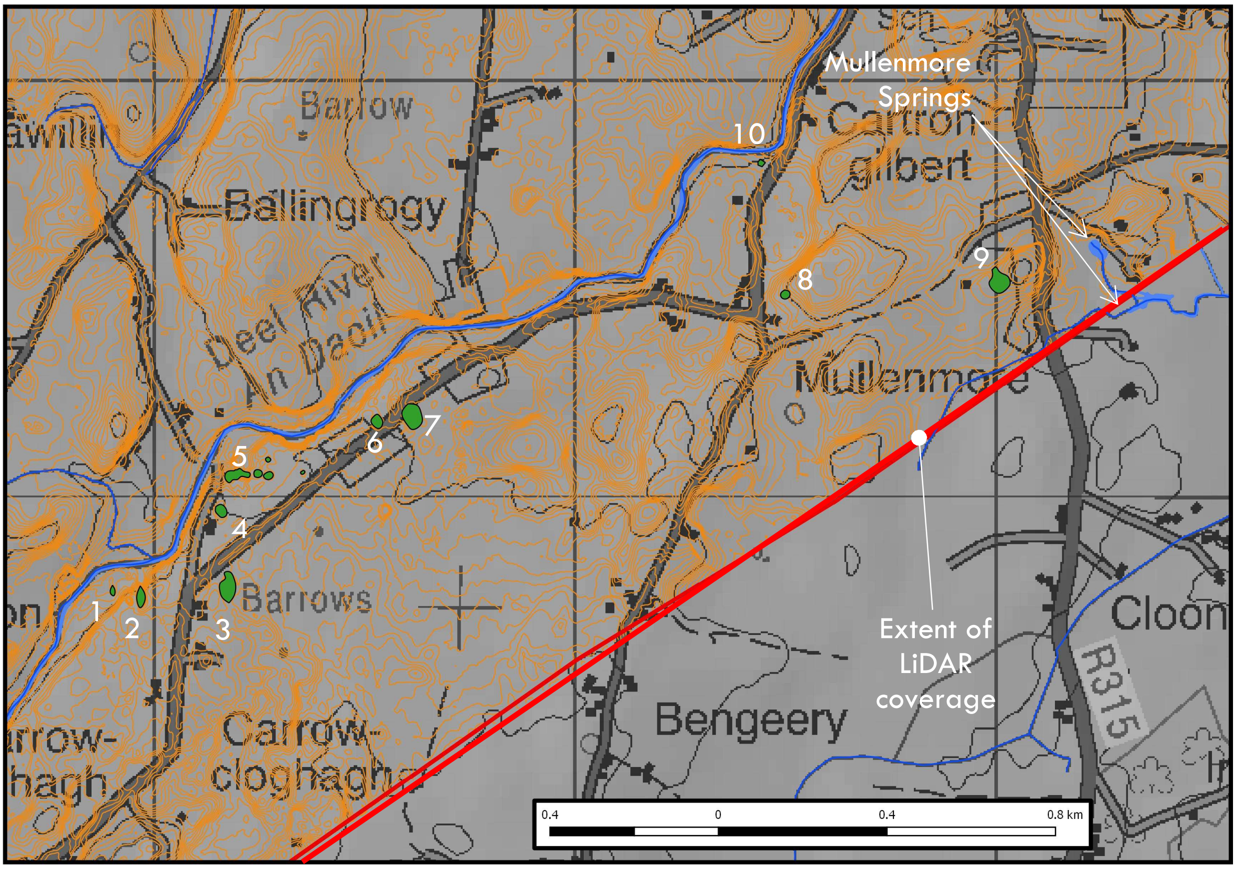

Figure 7A.6: Dolines (green) identified within area of LiDAR coverage (orange)

Table 7A.1 provides dimensions for these dolines as determined from available LiDAR mapping.

Ref.	Townland	Depth	Dimension 1 (N-S)	Dimension 2 (E-W)
1	Lecarrowcloghagh	2	43	11
2	Lecarrowcloghagh	11	26	112
3	Carrowcloghagh	20	76	43
4	Carrowcloghagh	2	54	31
5	Carrowcloghagh	8	29	118
6	Ballynalynagh	7	35	27
7	Ballynalynagh	8	57	41
8	Mullenmore North	3	23	23
9	Mullenmore North	8	47	46
10	Cartrongilbert	1.5	5	3

Table 7A.1: Locations and Dimensions of Main Dolines

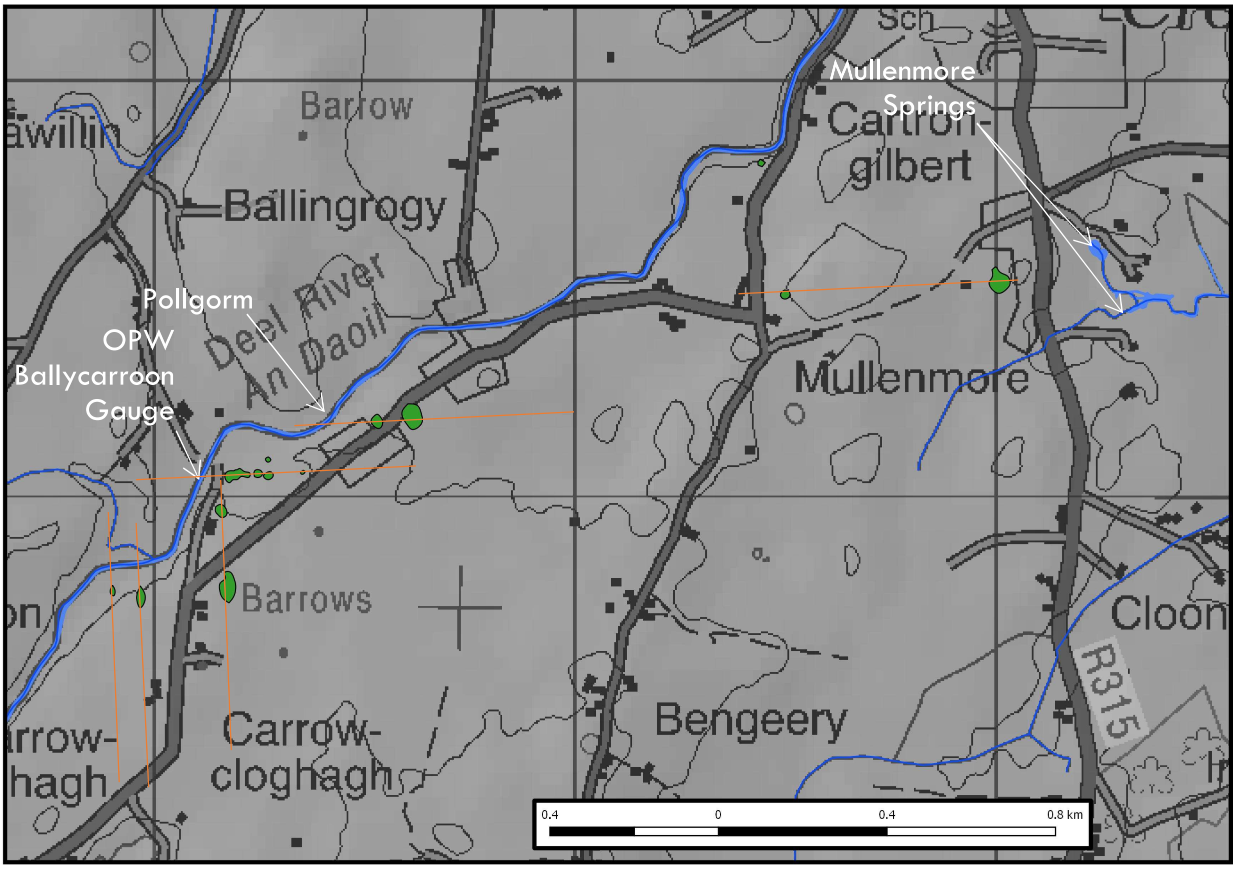

Figure 7A.7: Dolines (green) with N-S & E-W axes shown (orange lines)

7A.3.4 Sinking River

There was limited photographic evidence available of the River Deel running dry in Crossmolina Town prior to this investigation. However, in June 2016, the river ran dry from a point just downstream of a pool in the river known colloquially as Pollgorm through Crossmolina Town, leaving just stagnant pools of water: Plate 7A.2 shows the dry river bed with Crossmolina Town in the background.

Plate 7A.2 Dry River Bed, Crossmolina Town, June 2016

7A.3.6 Lough Agawna

Apart from those in the Deel channel (which are described in more detail under the Stage 2 Assessment below), one significant swallow-hole was located within the study area during the Stage 1 Assessment on the outlet from Lough Agawna, with a discharge of <100 litres/sec and a conductivity of 260-400 μS/cm.

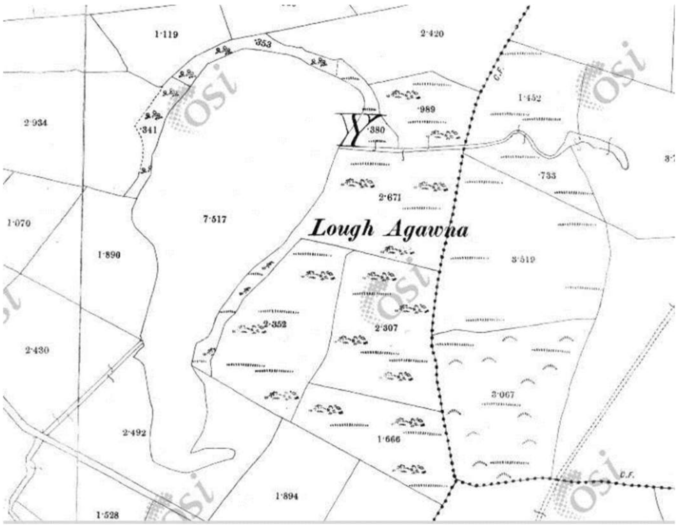

Plate 7A.3 Lough Agawna 25-inch edition OS map (survey date 1900) [OSi Licence SU 0003318]

Plate 7A.4 Lough Agawna swallow holes

7A.4 STAGE 2 ASSESSMENT

7A.4.1 Stage 2 Investigations

Following the completion of the Stage 1 Assessment the following tasks were yet to be completed:

- Assessment of the depth, nature and extent of karstification via the programme of geotechnical investigations,
- Location of all significant sinkholes in the River Deel channel and an estimate of inflows,

- Collection and analysis of hydrometric data from springs, sinks and the River Deel, and
- Tracing of selected swallow-holes and derivation of contributing areas to the main springs of the area.

As the above Stage 2 investigations progressed, it was also decided to carry out bathymetric and diving surveys of the Mullenmore Springs, along with a drone survey of the river and diversion channel route.

Details of each of the various Stage 2 Investigations are set out below, followed by the outcome of the Stage 2 assessment.

7A.4.2 Preliminary Geotechnical Investigation

The geotechnical contract was scoped, tendered and a tender assessment and report was submitted to OPW on 27 June 2016. Causeway Geotechnical, the successful tenderer commenced on site in mid-September 2016, with site work completed by end of February 2017.

The scope of the investigation was initially targeted at the land adjacent to the right bank of the River Deel, Mullenmore Springs, and the route of the diversion channel. Some site investigation was also carried out in Crossmolina Town to inform the assessment of the other flood relief options, such as flood walls, which remained under active consideration at the time. The contract scope was amended on site, based on the emerging findings of the Stage 2 hydrogeological assessment. On completion of the preliminary geotechnical assessment, the site work consisted of:

- 136 rotary open boreholes
- 18 rotary boreholes with core recovery
- 9 dynamic sample boreholes
- 5 cable percussive boreholes
- Four dynamic probes

The Contract also included groundwater monitoring which is ongoing. Further details are provided under a separate heading.

The ground conditions found are summarised in the preliminary geotechnical report (compiled by Causeway Geotech) as follows:

- Topsoil: Encountered typically 100-400mm thickness, with topsoil and subsoil extending to 1200mm depth in Crossmolina Town.
- Made Ground (fill): Reworked clay fill. Typically sandy gravelly clay with low to medium cobble content encountered in Crossmolina Town, BH21 (Diversion Channel, Chainage circa 450m at Cartrongilbert) and RC098 (adjacent to BH21) at up to 1.8m in depth. RCR100 (Diversion Channel, Chainage circa 300m at Cartrongilbert) encountered fill up to 5.20m with pieces of plastic.
- Peat: Encountered in RC042 (banks of River Deel upstream of the proposed channel) from 2.20m to 5.00m and in RC098 (as above) from 1.8m to 3.00m.
- Glaciofluvial Deposits: typically medium dense sands and gravels with localised pockets of firm sandy gravelly clays interspersed throughout.

- Bedrock (Limestone): Rockhead was encountered at depths ranging from 1.2m to 19.8m below ground level with varying numbers of voids encountered. Bedrock was found to be typically highly weathered and fractured at upper levels becoming more competent with depth.

Voids in the limestone bedrock were encountered in higher numbers along the banks of the River Deel and one was also encountered in the vicinity of the Mullenmore Springs. One small (300mm) void was encountered along the route of the diversion channel, at its eastern end in close proximity to the river bank. Further voids were encountered (1,200mm) in close proximity to the springs.

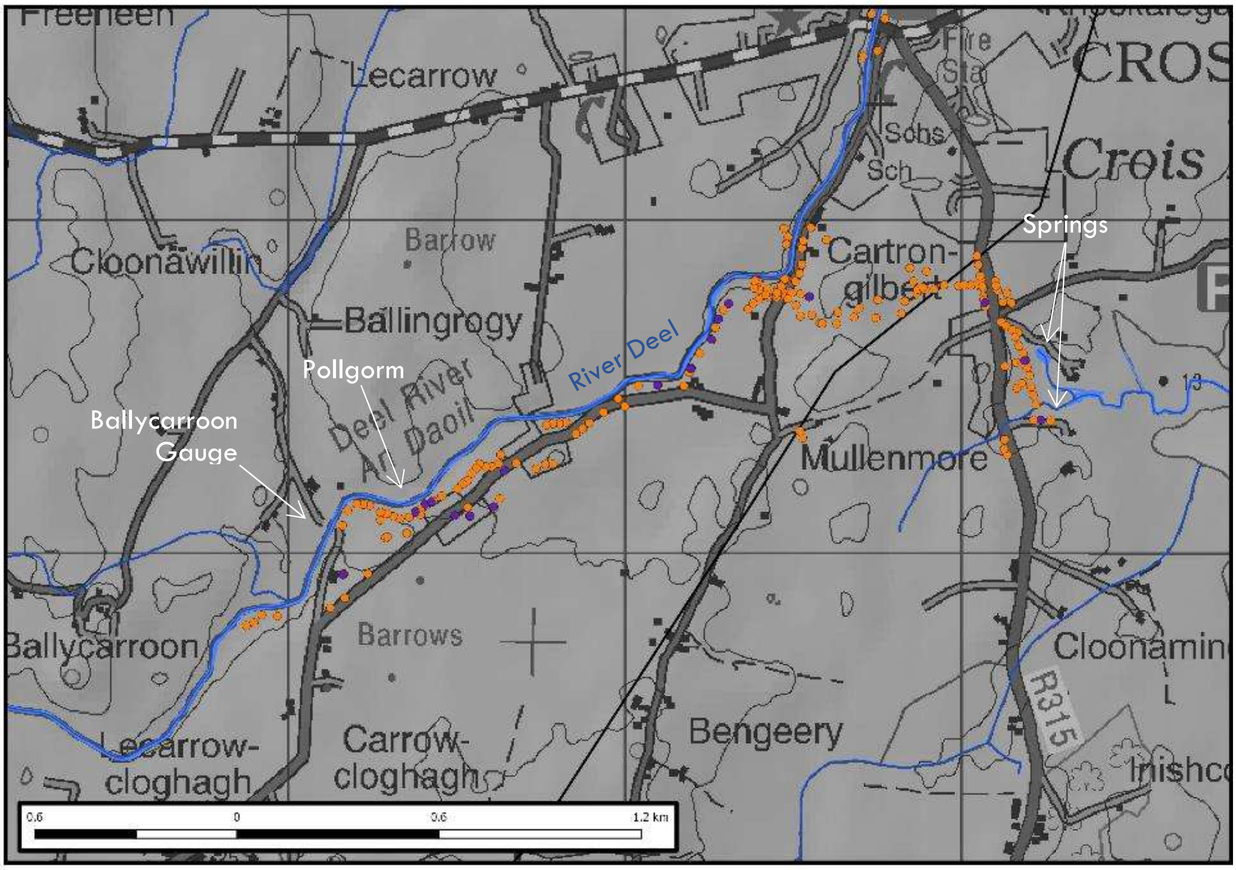

Figure 7A.8 Extent of Preliminary Geotechnical Investigations

Notes on Figure 7A.8:

- Geotechnical investigation points shown in **orange**
- Geotechnical investigation points shown in **purple** where voids were encountered

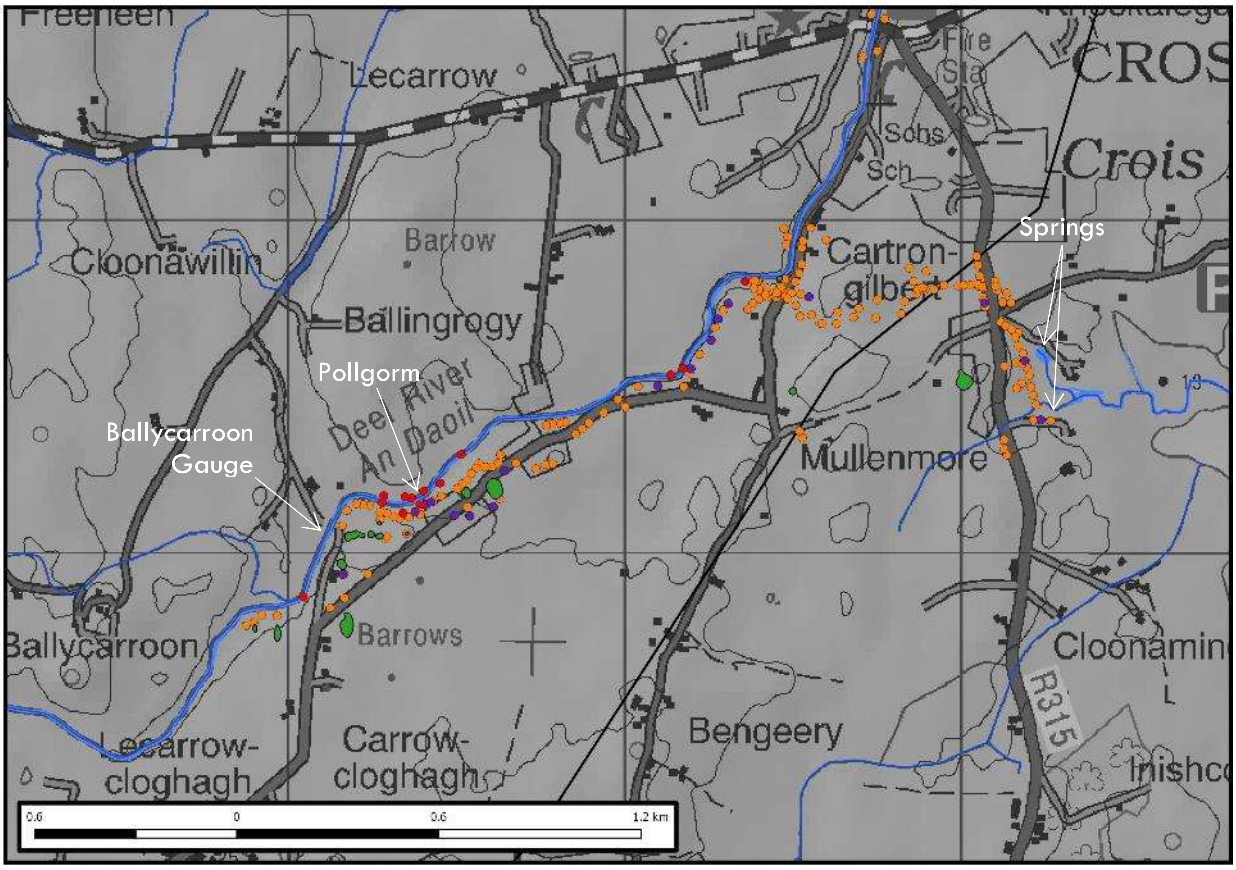

Figure 7A.9 Extent of Preliminary Geotechnical Investigations (orange and purple) with river sinks (red) and larger dolines (green)

7A.4.3 Geophysical Investigation

In Q4 2018, a collapse doline formed at Pollnacross in close proximity to the River Deel. Apex Geophysics Ltd were subsequently commissioned to carry out a geophysical survey of the area surrounding the doline in order to investigate the cause of the drop out. The purpose of the investigation was:

- to establish the location of karst conduits in the area and their character, i.e. whether they in bedrock; at the base of the subsoil; what their capacity is, etc., and
- to assist in establishing the relationship between the collapse doline and any karst conduits or other voids,

The geophysical investigation as accompanied by further geotechnical investigations, dye tracing, groundwater monitoring and hydrometric estimation.

The geophysical investigation consisted of 2D Electrical Resistivity Tomography (ERT) and Seismic Refraction profiling carried out over two sessions on 12 and 13 February 2019. A layout plan of the geophysical survey is provided on Figure 7A.10.

The survey did not detect any significant karst features in the bedrock underlying the collapse doline. A probable karst feature was detected along the riverbank, and a depression in the bedrock was also detected in the vicinity of one of the geotechnical investigation points, RCR080. RCR080 had also detected this feature, and it is noted at this point that the output from geophysical surveys when it comes to karst limestone is indicative only and requires hard data from drilling, etc., to confirm or refute its conclusions.

Further geotechnical investigation was recommended by Apex and this was completed as part of the geotechnical investigation (described separately above). Two new boreholes (BHs 32 & 34) carried out on foot of this recommendation were used as part of the July 2019 dye tracer experiment.

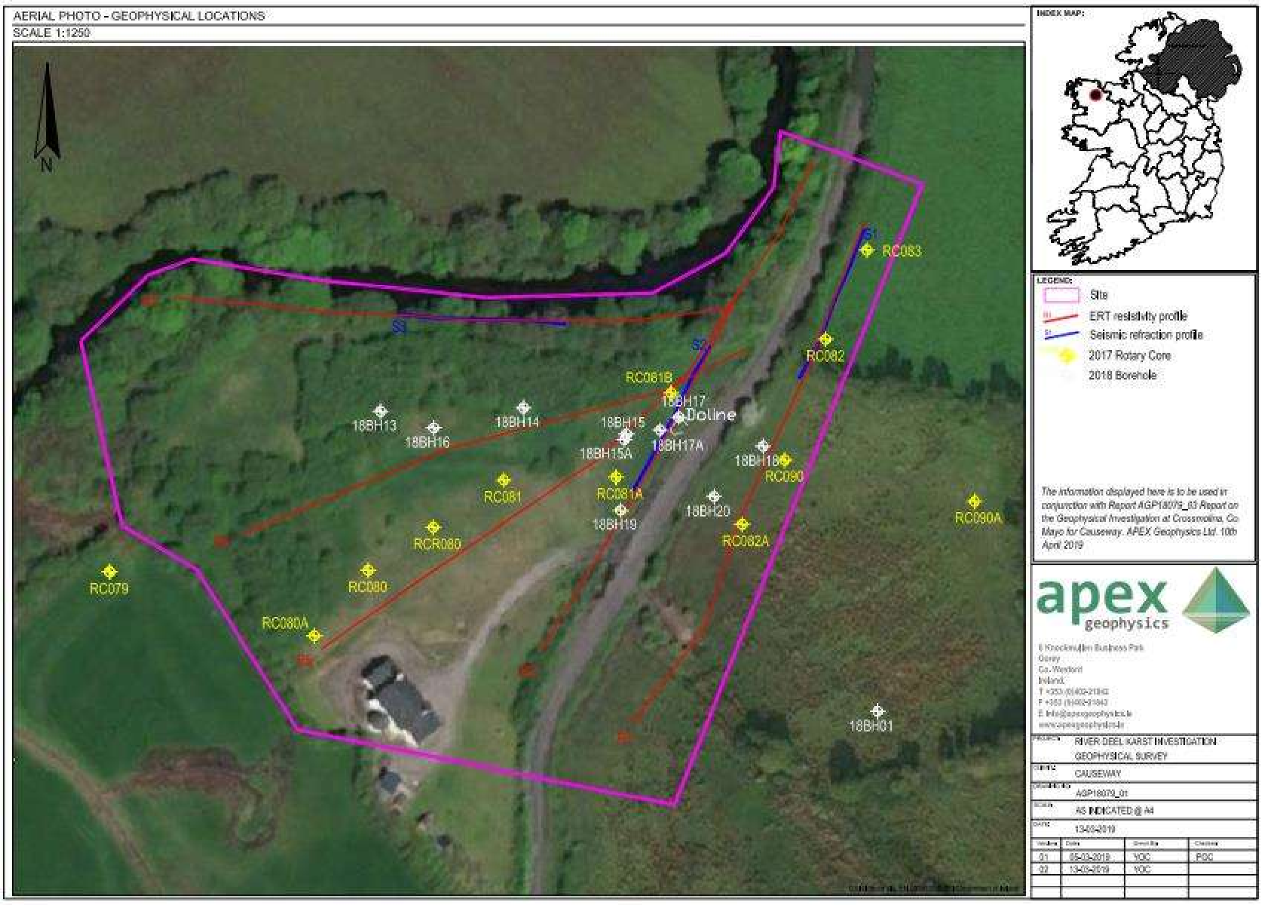

Figure 7A.10 Extent of Geophysical Investigations at Pollnacross (extract from Apex report)

7A.4.5 Groundwater Monitoring

As noted in relation to the geotechnical investigation, the geotechnical contract included groundwater monitoring, which is ongoing. Details of the groundwater monitoring programme are provided in Table 7A.2 and Figures 7A.11-15. The purpose of the monitoring is to gather information on groundwater response to changes in river levels and rainfall. The monitoring programme initially focused on the River Deel, Mullenmore Springs and the diversion channel. As the hydrogeological investigation progressed, the groundwater monitoring focused more on the River Deel at Pollnacross, Mullenmore Springs, and the diversion channel, where more loggers were installed. Conductivity probes were also installed in 18BH21, RCR090A and RC097. The purpose of conductivity monitoring is to compare conductivity in groundwater monitoring wells, the river and springs. This information is used to derive the origin and residence times of groundwater in the monitoring wells and spring outflow, the assumption being that higher conductivity in groundwater is indicative of higher residence times in limestone dominated aquifers. Active groundwater level loggers are shaded in green in Table 7A.3.

Ref.	Borehole Location	Period of Observations *	Ground Level (mOD)	GW Level Range (mOD)
	River Deel			
18BH02	Cartrongilbert (overlooking Pollnacross)	Jun 18 – Dec 19	25.17	13.96-16.14
18BH05	Mullenmore North	Jun 18 – Dec 19	22.18	15.54-19.18
18BH12	Mullenmore North	Nov 18 – Dec 19	20.21	17.14-19.56
18BH20	Cartrongilbert (Pollnacross)	Jun 18 – Dec 19	19.48	13.39-16.33
18BH21	Mullenmore North	Nov 18 – May 19	23.37	14.71-16.45
RC010	Mullenmore South	Mar 17 – Dec 19	14.23	12.12-13.53
RCR034A	Carrowcloghagh (Polldotia, Deel)	Mar 17 – Jul 17	27.76	18.08-19.06
RCR036	Carrowcloghagh (Polldotia, Deel)	Mar 17 – Jul 17	27.79	16.13-19.59
RCR036A	Carrowcloghagh (Polldotia, Deel)	Mar 17 – Jul 17	26.26	16.86-19.51
RC075B	Mullenmore North (Deel)	Mar 17 – Jul 17	23.17	15.63-17.31
RC077B	Mullenmore North (Deel)	Mar 17 – Jul 17	19.35	13.97-16.02
RCR084A	Cartrongilbert (Pollnacross)	Mar 17 – Sep 19	23.57	13.49-18.03
RCR090A	Cartrongilbert (Pollnacross)	Mar 17 – May 20	20.21	12.74-16.47
RCR097	Cartrongilbert	Mar 17 – Jan 20	20.10	13.62-16.44
RCR097A	Cartrongilbert	Mar 17 – Dec 19	21.85	13.53-16.72

* *A software malfunction resulted in no data recovery from active loggers in Q1/Q2 2020. Loggers have been reinstalled and continue to record data.*

Table 7A.2: Overview of Groundwater Level Monitoring

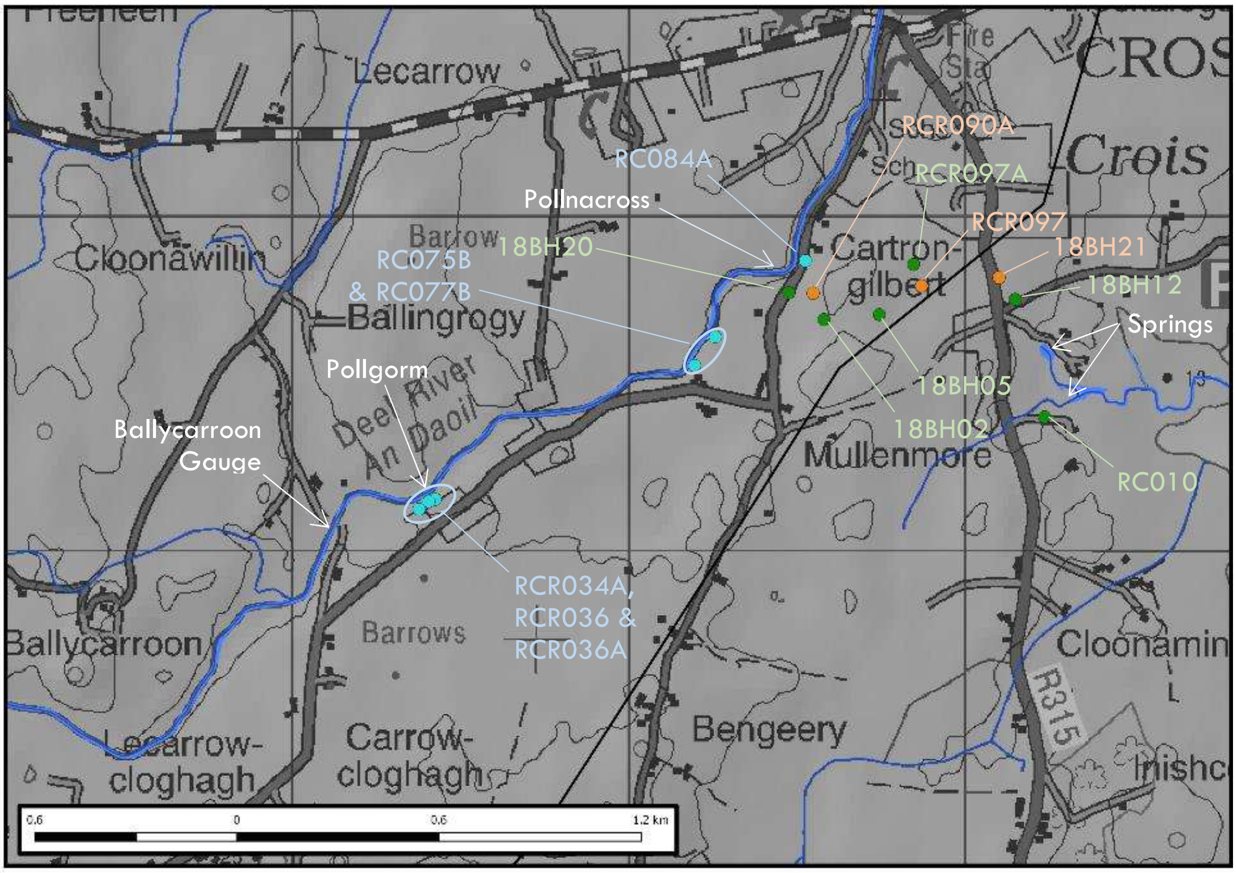

Figure 7A.11: Groundwater Monitoring Locations

Groundwater observations plotted in Figure 7A.12 demonstrate that the water table at Pollnacross is located below river water levels (refer to 18BH20, RCR090A and 18BH02). This is also observed at 18BH21 and RCR097. Away from the river, the form of the water table is a muted version of surface topography. The water table is elevated locally at two boreholes: 18BH12 to the North of the Lake Road, and 18BH05, which is located close to a surface drain. At two other locations (RCR097A and 18BH21), the recorded groundwater levels in the sand/ gravel aquifer intersects the invert of the proposed channel following periods of prolonged rainfall.

Frequency distribution of groundwater levels at each of the observation points in Figure 7A.13 demonstrates that for the period plotted on the graph, the water table remains permanently lower than the invert of the proposed channel. The sand/ gravel aquifer is elevated above the invert of the channel at certain locations as illustrated in Figure 7A.13. Based on available data, the water table is observed to lie permanently in the sand and gravel aquifer. The range of groundwater levels observed in 18BH05 is 3.64m (19.18 mOD to 15.54 mOD), while a smaller range (1.74m) was observed in 18BH21 (16.45 mOD to 14.71 mOD)

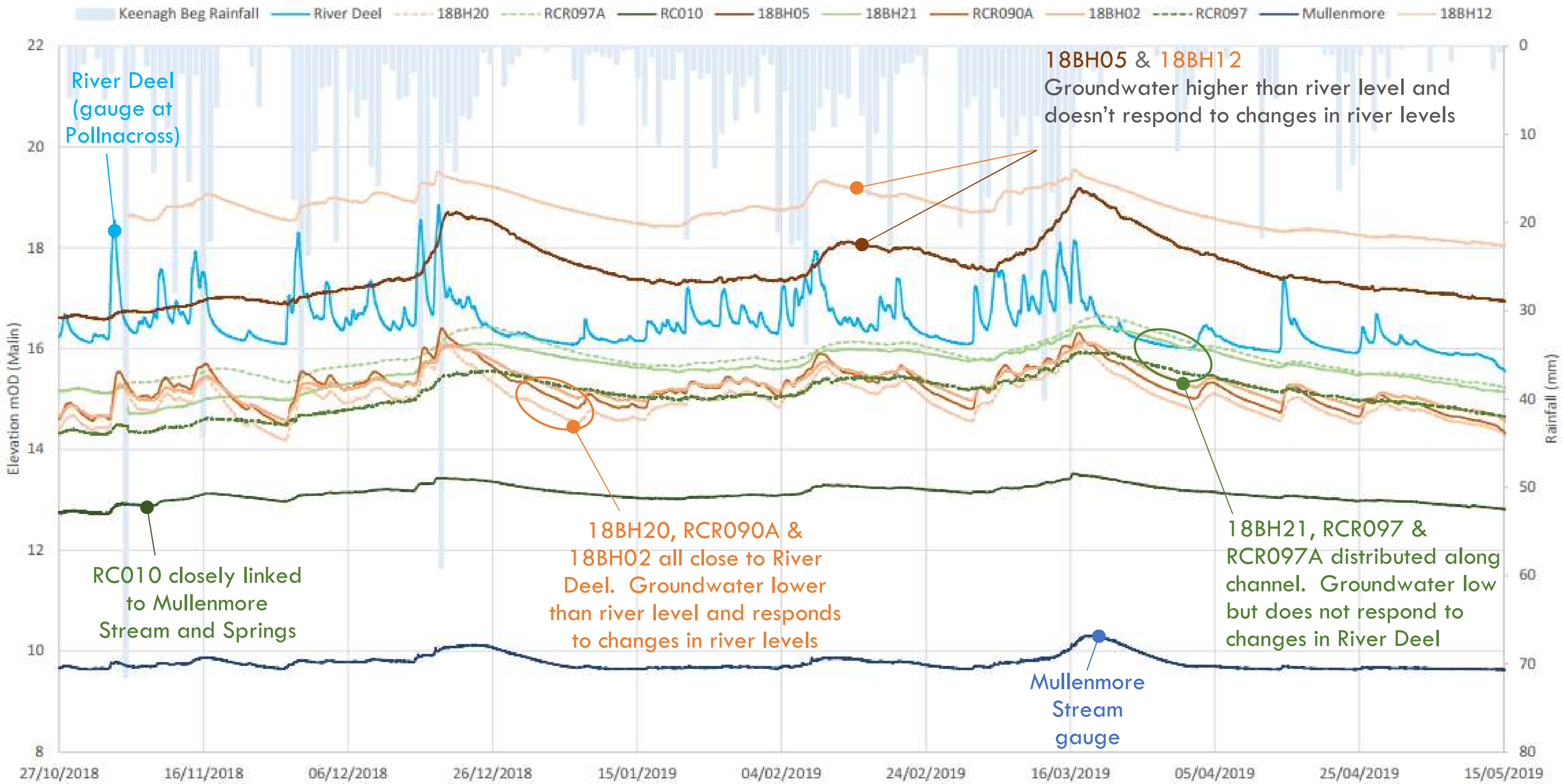

Figure 7A.12: Time Series Plot of Groundwater and River Levels (also showing rainfall at Keenagh Beg)

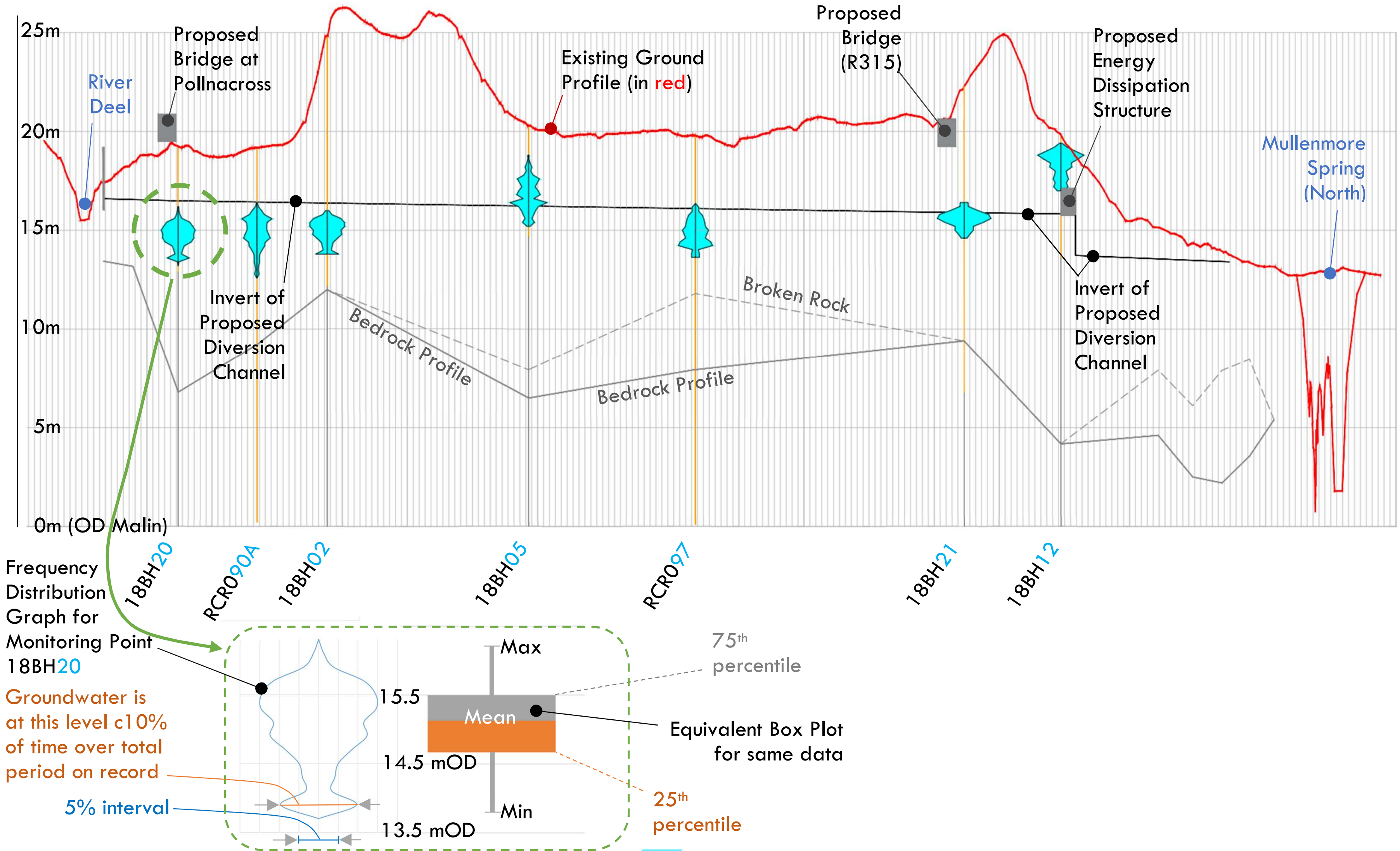

Figure 7A.13: Groundwater Level Frequency Distribution (shaded in cyan) at Monitoring Points Plotted on a Longitudinal Section of the Proposed Channel

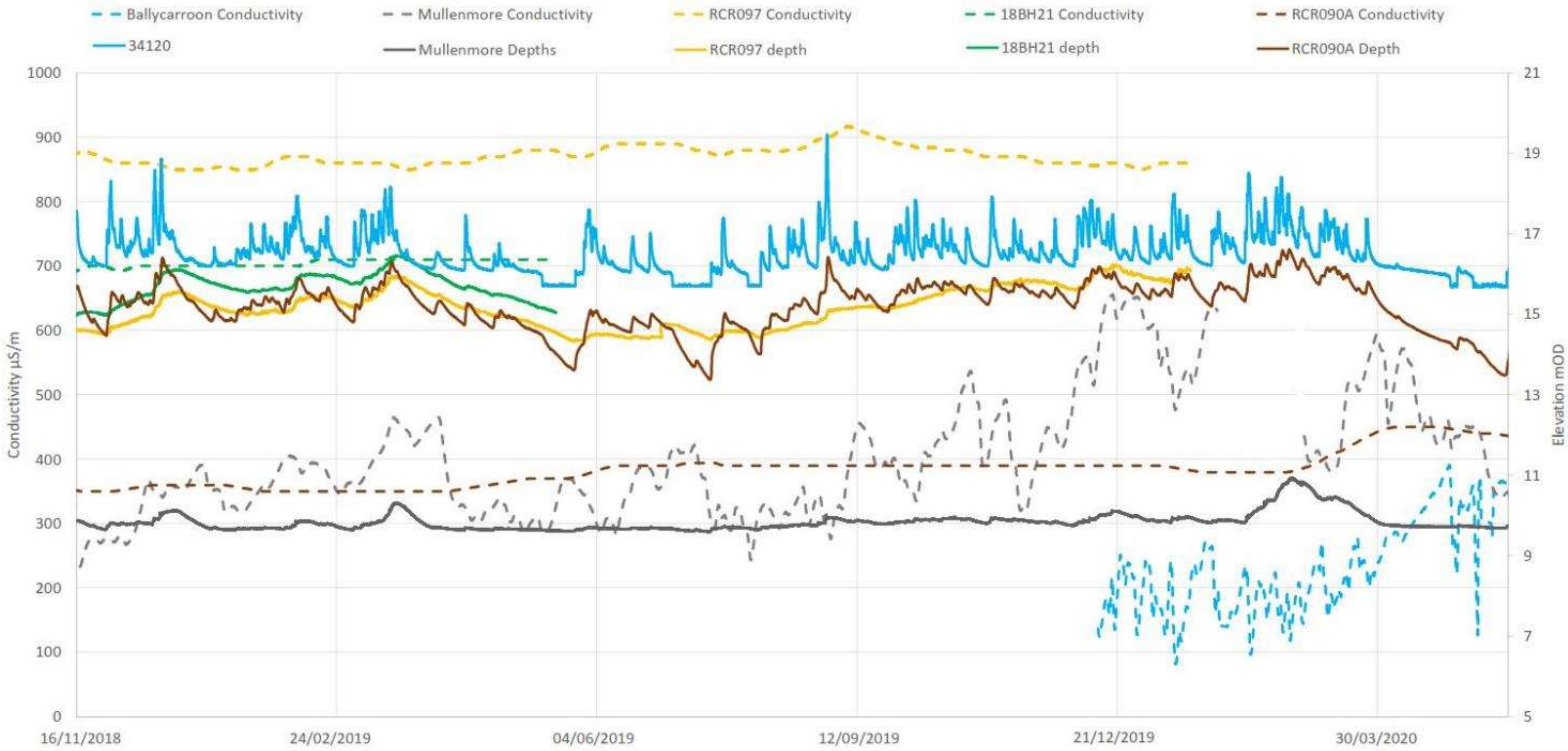

Figure 7A.14: Time Series Plot of Groundwater and River Levels and Conductivity Readings

Ref.	Borehole Location	Period of Observations *	Conductivity Range (Units)
	River Deel		
18BH21	Mullenmore North	Nov 2018 – Oct 2019	0.66 – 0.71
RCR090A	Cartrongilbert (Pollnacross)	Oct 2018 – May 2020	0.35 – 0.45
RCR097	Cartrongilbert	Nov 2018 – Jan 2020	0.85 – 0.92

Table 7A.3: Overview of Groundwater Conductivity Monitoring

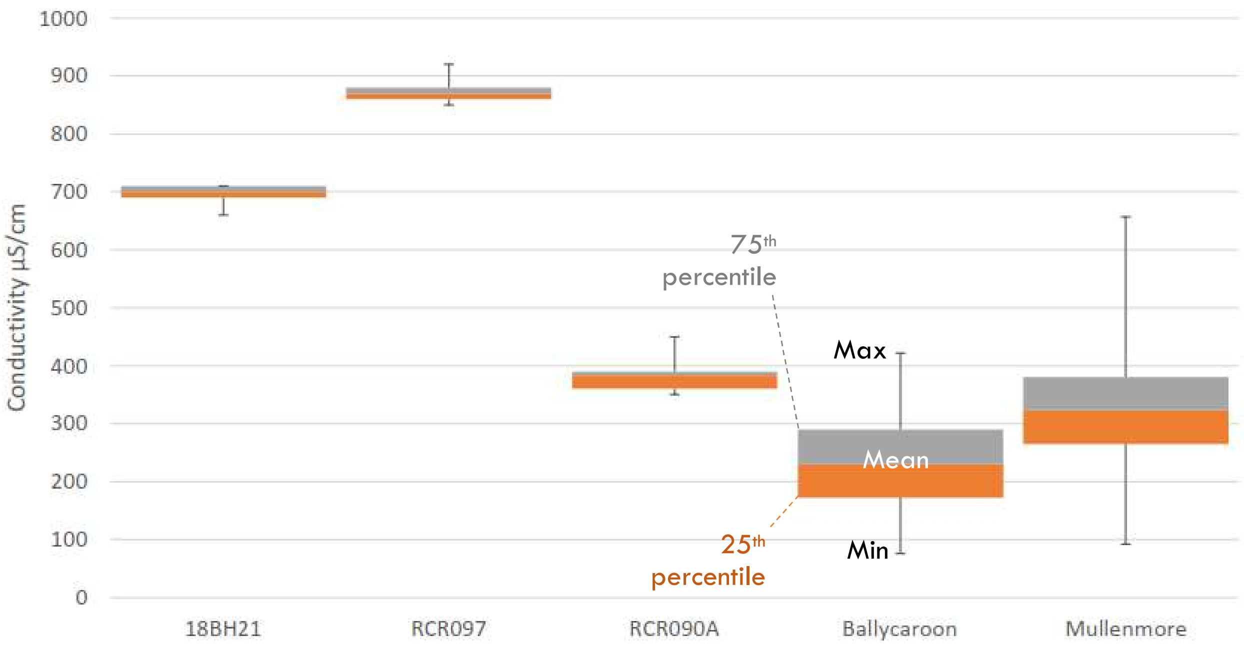

Figure 7A.15: Box Plot of Groundwater and River Conductivity Readings

Figure 7A.14 provides a summary of available conductivity and level data for the River Deel (conductivity probe at Ballycarroon with level data from Pollnacross), the Mullenmore Stream (outlet from the two springs), and three GI points along the diversion channel, namely: RCR090A, RCR097 and 18BH21. Figure 7A.15 also provides a range of conductivity values at each monitoring location.

Conductivity levels are lowest in the River Deel, which is to be expected considering the river catchment upstream of this point. Conductivity levels in the Deel respond relatively rapidly to changes in flow.

At the higher end, the conductivity data demonstrates that the slow responding groundwater at RCR097 and 18BH21 has conductivity levels characteristic of groundwater in close contact with the glaciofluvial deposits, typically medium dense sands and gravels detected during the geotechnical investigation.

The conductivity levels in RCR090A and at the outlet from the Mullenmore Springs are more similar to those in the River Deel, which supports the close connectivity via the karst aquifer and the close response to changes in river levels and flows. The

7A.4.6 Hydrometric Data

Hydrometric gauging was carried out by the OPW Hydrometric Team. The scope of the gauging exercise was increased based on the emerging findings of the Stage 2 Investigation.

The initial phase of low flow measurements were taken as river levels began to recede in in June, July and August 2016. This initial phase covered the OPW gauge at Ballycarroon, six river sections spaced out between Ballycarroon and Crossmolina Town, the Mullenmore Springs, Lough Agawna, and Tobernagowna. As swallow holes were identified, flow measurements and dye tracing results became available, the focus of the flow measurement changed, with a greater focus on the section of River between Richmond Bridge and Ballycarroon. The flow measurements were initially targeted at low flows in 2016. In February 2017, a series of flow measurements were taken at medium flows (c7 cumec) in order to assist in the identification of higher level swallow holes along the river banks.

A summary of the flow gaugings is provided in Table 7A.4 and in Figure 7A.15.

Ref.	Gauging Location	Number of measurements taken	Flow Range (cumec)	Period Covered
	River Deel			
1	Richmond Bridge	20	0.63 – 7.82	Jun 16 – Feb 17
2	Rathduff House	5	0.90 – 1.35	Oct 16
3	Ballycarroon House	15	0.39 – 2.62	Oct 16
4	Ballycarroon (permanent gauge)	20	0.79 – 1.14	Jun 16 – Dec 17
5	c400m downstream of Ballycarroon	6	0.18 – 1.20	Jul 16 – Aug 16
6	c800m downstream of Ballycarroon	3	0.16 – 0.91	Jul 16
7	c1,200m downstream of Ballycarroon	3	0.14 – 0.96	Jul 16 – Nov 16
8	c1,300m downstream of Ballycarroon	1	0.97	Nov 16
9	c1,600m downstream of Ballycarroon	7	0.24 – 0.86	Jul 16 – Aug 16
10	c2,000m downstream of Ballycarroon	2	0.21 – 0.75	Jul 16
11	c2,400m downstream of Ballycarroon	11	0.08 – 2.52	Jul 16 – Oct 16
12	Jack Garrett Bridge, Crossmolina Town	4	6.30 – 7.19	Feb 17
	Other Locations			
13	Mullenmore Springs (Combined)	20	0.79 – 1.12	Jun 16 – Feb 17
14	Mullenmore Spring (Southern Spring)	1	0.58	Jan 17
15	Tobernagowna (Spring)	4	0.035 – 0.041	Jun 16 – Jul 16
16	Lough Agawna (Swallow Hole)	3	0.11 – 0.12	Jul 16 – Aug 16

Table 7A.4: Overview of Hydrometric Gauging

A permanent gauge was established at the Mullenmore Stream and two gauges were available on the River Deel: one at Richmond Bridge and a second at Jack Garrett Bridge in Crossmolina Town. Two additional gauges were set up in 2018 at Pollnacross – one immediately upstream and second immediately downstream of the proposed channel intake structure.

The hydrometric data listed above was analysed together with hydrometric data at the OPW gauge at Ballycarroon (Station No.34007; period of record 1972 to present) and historic data for a decommissioned EPA gauge on the Mullenmore Springs (Station No. 34040; period 1979 to 2000), which is referred to be the EPA as Keesaun. Spot flow gaugings were also available for Richmond Bridge and Ballycarroon from 1976 – 1978.

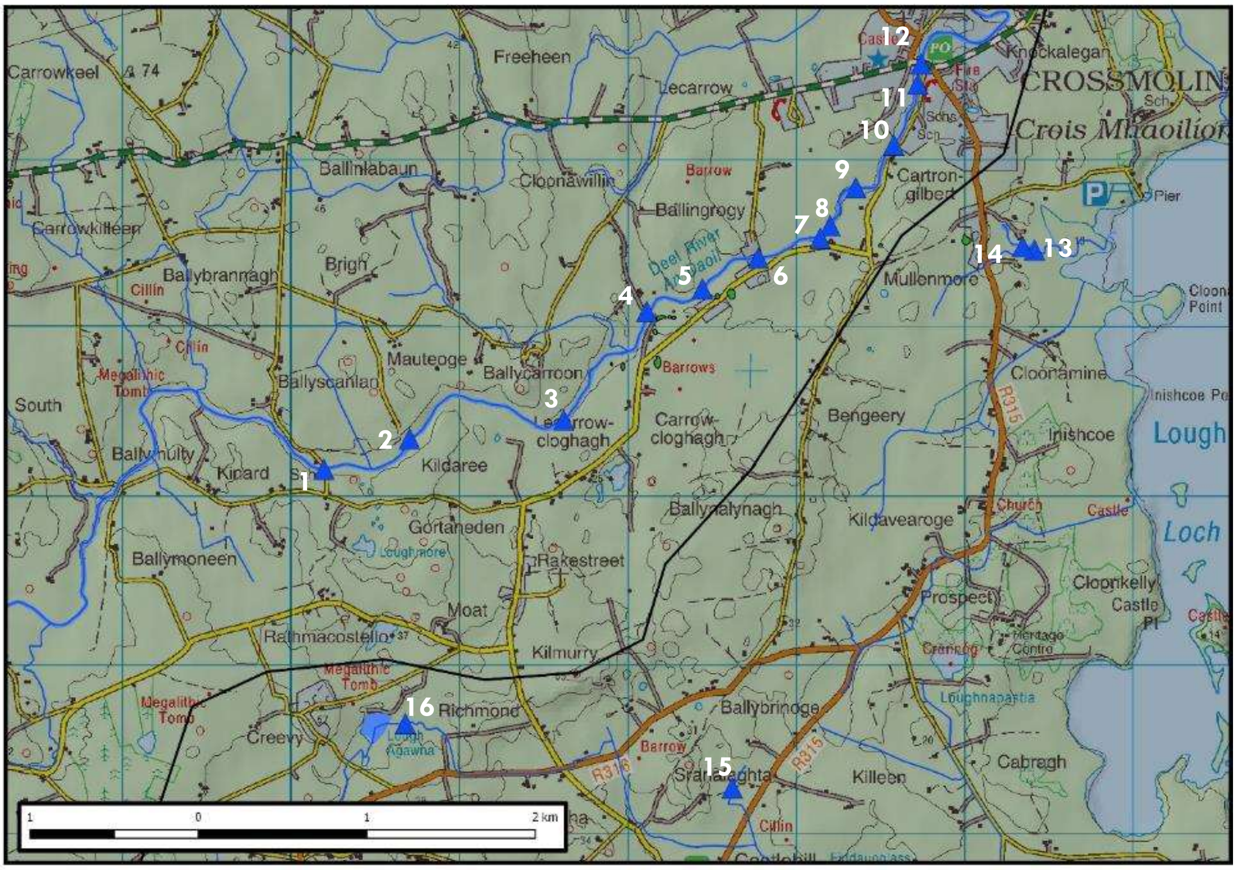

Figure 7A.15: Locations of Hydrometric Gauging Points

Conductivity probes were also installed at the gauges at Ballycarroon and Mullenmore as part of this investigation. Further details are provided in relation to the discussion on conductivity under the section on Groundwater Monitoring above.

7A.4.7 Surveys of Mullenmore Springs

A bathymetric survey of the Mullenmore Springs was carried out by OPW in September 2016. The survey found that the northern spring is deeper than the southern spring with an invert close to Ordnance Datum. This compares with a lake bed level of c30m below OD (refer to Section 7A.4.7). The northern spring consists of two pools, the deeper of which was included in the survey. The shallower southern pool within the northern spring was not covered by the bathymetric survey.

Plate 7A.5 Diving of South Spring, Mullenmore

An experienced cave diver was requested to examine the two Mullenmore spring pools in order to locate and explore any flooded karst conduits present. The springs were dived on 19 February 2017.

The northern spring consists of two pools, the more upstream of which was surveyed bathymetrically last year by OPW Hydrometric. The diver confirmed the findings of the bathymetric survey that the northern pool is 8-9m deep with a deeper cleft in bedrock descending to 12.5m below water level.

The downstream pool, which was not covered by the bathymetric survey, was found to be 4.5m deep with no deeper zones. Water flow was not detected in neither pool and visibility was close to zero.

The diver also confirmed the findings of the bathymetric survey that the southern pool as 8-8.5m deep over almost all of its area with no obvious zones of groundwater inflow except possibly in the area where the stream flows out of the pool.

The diver was highly experienced in diving karst conduits and would be much more familiar with what to look for etc., than would a commercial diver so the conclusions drawn are almost certainly valid.

The inference from this work is that water enters the spring pools diffusely through the sands and gravels that overlie bedrock, possibly originating in a now partially blocked major karst conduit some distance to the west of the springs, as indicated by the preliminary geotechnical investigation.

7A.4.8 Dye Tracing

Eleven dye tracer tests were performed in total.

Seven dye tracer tests were carried out between September 2016 and May 2017, as summarised in Table 7A.5. Each test proved connectivity between the relevant swallow hole(s) and both springs at Mullenmore.

A second round of four dye tracer tests was carried out in July 2019 following the discovery of a collapse doline and a previously unrecorded sink at Pollnacross. All four tracer tests proved connectivity with the southern Spring at Mullenmore. A fluorometer was not installed at the northern spring. Details are provided in Table 7A.5.