CEG8596 Project and Dissertation in Water Resources

Title:

Baseline Characterisation Assessment at Drummin Bog, Co. Carlow, Ireland.

Presented by:

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"Submitted in partial fulfilment of the requirements for the Degree of Master of Science in Applied Hydrogeology in the faculty of Science, Agriculture and Engineering."

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Declaration:

"I hereby certify that this work is my own, except where otherwise acknowledged, and that it has not been submitted previously for a degree at this, or any other university."

James Lalor

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Europe investing in rural areas

Finally, a word of thanks to my family: wife Ursula, Taigh and Flossy for keeping me grounded during my years of work at Newcastle University.

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Introduction 1:

The Drummin bog site is located in County Carlow in the south east of Ireland. The site can be located c. 140km (via M9 motorway) from Dublin. It is found in the locality of the village of St Mullins (via R729 public road), 0.5km from the banks of the River Barrow, which defines the border between Co. Carlow and Co. Kilkenny. **(See Figure 1.1 below)**. The bog covers area of 16 hectares. This area intersects the townlands of Drummin, Bauck and Ballyknock. It is surrounded by agricultural pasture land. **(See Figure 1.2 below)**

Figure 1.1. Drummin Bog Location.

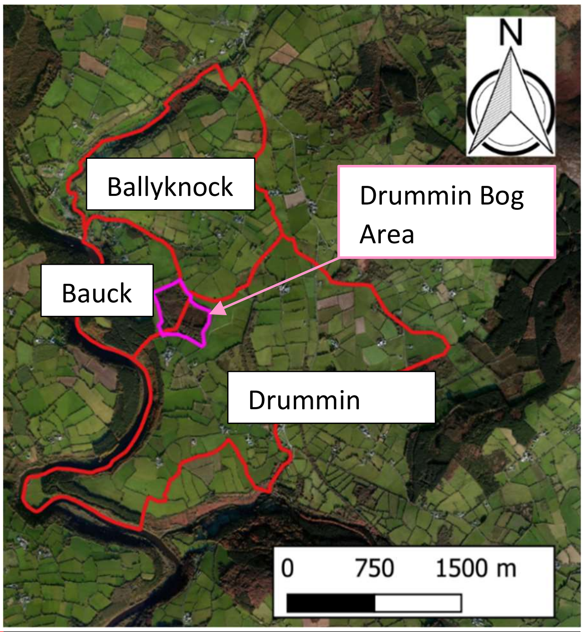


Figure 1.2. Drummin Bog Area.

The study Area of Interest (AOI) comprises of c.42% of the total area of the bog as can be seen in the highlighted area of **Figure 1.3** below. This equates to approximately seven hectares. The breakdown of land use within the AOI is 75% (five hectares) of partly drained cutaway bog (200 x 250m) and 25% (approx. two hectares) of mixed woodland and scrub.

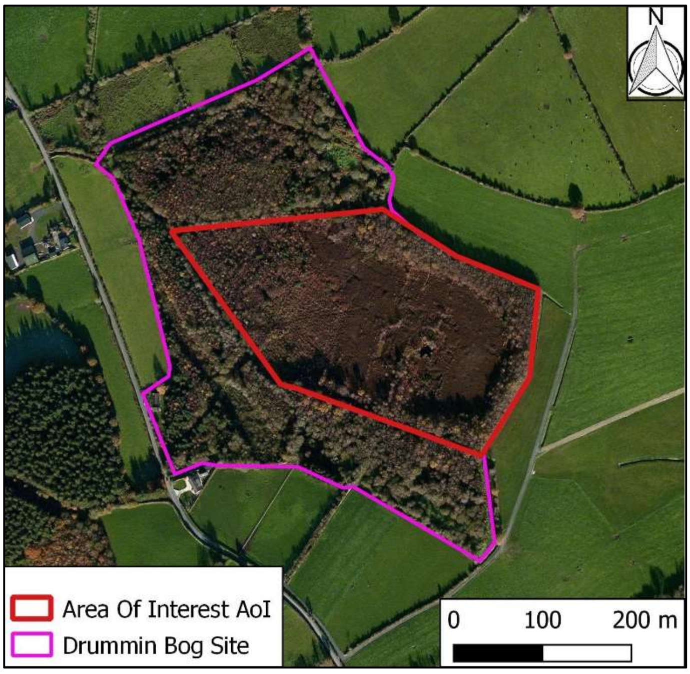


Figure 1.3. Area of Interest (AOI) on Drummin Bog Site, Co. Carlow

Aims 1.1

The overall aims of the research are following:

- Define current hydrogeological conditions on the bog and in its immediate surroundings.

- Identify existing bog drain network efficiency and functionality in the bog area. Assess areas that require most attention to prevent continued negative hydrogeological impacts on the bog's ecology.

- Establish long term hydrogeological and hydrological monitoring.

- Recommend measures to be taken for the long term restoration and protection of the bog.

Objectives 1.2

The objectives following on from the aims outlined above include:

- Establish robust and effective monitoring network within budget and timescale.
- Collect meaningful data sets that influence raised bog growth.
- Process and analyse collected data to establish conceptual understanding of the Drummin bog and local catchment environs and interactions.
- Present data to audience of non-scientific and scientific background in a meaningful format.

Literature Review 1.3

Classification of peatlands types are generally related to two different factors: source of nutrients and source of water. Bogs are ombrotrophic peatlands dependant on precipitation for water and nutrients, whereas peatlands or fens depend on groundwater for water and nutrient supply and are described as minerotrophic (Johnson and Dunham 1963). Bogs have been subject to anthropogenic activities for hundreds of years but particularly since mechanisation in recent decades. The most common anthropogenic influences on the bog environment are: turf (peat) production, agricultural expansion (grazing pasture), forestry, horticulture and flood control. Bogs and peatlands are an integral part of the Irish landscape, raised bogs which are less well known once covered c.5% of the island. The following are some salient comments to be mindful of in the discussion of raised bogs:

1. Raised bogs are formed from post glaciation lakes and shallow topographical saturated depressions, these habitats in which peat accumulates can be given the general term “mires” (Moore 1987) Once matured in their natural state they are represented by dome shape mounds of peat, hence the name raised bog.
2. According to Cross (1990), Irish raised bogs are classified as “oceanic raised bogs” and are comprised of 94% water. Raised bogs are typically treeless and are characterised by Sphagnum mosses, sedges and dwarf shrubs all of which have made the acidic, water logged and exposed terrain their home.

3. While harvesting of peat is the primary source of raised bog; destruction, burning, draining, grazing and planting of trees can cause significant desiccation of the ground beneath and also interfere with the natural process of evaporation following precipitation and storage capacity of the bog - central to its survival and growth.
4. A cross section of a raised bog can be observed in **Figure 1.3-1** below and has typically two hydrological layered zones: Acrotelm (upper layer) and Catotelm (lower layer).

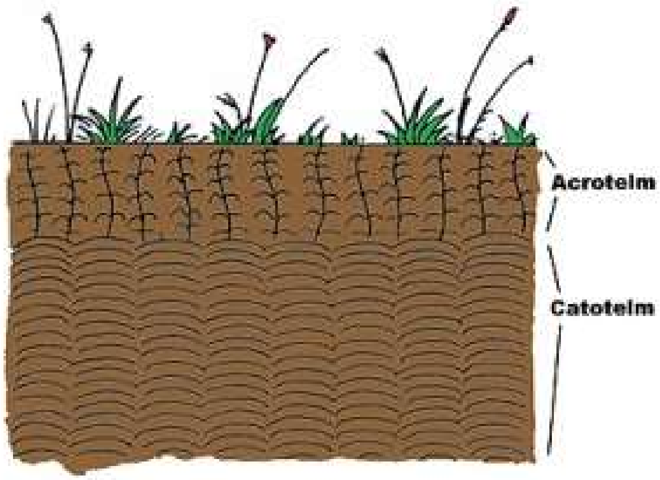


Figure 1.3-1 Two hydrological layers of the raised bog.
(Figure Courtesy of Irish Peatland Conservation Council)

5. From field studies completed by Kelly (1993) the acrotelm can vary in thickness between 0.3 – 0.5m. Ivanhov (1981) describes the acrotelm as having an oscillating water table and a high hydraulic conductivity for peat forming organisms. It is this high hydraulic conductivity according to Streefkerk (1997), that makes it critical to the hydrology of the bog; it is thus the most important aquifer in the bog system. This ability of the acrotelm to absorb and store water over time and then discharge the water during drier times helps it to maintain a stable phreatic table.
6. There is no defining boundary between the Acrotelm and the Catotelm: it can vary from place to place. In contrast it is well consolidated and exhibits a large degree of humification (generally increasing with depth). Due to this strong consolidation of the amorphous unit being constantly saturated, water movement within this zone is

very slow (< 1m/day). Since the catotelm is ombrotrophic, its sole recharge is from precipitation, there is no connection to groundwater. Streefkerk concludes that during high intensity rain the discharge from the acrotelm increases significantly and hence the transmissivity of it varies depending on the intensity of the precipitation occurring.

7. Raised bogs can typically be found on terrain below 130 masl, and with precipitation values of <1,250 mm p/a (Best Practice in Raised Bog Restoration in Ireland). Due to the anaerobic conditions in the mire environments, complete decomposition of plant materials and fibres is not possible and settles as a peat lithology. Eventually this increasing layer of peat displaces the water in the mire rising to the surface forming a bog. Eventually any contact between the surface plants and groundwater is lost leaving sole water dependency on precipitation. The formation stages of the raised bog are shown in **Figure 1.3-2** below:

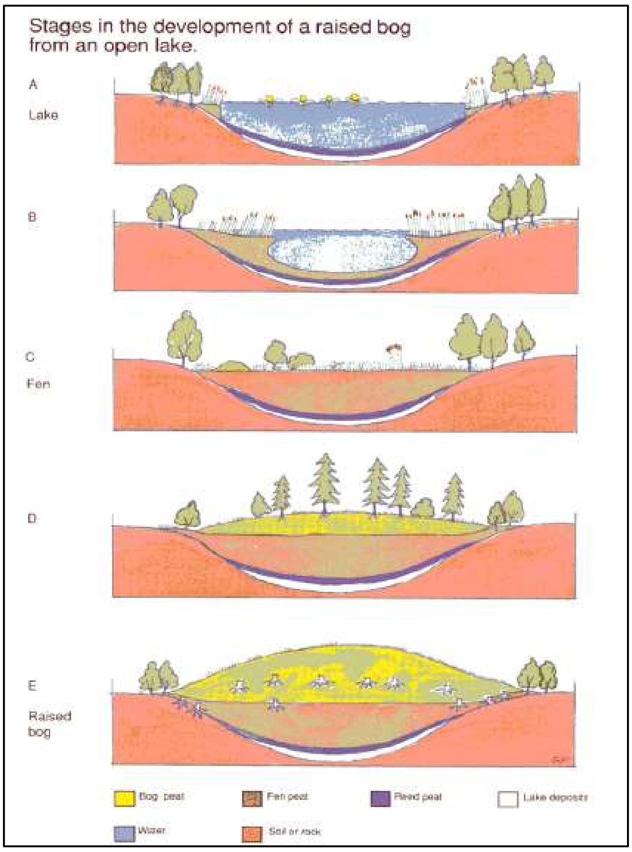


Figure 1.3-2: Formation of Raised Bog (after Cross 1990)

The research contained in this report is primarily focused on looking at the hydrological system of the bog in a spatial and temporal context. Also in presenting local meteorological data in a climatic context and local geology on a regional scale. By taking a small study area of c. seven hectares and comparing it with the larger historical and regional context, only then can we assess what the overall trends are and what are the real challenges as against the perceived challenges in rejuvenating this habitat. Statistical analysis of the historical data using Standard Precipitation Index values and Rainfall Anomaly Indices will be used to assess precipitation events, while box plot analysis will be used to look at precipitation and temperature statistics.

Raised Bog Hydrology 1.3.1

A healthy raised bog is an ever changing environment due to its water and nutrient supplies being sourced primarily through precipitation. Water is initially lost through evapotranspiration and vertically from the catotelm if the confining mineral clay layer is absent, however there is a significant confining lacustrine clay layer at Drummin Bog. There is varying transmissivity (depending on intensity of precipitation) from the acrotelm to the catotelm where hydraulic conductivity can be very slow. A healthy raised bog environment requires water levels to be approximately at surface level for most of the year. According to Kelly and Schouten (2002) seasonal fluctuations should not exceed 0.2m and static water levels (SWL's) should remain around 0.1m from surface, except for short durations of time. **Figure 1.3.1-1** below demonstrates these hydrological points and also gives a good example of a typical cross section of an Irish raised bog. Raised bogs often have a clearly discernible perimeter, which is often referred to as the *rand*. In the case of Drummin Bog, owing to extensive draining and agriculture, the perimeter is unclear.

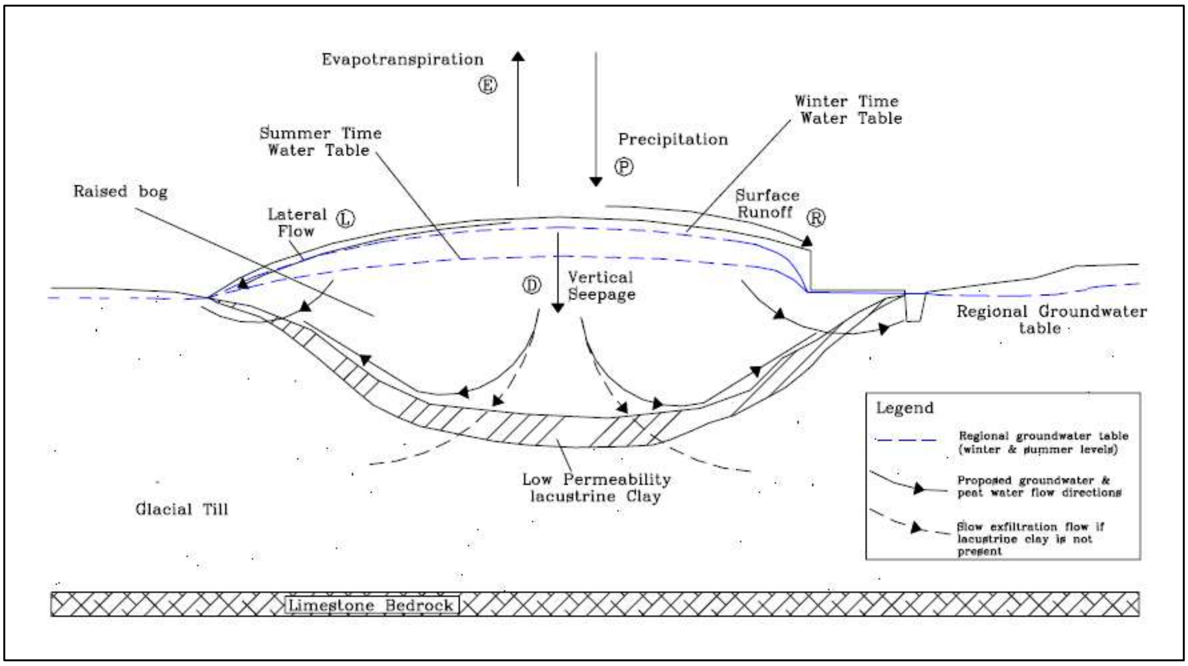


Figure 1.3.1-1 Water balance of a raised bog with domed relief (Streefkerket 1989)

Raised Bog Climatology 1.3.2

Etherington looked at the relationship between the precipitation and evaporation, and also demonstrated extremely well the relationship between ombrotrophic wetlands and groundwater while also the extent of the reliability of the ombrothrophs to precipitation and evaporation. A graphical diagram of his findings is shown below in which the proposed relationship between mires in terms of the relative influence of rainwater and groundwater in their hydrological input. See **Figure 1.3.2-1**

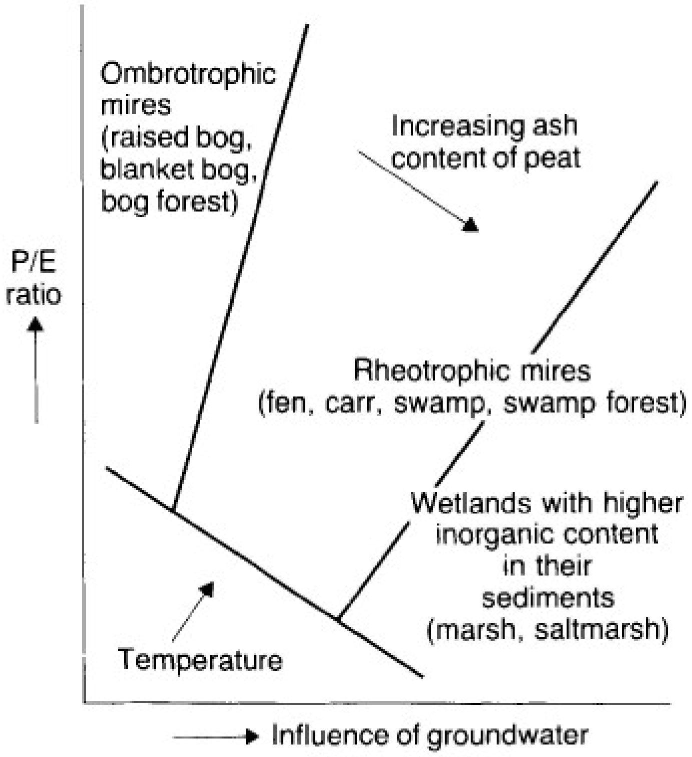


Figure 1.3.2-1 Rainwater and groundwater input relationship (modified from Etherington 1983).

Raised Bog Nutrient Supply 1.3.3

Since precipitation is the primary source of nutrients for the sphagnum, the ombrotrophic surface water found on raised bogs are generally below 4.5 pH (<4.5 pH) (Moore and Bellamy, 1974). They also have a very low electrical conductivity (EC) value (50-100 µS/cm). This conductivity is indicative of younger waters i.e. precipitation. The dominant plant species on the raised bog is the sphagnum mosses which capture the nutrients they require from the precipitation and in exchange release hydrogen ions reducing further the pH. An overview of ideal Active Raised Bog (ARB) conditions can be found in **Figure 1.3.3-1** below.

Conditions required to maintain or restore good quality ARB habitat		
Hydrological	High water level	Above surface
	Mean water level	At or above the ground surface with max seasonal fluctuation <20cm
	Low water level	10cm below ground surface (except for very short intervals)
Topographical	Local surface slope	0.3% - 0.6% (depending on depth of effective rainfall)
Water Quality	pH level	< 4.5
	Specific Electrical Conductance (SEC)	50 - 100 µS/cm

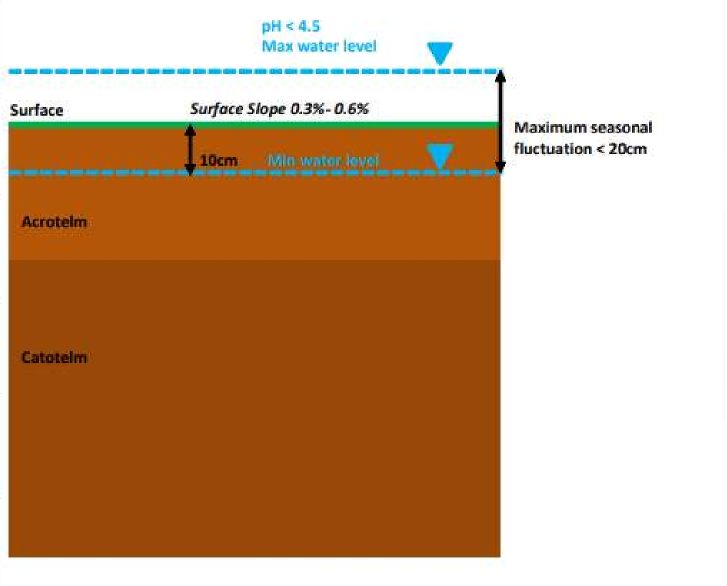


Figure 1.3.3-1 Conditions required to maintain or restore good quality ARB habitat. (Best Practice in Raised Bog Restoration in Ireland. Irish Wildlife Manuals No.99)

Baseline Monitoring Network Establishment 1.3.4

The conditions to promote ARB to develop progressively while simple are complex in their interactions. Without establishing a quality baseline monitoring network key aspects can be omitted in assessing the physical inputs and outputs of the study area, for example a robust water balance equation. It is also a key to responsible targeting of resources to know where they are needed most for restoration of the habitat. Monitoring allows an assessment to be made whether restoration and conservation targets are being met. Good monitoring also allows the scientist to demonstrate any impacts, negative or positive, of restoration efforts. In order for a restoration program to happen a restoration plan must be in place and this must be based on quality sampling baseline data drawn from a well thought out and robust monitoring network. All aspects of the hydrological cycle must be monitored: precipitation, run-off, recharge, evapo-transpiration and atmospheric pressure. They are all inter-related especially in the context of raised bogs.

Environmental Setting 2:

Bedrock Geology 2.1

The geology beneath the Drummin Bog is "Blackstairs Type 2 Equigranular Granite" described by the GSI as "pale in colour, fine to coarse-grained granite". This unit stretches from St Mullins in the south-west to Black Rock Mountain north of Kiltealy, Co. Wexford. These granites would have been subjected to a variety of tectonic stresses leading to faulting and fracturing. Shear zones have been mapped previously in the granites but not in the local area of the Drummin Bog. **See Appendix 1. Figure 1.**

Further discussion of the site geology is contained in *Geophysical Survey Review 2.6*.

Topography and Surface Hydrology 2.2

The bog lies between 63 and 68 masl and is located in the southern area of the Barrow catchment at a topographical "bottle neck" between the Brandon Hill and the foothills of the Backstairs Mountains. An analysis of glacial deposits within the catchment demonstrates the significance of the Drummin bog site in the catchment context **See Appendix 1. Figure 2**. The AOI is surrounded by mainly deciduous woodland on the greater Drummin Bog footprint. The bog is drained internally by a network of open drains and surrounded by a peripheral drain which flows to a tributary of the Aughavaud River to the north. This peripheral drain is the primary drainage surface water discharge route from the AOI. A proportion of the reclaimed bog also flows into this drain. A second water course, not part of the AOI but part of the former bog (now reclaimed), flows south ward into the Aughanagh River and Pollmounty River. All of the rivers mentioned above are part of the Barrow catchment and constitute local hydrological boundaries. **See Appendix 1. Figure 3.**

The bog is part of the surviving former peatland as can be observed in **Figure 2.2.1** below, formerly known as the "Red Bog". This 6" map produced in 1900's indicates that significant drainage programs have been undertaken over generations to reduce the area of the bog to it's current size.

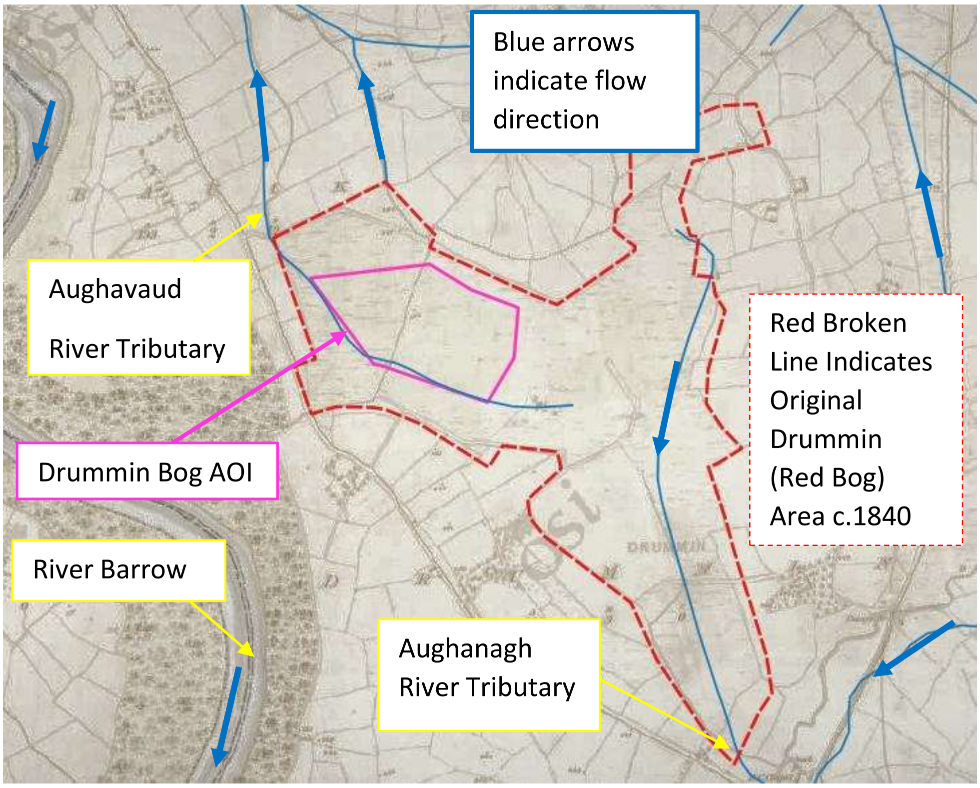


Figure 2.2.1 Drummin Bog AOI observed in observed on 6" 1837-1842. (http://map.geohive.ie/)

At its closest point the River Barrow is located 300m distance from the south eastern corner of the bog flowing in a southerly direction for 34 km before joining the estuary at New Ross. This figure indicates a very close relationship between the bog and the local hydrological regime. The River Barrow is the primary river with the sub-catchments of Aughavaud River, Aughanagh and Pollmounty surrounding it. Aerial imagery as late as 2005 to 2012 shows further drainage works reclaiming bogland to the east of the bog into agricultural land. This drainage relationship is examined closer later in this document examining LiDAR survey and AOI drainage networks.

Bedrock Hydrogeology 2.3

The GSI classifies the bedrock as "Granites and other Igneous Intrusive Rocks" (GII) which are generally pale fine to coarse grained granite. It is classified as a "Poor aquifer – bedrock which is generally unproductive except for local zones (PI). It is thought that fracture flow is the dominant flow path in this type of bedrock with main flows being channelled through weathered and fractured zones. Most of the fracture areas are in the top 20m of rock head and are considered shallow. The bedrock of the AOI will be discussed in more detail later in the *Geophysical Survey Review 2.6*, however it was found to exhibit some fracture infil beneath the AOI. **See Appendix 1. Figure 4.**

Aquifer Vulnerability 2.4

The groundwater vulnerability rating is a measure of how susceptible the underlying aquifer is to contamination and is a function of the nature and thickness of the overburden. The groundwater vulnerability rating for Drummin Bog is classified by the Geological Survey of Ireland (GSI) as Moderate, surrounded by an area of highly vulnerable aquifer, becoming extreme to the west towards the River Barrow. **See Appendices 1. Figure 5.**

Depth to rock	Hydrogeological Requirements for Vulnerability Categories				
	Diffuse recharge			Point Recharge	Unsaturated Zone
	high permeability (*sand/gravel*)	Moderate permeability (*sandy subsoil*)	low permeability (*clayey subsoil, clay, peat*)	(*swallow holes, losing streams*)	(*sand & gravel aquifers only*)
0–3 m	Extreme	Extreme	Extreme	Extreme (30 m radius)	Extreme
3–5 m	High	High	High	N/A	High
5–10 m	High	High	Moderate	N/A	High
>10 m	High	Moderate	Low	N/A	High

i *N/A = not applicable.*
ii *Release point of contaminants is assumed to be 1–2 m below ground surface.*
iii *Permeability classifications relate to the engineering behaviour as described by BS 5930.*
iv *Outcrop and shallow subsoil (i.e. generally <1.0 m) areas are shown as a sub-category of extreme vulnerability.*
(amended from Deakin and Daly (1999) and DELG/EPA/GSI (1999))

Figure 2.4.1. Vulnerability Classification Table. (Courtesy of Geological Survey of Ireland)

Quaternary 2.5

The subsoils beneath the bog are classified as Till Derived Chiefly From Granite (TGr). They are described as moderately permeability subsoils overlain by poorly drained gley soil and are also classified as moderate permeability and vulnerability. These quaternary sediments will also be discussed in more detail later in the *Geophysical Survey Review 2.6* section, for a map of regional quaternary information **See Appendices 1. Figure 6.**

Field Surveys 3.0

There were four surveys undertaken over the AOI.

- Geophysical Survey.
- Lidar Survey.
- Site Drainage Survey.
- Photogrammetry Survey.

Each of these surveys will be discussed in this chapter.

Geophysical Survey Review 3.1

A geophysical survey was commissioned as part of this research during February 2020. See **Figure 3.1-1** below.

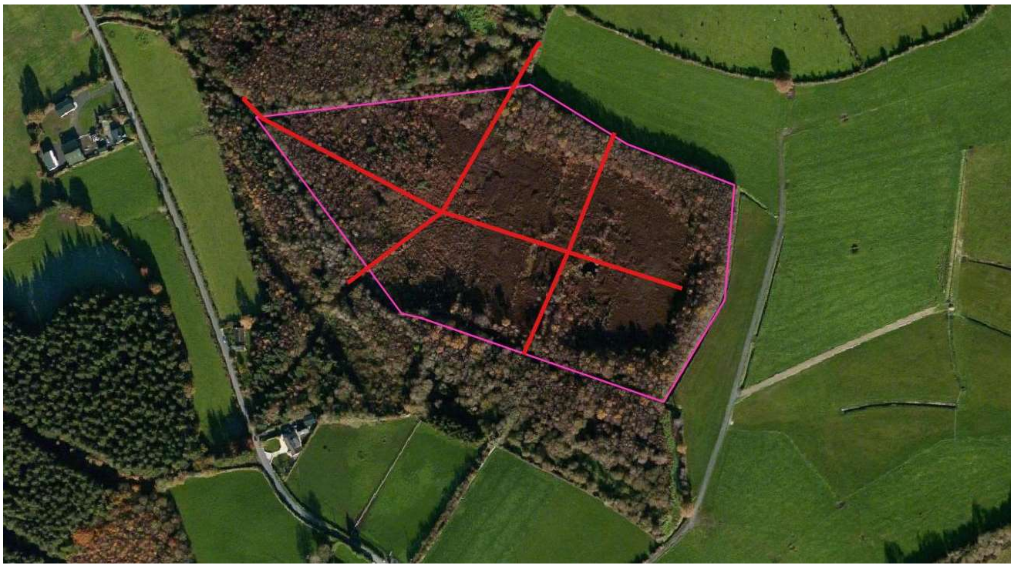


Figure 3.1-1 Red lines indicating transect lines within the AOI.

Surveys were undertaken using the following techniques:

- Ground Penetrating Radar (GPR).
- Electrical Resistivity Tomography (ERT).
- Seismic Refraction.

The survey was undertaken across the main longitudinal axis of the site and two lateral lines. These lines also acted as guidance locations for later piezometer installations on the site, which in turn were used in calibration of data. The report can be found in **Supplementary Report Material Folder.** Salient comments drawn from the report include:

- Thickest peat profiles are located in a topographic low found in underlying geological formations. Clay and silts were deposited in this depression prior to transitioning into "fen type" organic soils, with raised bog peats forming at a later stage.
- Maximum depth of peat was found to be 5.7m thickness.
- The deeper geology was identified as crystalline granite, underlying more weathered zones above, shallowest in the south of the site. A zone of more granular till material was identified to the east of the site.

This information suggests that initially a fen type bog environment was formed in a depression in the local granite geology fed by ground water mineralized springs (possibly via fracture flow), after which raised bog growth was initiated as the initial fen environment gradually disconnected from its mineralized groundwater source of nutrients. This information aligns with the earlier information on bedrock geology and also the proximity of the AOI to fault (associated) structures in **Figure 1, Appendix 1.** It was found during piezometer installation that piezometer MW01 which was 3.9m BGL in loose coarse sandy silt, was seasonally artesian. Evidence implying a potential fault/fracture in the granites as suggested by the geophysics. It also suggests a hydraulic pressure from outside of the side, potentially from the more elevated slopes of the Blackstairs Mountains. This information indicates that not only is the AOI tied to the local reclaimed bog in the environs of the site but is influenced by precipitation and hydrogeology in a much wider regional geographical context. The shallow weathered granites detected in the survey are linked to the origins of the bog. This will be discussed in more detail later in the piezometer installation section as two types of peats were found to be common throughout the AOI.

LiDAR Information Review 3.2

LiDAR surveys had been commissioned by the National Parks and Wild Life Service in recent years. The surveys were carried out using a low-flying (c. 3,500ft) aircraft with LiDAR scanner attached. Generally returning a point density of 10-15 points/m2 and provide a vertical accuracy of +/- 150mm. The point accuracy is reduced in areas of dense canopy cover but overall this data is considered a very high resolution dataset. Generally, the information seems positive with LiDAR flow lines flowing towards the obvious established water courses surrounding the site, however there are some anomalies.

A check on the elevation accuracy of the LiDAR is contained in **Figure 7, Appendix 1.** This is done using the surveyed spot heights of the piezometer tubes (installed as part of groundwater monitoring network) less stick-up height to give ground elevation mOD. It is quite accurate in areas where the tree canopy is thin or none (center of the AOI), as suggested above but is less reliable where the tree canopy is dominant in the west of the AOI.

Linear flow paths described earlier can indicate depressions also. When interpreting LiDAR information, it is important to remember in cases where the model is not able to predict an accurate outflow, it has to fill the elevation within this area to allow it predict where flow would continue, leading to some interpretation on part of the model. Likewise flow paths on the agricultural land are not necessarily areas where one would expect overland flow, but where there could be several flow paths converging indicating an increase in catchment area and therefore higher probability of encountering wet conditions or flow (particularly ephemeral flow during increased precipitation). **Figure 3.2-1** below shows the LiDAR information covering the greater study area, while it has very little meaning when it stands alone in this context, when plotted with GIS of the wider area it turns out to be remarkably accurate and a very useful tool in picking up drainage patterns that otherwise may be very difficult to find on the ground. It's important to recall that the magenta AOI boundary in the figure is also a peripheral drainage ditch and considered a significant hydrological boundary control. The full suite of LiDAR maps and images can be found in **Supplementary Report Material Folder.**

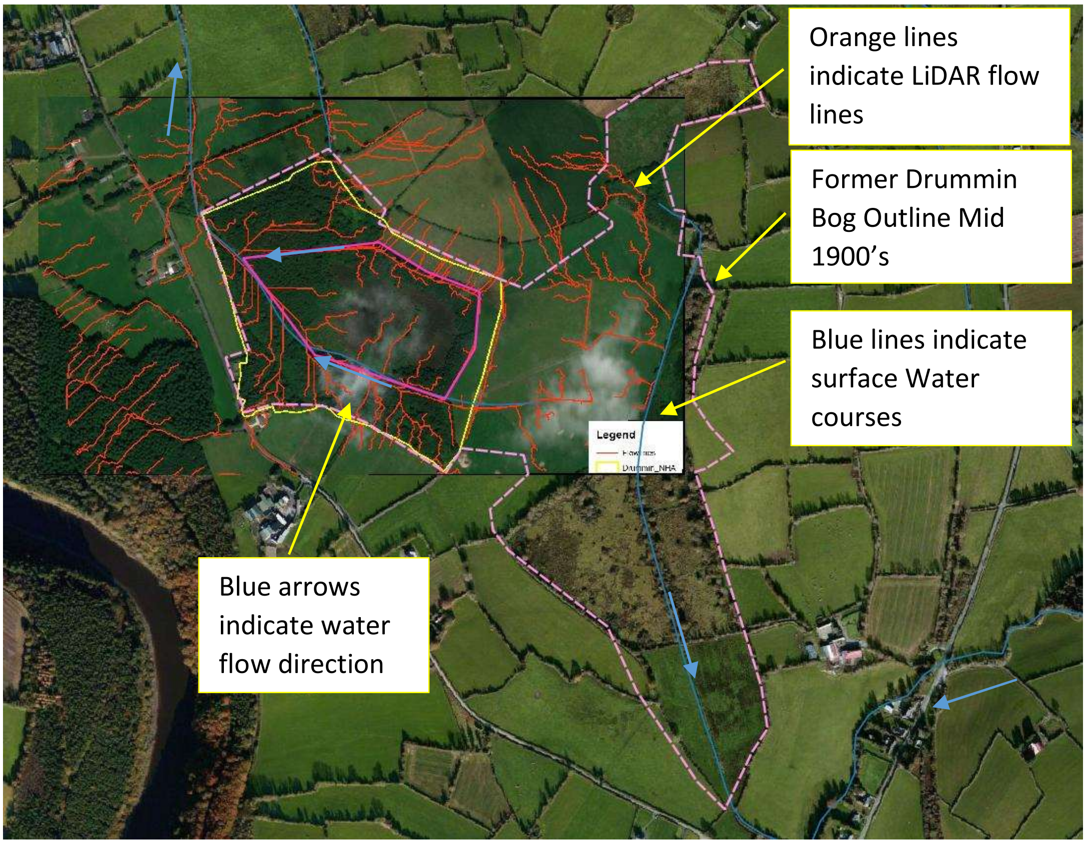


Figure 3.2-1 LiDAR flow lines image georeferenced onto topographic image of AOI.

Drain Survey 3.4

A walkover drain survey was undertaken on and around the AOI. It was not possible to go further beyond the bounds (or seek permission to) due to Covid-19 restrictions. The walk around the site indicated only one drain to be flowing into the peripheral AOI drain. It is suspected that this drain may be a collector drain for several smaller drains feeding into it, (however this is not confirmed at this point). This drain was found to have a maximum flow of 1.1 ltrs/sec on the 20th of February 2020 and a minimum flow of 0.01 ltrs/sec on 2nd of June 2020, but never ran dry. The hydrochemistry of this drain was also analysed and it is discussed later in the research.

The survey was undertaken to gain an assessment of the accuracy of the LiDAR imagery in delineating the extensive and concealed drainage network within the AOI. The survey also attempted to find the plastic sheet piling installed previously in attempt to enhance the peat saturation in some parts of the AOI. The results can be observed in **Figure 8, Appendix 1.** The survey indicated a reasonable level of accuracy, a significant proportion of the site on the periphery and western section is inaccessible, due to thick woodland growth. It is thought that there may be significantly more connectivity on the site than what is indicated by the LiDAR survey.

Contours and topographic elevations are normally considered an indication of likely flow paths (not necessarily open channels) and should be used as an indicator only of where one could expect flow to be directed towards. An assessment of piezometer elevations points and water levels will be discussed later in groundwater flow. The groundwater flow has been altered by anthropogenic activities. Eight sheet piles were located, some were in water logged channels, while others were in dry channels. Almost all were found to be loose and hence deemed ineffective.

Photogrammetry 3.5

A photogrammetry survey was also undertaken of the Drummin Bog area. Photogrammetry involves flying a drone along overlapping flight paths and using a software package to triangulate overlapping cells to create a surface grid. This approach, while much more efficient than LiDAR surveys, only generates a Digital Surface Model (DSM) including all vegetation and surface objects. The accuracy of the dataset is not as high as the results from the LiDAR data. This means that where there is a tall vegetation, the data is providing the elevation of these objects rather than the ground surface. While some software packages include algorithms that enable processing of a Digital Terrain Model (DTM) from photogrammetry, the results from these are very poor on these type of sites. The full suite of Photogrammetry maps and images can be found in **Supplementary Report Material Folder.**

Monitoring Network Design & Establishment Methods 4:

All available literature and resources have now been examined in relation to the desk studies of the site, the first of the objectives can be addressed establishing a sound footing for the follow-on objectives. That is “to define current hydrogeological conditions on the bog and in its immediate surroundings”.

There are two reasons for designing a monitoring network. Firstly, to develop and validate a conceptual understanding of surface and ground water systems and investigate how climatic variables impact upon them. This data provides a base of evidence to support decision making in terms of peatland rehabilitation (in all its facets). Secondly, monitoring provides a baseline of evidence for impacts associated with developments in rehabilitation practice over extended periods of time.

The method of collection, processing and presentation must be done with an eye on why it is being done, what is its application and who is the target audience (in terms of reporting). A failure to address these questions can result in inappropriate data gathering that the monitoring was first established to consider. Since no baseline monitoring was undertaken previously, Drummin bog represented a blank canvass to the field scientist. While this is a difficult starting point in terms of assessing the study area due to the amount of unknown variables, it also presents a great opportunity in terms of building the most efficient functioning monitoring network within the very tight margins of public sponsorship, whilst ensuring value for money.

The AOI of the Drummin Bog site is 7 hectares. This makes setting up a monitoring network quite manageable in terms of deployment of resources and time investment by the scientist during field visits. The project work can be divided into two main phases as can be seen in **Table 4.0** below:

Phase 1: Collection of Data:	Phase 2: Data Analysis & Discussion:
Meteorological Data	Raised Bog Water Balance
Water Level Data	Surface Drainage Controls
Piezometer Installation	Meteorological Impact on Flow and Groundwater Levels.
Surface Water Flow Data	Hydrochemistry Review
Groundwater Level Monitoring	Future Planning
Hydrochemistry Sampling	Closing Comments
Climatic Data	

Table 4.0 Project Work Plan.

It was planned to undertake a borehole survey of the local area surrounding the AOI to identify groundwater head data in the greater locality but this was not possible due to the Covid-19 emergency.

Monitoring Network Design 5:

Meteorological Data 5.1

Drummin Weather Station (DWS) was established on the site and is located c.250m south-west of the site. It was chosen due to its proximity to the site but also due to being a secure location. The station is located on the top of outhouses to avoid as much as possible the impact of shelter from trees. **See Appendix 1, Figure 9**. The weather station was purchased from Capital Water Systems Ltd, Co. Roscommon. It consisted of refurbished Vailsala WXT520 Weather Station including logger cable and a Supply Hawk XT Datalogger (non telemetry) and configuration software. A stainless steel rain gauge tipping bucket was also included in the purchase. The WXT520 monitors the following parameters:

- Wind Measurement - the wind sensor has an array of three equally spaced ultra-sonic transducers on an even plane. Wind speed and wind direction are determined by measuring the time it takes the ultra sound to travel from each transducer to the other two.
- Precipitation - the precipitation sensor comprises of a steel cover and a piezoeletrical sensor mounted on the bottom surface of the cover. The sensor detects the value of the individual rain drops. The signals from the impact of the raindrops are proportional to the volume of the raindrops. The tipping bucket was found to collect almost 22% more precipitation than the percussive plate sensor owing to the temperate nature of Irish rain during the period of monitoring. For the duration of this research all precipitation values and references are related to the tipping bucket values.
- Pressure, Temperature, Humidity (PTU) - The PTU sensor consists of:
  - capacitive silicon BAROCAP to measure pressure
  - capacitive ceramic THERMOCAP to measure temperature
  - capacitive thin film polymer HUMICAP

The weather station must be aligned in a northward direction in order for it to measure wind direction accurately. Historical rainfall data and PE data is collected for a Met Eireann station at Oak Park, Co. Carlow located 43km north. By purchasing the weather station it saved money on an extra data logger for groundwater level transducers to compensate barometric pressure. Meteorological data can be found in the **Supplementary Report Material Folder** accompanying this report. Further discussions on weather and climate will follow later in this report.

Piezometer Installation 5.2

Ten piezometers (piezos) were drilled into the raised bog, a further three were installed manually during the drought of June 2020 in targeted locations of the bog where water level was at surface and pockets of sphagnum moss were surviving. The locations for the ten piezos were based on planned geophysical survey transects running east-west and north-south across the bog.

Originally ten sites were identified for installations for shallow and deep piezometers but due to time and access difficulty only six sites could be accessed and ten piezometers installed. See **Photos 5.2-1a and 5.2-1b** below. Details of all locations (including piezometers and standpipes) **Appendix 1, Figure 9**. Well logs can be found in **Appendix 2.**

Photos 5.2-1a and 5.2-1b. Mobilisation and set-up of rig across concealed drains and woodland made piezometer installation a challenge.

Lithology information and construction details and elevation are all contained in borehole logs. Some logging photos can be seen below in **Photo 5.2-2a, 5.2-2b and 5.2-2c.**

Photo 5.2-2a, 5.2-2b and 5.2-2c. Piezometer Logging and installation work.

Groundwater Level Monitoring 5.3

The groundwater level monitoring was undertaken using both pressure transducers were purchased from Measurement Systems Limited, UK and an OTT dip cable. The transducer instruments are:

- HOBO U20L-01 Water Level/Temperature Data Loggers: It features 0.1% measurement accuracy and has a range of 9m.
- BASE-U-4 Optic USB Base Station: is used to offload data from any HOBO data logger with an Optic USB interface. The Optic USB Base Station connects to the laptop via USB, while connecting to the logger via an appropriate coupler.
- HOBOware Pro Software for Windows/MAC: is the software suite for logger management, data graphing, data analysis, and data export. It includes a USB interface cable.

Two transducers were deployed in shallow piezometers in the central area of the site where peat is deepest and two were deployed at these same locations targeting the lacustrine clay unit underlying the peat. All transducers were synchronised and set to log every 4 hours in tandem with that of the weather station. Regular downloading was undertaken monthly at least and each time site monitoring of all piezos was also undertaken. The electronic data was calibrated to match the manual dips as a QA/QC approach to data handling.

An electronic dip meter was used to measure the water levels at all locations where piezometers and stand pipes were installed during the various rounds of monitoring work. Data from manual water level and transducers are contained in **Supplementary Report Material Folder.**

Surface Water Flow Data 5.4

Water flow on site has been a challenge to measure with accuracy due to very low flows in particular. On the AOI itself there are a series of excavated drains running north-east to south-west in orientation, some though are interconnected through shared sumps. Several of these drains are found to have had plastic sheet piling deployed from years gone by but little is known of their location or the methodology used to install them. See **Photo 5.4-1** below. Where they have been located during the drain walkover survey, they have been found in general to be ineffective, often times due to being loose in the drainage channel or not penetrating the base or sidewall of the channel sufficiently. On other occasions water in the channel both sides of the pile, which is not desirable and a cause of concern. It is understood that approximately 12 of these structures had been installed, eight have been located. Also during the walkover survey observations were undertaken on the periphery of the site to ascertain the status of the drains were feeding into it both from the AOI and also from the surrounding pasture (reclaimed bog). One pasture drain (PD GW) was located discharging into the main drain, no others were visible or actively discharging. This drainage pipe "Pasture Drain" (PD GW) ran from beneath

Photo 5.4-1 Faulty Sheet Pile

surrounding agricultural land discharging into the drain. It's location can be seen (on the most northerly tip of the site) in **Appendix 1, Figure 9**. It always flows and represents a good example of groundwater flow variation and chemistry of the wider catchment. Its source is unknown but thought to be fracture flow from within weathered granites. The hydrochemistry of this flow is discussed later in this report. The flow was measured using a stopwatch and a container of known volume.

Photo 5.4-2 (Left). PD GW flow 26th February 2020. Flow Rate = 1.3 litres/sec.

***Figure** June **5.4-3** (Right). PD GW flow 24th June 2020.* Flow Rate = 0.02 litres/sec.

This discharge was measured during various monitoring rounds using a bottle and a stop watch providing sufficient accuracy. Flow values and comments can be seen in **Table 5.4.4** below. The flow indicates great variability in flow where wet weather periods can be observed to flow 2 orders of magnitude higher than in drought conditions.

DateTime	Comments	Discharge [Q] (ltrs/s)
20/02/2020	Very Wet Weather. High flows	1.07
26/02/2020	Very Wet Weather. High flows	1.27
20/03/2020	Mixed March. Cold & relatively dry	0.39
01/04/2020	Dry March, cold	0.13
28/04/2020	Dry April, cold	0.15
20/05/2020	Dry May, warm	0.02
02/06/2020	Dry May, just before Storm Arthur	0.01
24/06/2020	After Recent Dry Spell	0.02
09/07/2020	After 2 days of rain, warm	0.03
06/08/2020	Unsettled weather pattern	0.04

Table 5.4-4 Flow values recorded at PD GW.

Six drainage channels were found exiting the bog to the south into the main peripheral drain. These drains were considered to be ephemeral and only observed to be flowing during significantly wet weather periods when several flows could be considered to be < 1liter per minute; only one was observed to exhibit flow after rainfall events of Storm Arthur in June 2020, **see Photo 5.4-5 below**. It was however impossible to accurately gauge them due to them being found in wide shallow peat filled drains and flows which would be better perhaps described as seepage discharge. These drains are however considered significant to the water balance of the site. It is worth noting that on a raised bog vulnerable to precipitation for its survival and development, drains that discharge water when it becomes abundant are of serious concern. In the context of raised bog rehabilitation, they prevent recharge of peat and storativity of water within the raised bog peat. This action thus prevents growth of the sphagnum moss and restricts existing moss to water particularly in times of greatest need such as Summer.

Photo 5.4-5 Ephemeral Drain Discharge. June 2020

The peripheral main drain which drains the AOI needed to be measured accurately also. It was thought to install a v-notch weir here immediately on commencing the field work but the scale and range of flows was not known. Since the drain had been dredged in recent years, it had good trapezoidal definition and straight channels. It was however overgrown with grasses and forest debris and an attempt was made to get a flow along a stretch using a float and stop watch but this was found to be impractical and unreliable.

Despite clearing the drain prior to flow test the float still was getting stuck, secondly the breeze on-site was blowing the float up stream and hence the data was unusable. Further investigation found that the drain exited the site via a culvert consisting of several concrete pipes with the combined flow exiting here. An attempt was made to access this flow and measure with a bucket and stop watch but flow was backed up downstream and hence a bucket flow was not possible. An attempt was also made to get a float via the culvert but this was also getting stuck and giving erratic results on various attempts to measure.

Figure 5.4-6 *February 2020*

Figure 5.4-7 *June 2020*

It was decided at this point to discharge a salt-gulp solution as a method to measure this flow accurately. Since Hobo water level transducers and software were purchased for monitoring water levels, it was cost-effective to purchase a HOBO U24-002 Salt Water Conductivity in line with previous Hoboware purchased for groundwater level monitoring.

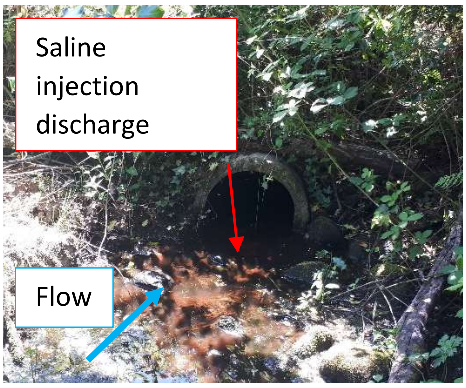


Photo 5.4-8 Exit Flow- Coilte Culvert

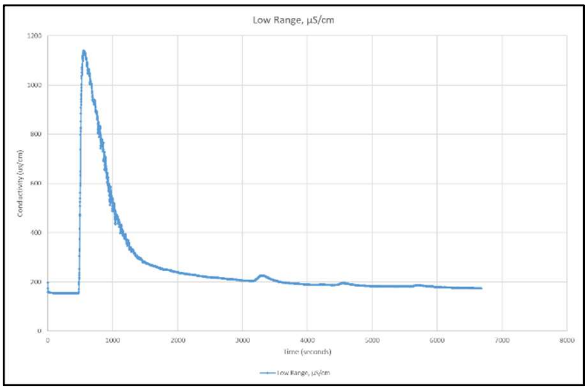


Photo *5.4-9* *Salt Gulp Flow Measurement Graph*

A 7.5% saline solution was discharged into the channel, the culvert was measured with flexi rods as 9.1m long and travel time calculated in seconds. A simple flow calculation

Q=VA, **where A= r2(ϴ-Sinϴ)/2**

is thence used to calculate the flow velocity with accuracy. Flow volume data is only available from 28th of April 2020, while it missed the wet weather events of February 2020, it did capture the low flow events of May/June 2020 and results are shown in **Table 5.4-10** below.

Date	Coilte Culvert	PD GW
	Ltrs/sec	Ltrs/sec
28-Apr-20	4.34	0.15
28-May-20	0.59	0.02
02-Jun-20	0.25	0.01
24-Jun-20	2.72	0.02
09-Jul-20	1.76	0.03
06-Aug-20	1.14	0.04

Figure 5.4-10. Flow calculations at Coilte Culvert v PD GW 2020.

These measurements indicate a low flow value of 0.25 litres/sec for 2nd of June, during the same period flows at PD GW were 0.01 litres/sec. These flow values can be considered low flow or base flow values and indicate an ecosystem under extreme stress. There is no relationship between the flow values measured at both points; it is suspected that this is mainly due to the significant drawdown of water from the drain by woodland along the riparian zone of the peripheral drain.

The saline solution was found to be an ideal method of flow measurement and an especially good practice in assessing the flow volume of a stream before investing time and resources in a permanent structure that may not be suitable for future extreme flow event such as low and high flows. In order to calculate how much of the water budget of the site is being lost through the vegetation it is particularly important that this peripheral drain flow is measured accurately.

Figure 5.4-11 Standpipe 1 (SP1).

Two stand pipes (SP1 and SP2) have been established as part of the monitoring network in the main drain (and a third SP3, in the drainage sump in the inner area of the bog) and were also monitored as part of the regular monitoring program (**See Appendix 1, Figure 9 for monitoring locations**). It is hoped that once the flows can be accurately measured using the salinity logger, a stage discharge curve can be developed, measuring flowrates and water depths in the main drain. All piezometers and stand pipes on site had a measuring notch cut into the top of the vertical poly-pipe (see **Figure 5.4-11)** to ensure that always during monitoring rounds, water levels will always be taken from exact sample point to limit the errors. An attempt to establish a rating curve to match the standpipe water level at (SP1) to the flows of either the PDGW or the Coilte Culvert based on the equation provided in the National River Flow Archive (https://nrfa.ceh.ac.uk/ratings-datums) was attempted during this research, and appears to be working better with the wet weather and the peak flows rather than with the low flow values in PD GW, but lacks consistency. The peripheral drain can "back-up" with water during the low flow times and hence erroneous relationship readings between water level and flow readings for Coilte Culvert or PD GW. Presently it is thought that one would need many more points to develop a reliable rating curve. The calculation sheet can be found in the **Supplementary Report Material Folder.**

Groundwater Level Monitoring Data 5.5

Standpipe and piezometer water levels from across the AOI can be seen in **Figure 5.5-1** below and demonstrate the contrasting water levels of a wet and dry period on the Drummin Bog AOI environment. Two things of particular interest here are the MW01 is seasonally artesian (Feb to Mar 2020) suggesting the penetration during drilling of a confined aquifer layer. This is significant as it suggests that there is an upward pressure of ground water from beneath the peat and lacustrine clays units as suggested by the granular fill material in the geophysical survey. Secondly, it demonstrates that the groundwater environment beneath the AOI is a very dynamic environment.

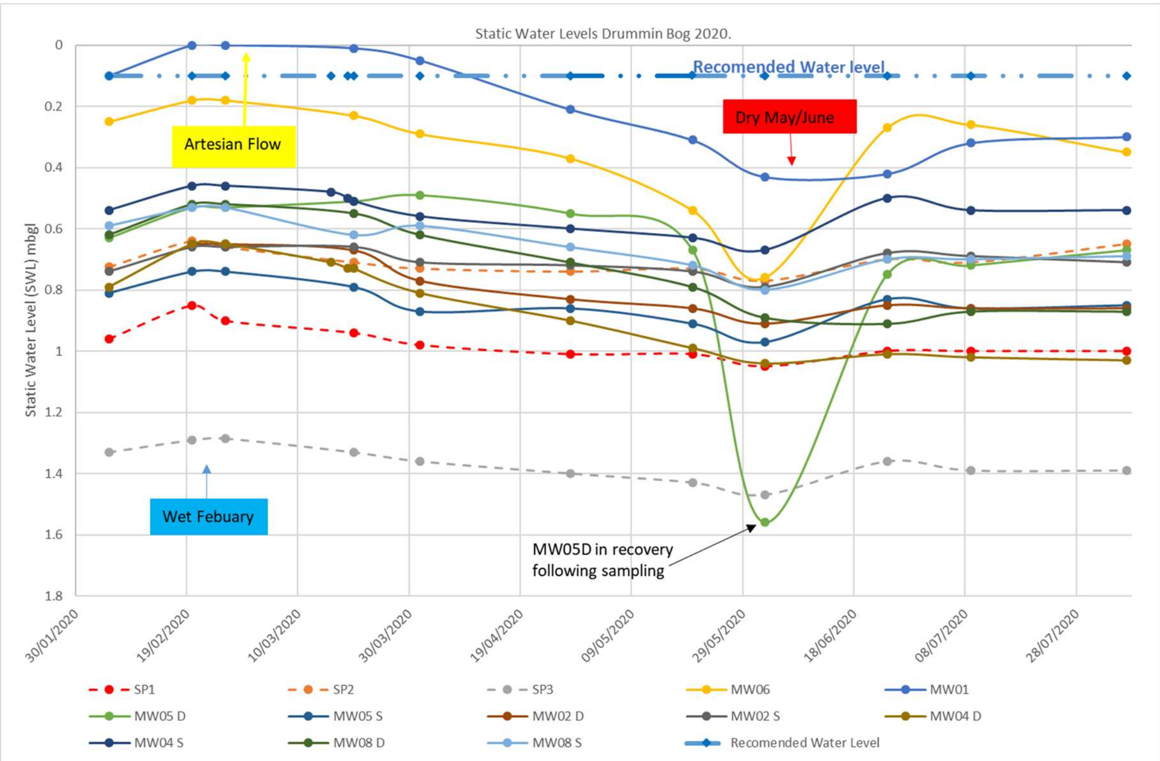


Figure 5.5-1 Piezometer & Standpipe Water Levels

It is important to note (at this point) that low flow sampling of MW05 "Deep" and "Shallow" and MW04 "Deep" and "Shallow" occurred on the 25th of May 2020. MW05D exhibited significant drawdown and hence what appears in **Figure 5.5-1** as a significant negative environmental impact to ambient water level at this monitoring point, is in actual fact the dynamic water level recovering following purging and not the effect of climatic influence. MW02S showed the least SWL change at 0.13m, while MW06 showed the greatest fluctuation at 0.58m. MW06, which was not sampled but shows significant impact of dry weather and recharge is interesting as at the confluence main peripheral drain before it leaves the site.

Figure 5.5-2, below shows the hydrograph for MW04 Deep and Shallow piezometers. Manual dips collected intermittently are used to calibrate and check data sets.

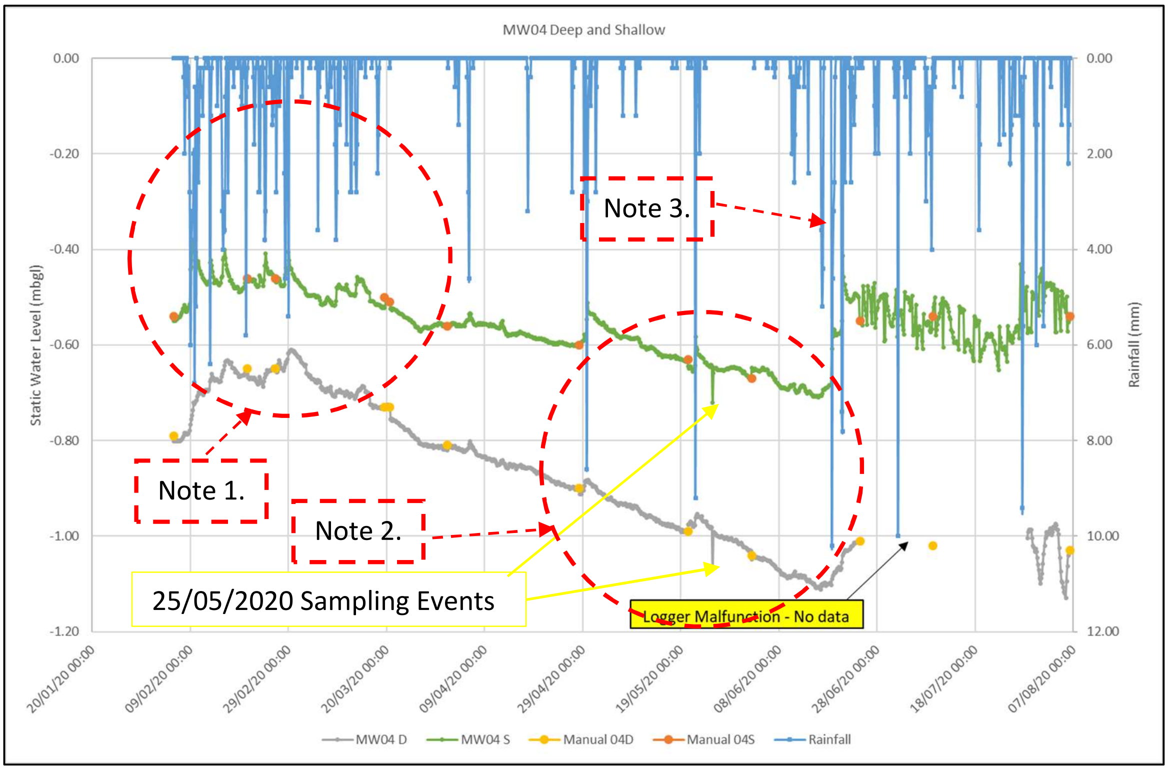


Figure 5.5-2 MW04 Deep and Shallow Hydrograph.

Note 1. *Storms Ciara, Denis and Jorge make impact. Rainfall was 302% of 30 year LTA at local met synoptic station for Feb 2020.*

Note 2. *Rainfall was 22% of 30 year LTA at local met synoptic station for May 2020.*

Note 3. *Following drought period, significant rainfall causes recharge response.*

Response of water levels to precipitation events is a lot less "flashy" at MW05 Deep and Shallow than MW04 Deep and Shallow. This is thought to be due to the depth of the various piezometers.

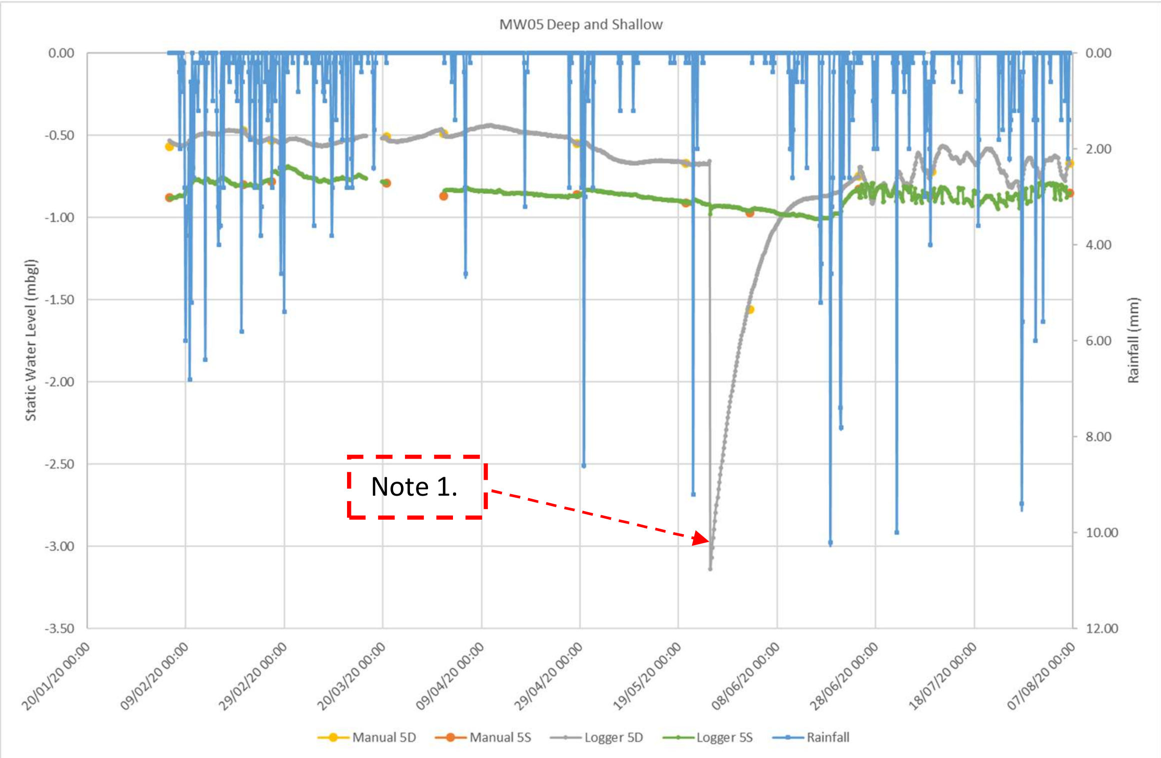


Figure 5.5-3 MW05 Deep and Shallow Hydrograph

Note 1. *MW05 Deep was significantly impacted by sampling, making a partial recovery before recharge occurs. While unintentional the data gives good insight into the hydraulic conductivity of the lacustrine clay unit at this location as will see later in the research.*

Name	Depth (mbgl)	Screen (m)
MW04D	3.9	3.4-3.9
MW05D	4.5	4.0-4.5
MW04S	2	1.0-2.0
MW05S	2.9	1.9-2.9

Figure 5.5-4 Piezometer screen depths at transducer site locations

Hydrochemistry Sampling 6.0

On the 26th of May 2020, six locations were sampled. No.4 piezometer locations, the drainage pipe at PD GW and the peripheral drain surface water Coilte Culvert which exits the site discharging into a tributary of the Aughavaud River. The piezometer locations as already stated were MW04 Deep and Shallow, MW05 Deep and Shallow. The reason this date was chosen to undertake the work was the summer dry period was ongoing and it was felt to be the best time in which to get a truly representative sample of low flow conditions on site. Due to relaxing in Covid-19 restrictions, this allowed Van Walt (UK) to provide a low flow sampling unit and YSI multi probe (with flow through cell) in order for the sampling to be conducted in accordance with best practice. A bladder pump had been the preferred option but with projects and sites still closed across UK and Ireland only the Eijkelkamp 12v Peristatic Pump was available, which worked very well.

Quality Control and Set-up. 6.1

The purpose of the sampling was to obtain representative water samples from as close to their natural environment as possible; and in the case of the piezometer samples try not to dewater the piezometers and jeopardise ongoing water level monitoring. Prior to sampling calibration checks were undertaken on the YSI multi probe to ensure field data measurements could be verified (records of these checks are contained in **Supplementary Report Material Folder**).

The YSI was fitted with pH, Conductivity, Redox and Turbidity sensors. There was however no way to calibrate/check the turbidity sensor. Due to Covid-19 restrictions, no individual turbidity cases with calibration fluids were available.

Sampling Activity 6.2

Field data capture sheets (FDCS) were drafted to ensure that the maximum consistent amount of data was collected at all times in all locations. Copies of the field data sheets and Standard Operating Procedures from the US EPA which were used for the purging and sampling methodologies are to be found in **Supplementary Report Material Folder**.

Following pre-sampling final checks, it was time to commence sampling, filling out the FDCS as the sampling set-up was undertaken. The setup is best described in **Photo 6.2-1** below.

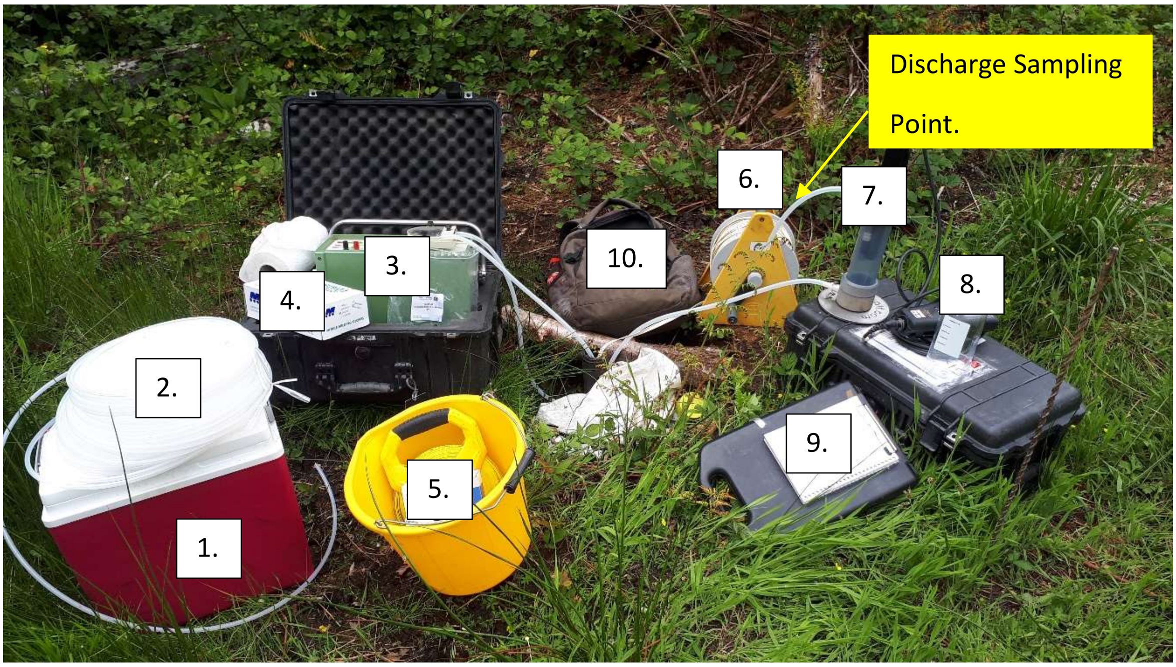


Photo 6.2-1 Sampling Set-up.

The various items in **Photo 6.2-1** are described in **Table 6.2-2** below.

Item	Purpose	Item	Purpose
1	Cooler box, ice packs & bottles	6	Dip meter
2	6mm diameter silicone tubing	7	Flow through cell
3	Peristatic pump unit	8	YSI multi probe
4	Nitrile gloves	9	FDCS notes and stationary
5	Measuring bucket	10	Field bag

Table 6.2-2 Sampling equipment and set-up.

Once sufficient field physiochemical criteria, as set out in **Table 6.2-3** below had been established samples were collected.

Turbidity (10% for values greater than 5 NTUs; if three Turbidity values are less than 5 NTUs, consider the values as stabilized),
Dissolved Oxygen (10% for values greater than 0.5 mg/L, if three Dissolved Oxygen values are less than 0.5 mg/L, consider the values as stabilized),
Specific Conductance (3%),
Temperature (3%),
pH (± 0.1 unit),
Oxidation/Reduction Potential (±10 millivolts).

Figure 6.2-3 US EPA Low Flow Sampling Field Parameter Values.

Field Sampling Discussion 6.3

Only in the case of MW05D was there significant drawdown of the water level MW05D was pumped first at 0.003 l/sec whereas the subsequent ones were pumped at 0.002 l/sec, which was the lowest pumping rate attainable.

The main benefit of the flow through cell is that it allows the continuous analysis of the purge water in a stable and controlled manner, secondly it prevents the samples from becoming aerated on discharge from the piezometer giving a more representative sample of the anoxic and reducing environment from where the samples originated. Once groundwater sampling was complete at the piezometers was complete, the Coilte Culvert (CC SW) was sampled and also PD GW.

The turbidity probe was not functioning correctly during the sampling work and hence only the visual description is accurate rather than the values for formazin units recorded and hence are not included in the results but are recorded in the FDCS's. It is possibly because it was not housed in a dark (light proof chamber). The flow through cell is transparent and hence the photo sensor on the probe does not work efficiently. The samples collected can be seen in **Figure 6.3-1** below.

Figure 6.3-1 Samples (L-R) MW05S, MW05D, MW04S, MW04D, (CC SW), PD GW

The samples were dispatched within 8 hours to an accredited laboratory for analysis for a specified range of parameters.

Laboratory Results 6.4

The results of field parameters and the laboratory samples are presented below in **Tables 6.4-1 and 6.4-2**. In the tables are the various parameters analysed for. All laboratory issued reports and sampling methods can be found in **Supplementary Report Material Folder**.

Laboratory sample quality control included blank sample, duplicate, matrix spike and a laboratory control sample. The Limit of Reporting (L.O.R) in some cases is different due to the method of analysis used to process the sample. This was due to the variation in levels of suspended solids in some of the samples, that not all samples could be analysed using the same process.

Drummin Bog. Hydrochemistry 26/05/2020									**SI No.9 of 2010**
Purged Sample Field Data	**Units**	**L.O.R.**	**MW04D**	**MW04 S**	**MW05 D**	**MW05 S**	**PD GW**	**CC SW**	
Temp	**oC**	N/A	11.5	11.3	10.8	10.8	10.9	12.2	
DO	**%**	N/A	4.3	9.3	3.3	4.2	76.5	61.5	
Specific Conductivity. (SPC)	**µS/cm**	N/A	422.5	74.7	765	301.3	582	245.3	
Total Dissolved Solids. (TDS)	**mg/l**	N/A	274.6	48.6	497.3	195.8	378.3	159.4	
pH	**pH**	N/A	6.43	4.28	6.95	5.78	6.85	6.85	
ORP	**mV**	N/A	-58.1	144.2	-135.1	35.5	121.8	121.8	
Colour, odour, sheen		N/A	Slightly Opaque	Peat/Opaque	Clear	Peat/Opaque	Clear	Opaque	
Laboratory Analysis Results. Aggregate Parameters. Drummin Bog. 25/05/2020									
Alkalinity Total CaCO3	mg/l	N/A	**200**	**20**	**358**	**132**	**274**	**98**	
Alkalinity Total HCO3	mg/l	N/A	**244**	**24**	**437**	**161**	**334**	**120**	
Ammonia	mg/l	N/A	**6.68**	**1.26**	**26.65**	**12.68**	**0.63**	**0.04**	
BOD 5 day Total	mg/l	N/A	**15**	**7**	**55**	**23**	<5	**3**	
Chloride	mg/l	N/A	**14.9**	**15.1**	**19.6**	**17**	**13.7**	**18.3**	**24 - 187.5**
COD Total	mg/l	N/A	**74**	**192**	**68**	**244**	**15**	**53**	
Nitrate	mg/l	N/A	**19.5**	<1.0	<1.0	<1.0	<1.0	**1.6**	
Nitrite	mg/l	N/A	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Orthophosphate	mg/l	N/A	**0.06**	**0.02**	**1.41**	**0.08**	**1.32**	<0.02	
Sulphate	mg/l	N/A	<5.00	**5.79**	**5.86**	<5.00	**18.26**	<5.00	**187.5**
Suspended Solids	mg/l	N/A	**64**	**9**	**27**	**60**	<5	<5	
Total Organic Carbon	mg/L	0.50	**17.4**	**59.5**	**11.0**	**24.6**	**8.06**	**19.8**	
Dissolved Metals / Major Cations									
Parameter	**Units**	**L.O.R.**	**MW04D**	**MW04 S**	**MW05 D**	**MW05 S**	**PD GW**	**CC SW**	
Aluminium	mg/L	0.010	**0.074**	**0.163**	<0.010	<0.010	<0.010	**0.060**	0.15
Antimony	mg/L	0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	
Arsenic	mg/L	0.0050	**0.0111**	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.0075
Barium	mg/L	0.00050	**0.0223**	**0.00434**	**0.0170**	**0.0181**	**0.00916**	**0.00447**	
Cadmium	mg/L	0.00040	<0.00040	<0.00040	<0.00040	<0.00040	<0.00040	<0.00040	0.00375
Calcium	mg/L	0.0050	**49.7**	**1.35**	**70.2**	**24.6**	**90.3**	**31.5**	
Cobalt	mg/L	0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	
Copper	mg/L	0.0010	<0.0010	**0.0050**	<0.0010	**0.0016**	**0.0016**	**0.0016**	1.5
Iron	mg/L	0.0020	**0.988**	**0.982**	**0.0500**	**0.262**	**0.0226**	**0.119**	0.2
Lead	mg/L	0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	0.01875
Magnesium	mg/L	0.0030	**4.04**	**1.82**	**6.22**	**2.28**	**9.09**	**7.00**	
Manganese	mg/L	0.00050	**1.24**	**0.0185**	**1.81**	**0.127**	**0.418**	**0.00242**	
Mercury	µg/L	0.010	<0.010	**0.014**	<0.010	<0.010	<0.010	<0.010	0.00075
Nickel	mg/L	0.0020	**0.0022**	**0.0108**	**0.0041**	<0.0020	**0.0021**	**0.0024**	0.015
Potassium	mg/L	0.015	**1.55**	**0.428**	**3.88**	**1.81**	**1.58**	**0.331**	
Silicon	mg/L	0.010	**3.85**	**0.332**	**8.67**	**8.56**	**4.79**	**2.52**	
Sodium	mg/L	0.030	**16.6**	**4.38**	**28.6**	**7.50**	**10.0**	**9.21**	150
Strontium	mg/L	0.0010	**0.0686**	**0.0092**	**0.102**	**0.0340**	**0.114**	**0.0520**	
Tin	mg/L	0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	

Note 1: Cells highlighted in bold font indicate values above L.O.R values.

Note 2: Cells highlighted in bold and red infill font indicate values above guidance thresholds.

Table 6.4-1 Laboratory Analysis Results, Part 1

Total Metals / Major Cations	Units	L.O.R.	MW04D	MW04 S	MW05 D	MW05 S	PD GW	CC SW	
Aluminium	mg/L	0.010	1.41			0.212			
Aluminium	mg/L	0.010		0.375	0.032		<0.010	0.072	
Antimony	mg/L	0.020	<0.020			<0.020			
Antimony	mg/L	0.010		<0.010	<0.010		<0.010	<0.010	
Arsenic	mg/L	0.010	<0.010			<0.010			
Arsenic	mg/L	0.0050		<0.0050	0.0072		<0.0050	<0.0050	
Barium	mg/L	0.00050	0.0294			0.0267			
Barium	mg/L	0.00050		0.00499	0.0588		0.00897	0.00459	
Cadmium	mg/L	0.0020	<0.0020			<0.0020			
Cadmium	mg/L	0.00040		<0.00040	<0.00040		<0.00040	<0.00040	
Calcium	mg/L	0.050	50.6			28.3			
Calcium	mg/L	0.0050		1.41	73.5		90.6	31.5	
Cobalt	µg/L	0.0020	<0.0020			<0.0020			
Cobalt	mg/L	0.0020		<0.0020	<0.0020		<0.0020	<0.0020	
Copper	mg/L	0.0010		0.0066	0.0023		0.0016	0.0015	
Copper	mg/L	0.002	0.0029			<0.0020			
Iron	mg/L	0.0050	5.02			4.56			
Iron	mg/L	0.0020		1.14	8.45		0.0654	0.165	
Lead	mg/L	0.0050		<0.0050	<0.0050	<0.0051	<0.0050	<0.0050	
Lead	mg/L	0.01	<0.01						
Magnesium	mg/L	0.0030		1.89	6.36		9.12	6.99	
Magnesium	mg/L	0.02	4.35			2.65			
Manganese	mg/L	0.00050		0.0199	2.20		0.421	0.0172	
Manganese	mg/L	0.00050	1.38			0.195			
Mercury	mg/L	0.020	<0.020			<0.020			
Mercury	mg/L	0.010		0.020	0.017		<0.010	<0.010	
Nickel	mg/L	0.005	<0.005			<0.005			
Nickel	mg/L	0.0020		0.0120	0.0044		0.0026	0.0022	
Potassium	mg/L	0.015	1.75			2.1			
Potassium	mg/L	0.015		0.484	4.12		1.59	0.327	
Silicon	mg/L	0.010		0.699	9.04		4.80	2.56	
Silicon	mg/L	0.6	5.92			10.1			
Sodium	mg/L	0.030		4.48	29.6		10.2	9.38	
Sodium	mg/L	0.03	17.9			8.76			
Strontium	mg/L	0.0010		0.0098	0.112		0.114	0.0521	
Strontium	mg/L	0.001	0.0719			0.0385			
Tin	mg/L	0.01	<0.010			<0.010			
Tin	mg/L	0.010		<0.010	<0.010		<0.010	<0.010	

Tablee 6.4-1 Laboratory Analysis Results, Part 2

Laboratory Results Discussion 6.5

The water sample temperatures on the day of sampling range from 10.8 to 13.6° C, with a mean of 11.3° C. The pH was found to have a mean of 6.2 units and a range of 4.28 (MW04S) to 6.95 (MW05D) units. The SPC values are as one would expect from the various sample points; highest in deep piezometers and PD GW and lower in the shallow piezometers and peripheral drain. There is however a contrast is noticed for MW04S and MW05S reading 74.7 and 301.3 µs/cm respectively, these sample points are c.150m apart and both in shallow peat. It is interesting to also note that MW05D also has the most elevated SPC value of 765.0 µs/cm. This contrast is also noted for the shallow piezometers alkalinity values with MW05S being almost 3 times that of MW04S. All values for Dissolved Oxygen (DO) were very low for piezometer samples as would be expected and displayed signs of aeration for samples which did not use the flow though cell. Both MW04D and MW05D had the lowest values for ORP, indicative of water devoid of dissolved oxygen due to cations being in their least charged form. TOC values are elevated particularly in the shallow piezometer samples; this however would be considered normal due to the presence of humic and fulvic material relating to the decomposition of plant matter. According to Younger, (Groundwater in the Environment), Groundwater fed by recharge through peat and similar soils can often pick up a high TOC >10mg/l.

The level of calcium is very low in MW04S, Total = 1.41mg/l, the next value above this is MW05S which is 28.3mg/l. The lab was re-checked and re-tested this sample but give assurances it was correct. It also has the lowest magnesium, manganese and strontium, but the highest nickel and mercury. The subject of MW04S is discussed further in next section in terms of anion-cation balance check.

Finally, a comment on flow rates of various sample points. The piezos were sampled between 0.002 and 0.003 ltrs/sec following stabilisation of field parameters. PD GW recorded a flow of 0.02ltrs/sec and CC SW (Coilte Culvert) 0.6ltrs/sec.

Laboratory Results Analysis 6.6

On receipt of sample results from the laboratory a cation-anion balance check was undertaken as a quality control check. The details can be seen in **Table 6.5-1** below;

Parameters	MW04D	MW04 S	MW05 D	MW05 S	PD GW	CC SW
	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L
Calcium	2.52	0.07	3.67	1.41	4.52	1.57
Magnesium	0.36	0.16	0.52	0.22	0.75	0.58
Sodium	0.78	0.19	1.29	0.38	0.44	0.41
Potassium	0.04	0.01	0.11	0.05	0.04	0.01
Nitrate (Amonical Nitrogen N)	0.48	0.09	1.92	0.91	0.05	0.00
Cations Σ	***4.19***	***0.52***	***7.50***	***2.98***	***5.80***	***2.57***

Parameters	MW04D	MW04 S	MW05 D	MW05 S	PD GW	CC SW
	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L
Alkalinity Total (CaCO3)	4.03	0.40	7.21	2.66	5.52	1.97
Sulphate	0.10	0.12	0.12	0.10	0.38	0.10
Chloride	0.42	0.43	0.55	0.48	0.39	0.52
Anions Σ	***4.55***	***0.95***	***7.88***	***3.24***	***6.28***	***2.59***

	MW04D	MW04 S	MW05 D	MW05 S	PD GW	CC SW
	-4.17	-28.85	-2.47	-4.23	-4.00	-0.53
	Good	Poor	Good	Good	Good	Good

Figure 6.5-1 Cation-Anion Balance Check

Five of the six samples gave favourable results within a negative 5% range. MW04S however is problematic. The field sampling was done accurately and carefully following guidelines. The laboratory was asked to recheck sample which was done and no changes made. It is advised at this time that this sample is untrustworthy based on this check.

An ion bar diagram shows a strong symmetry between MW05D and PD GW and a very low ionic presence of MW04S in **Figure 6.5-2** below

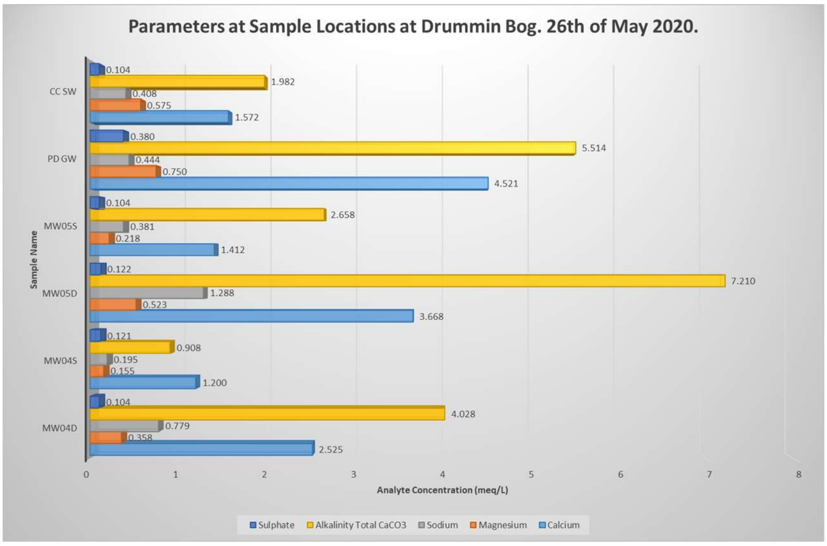
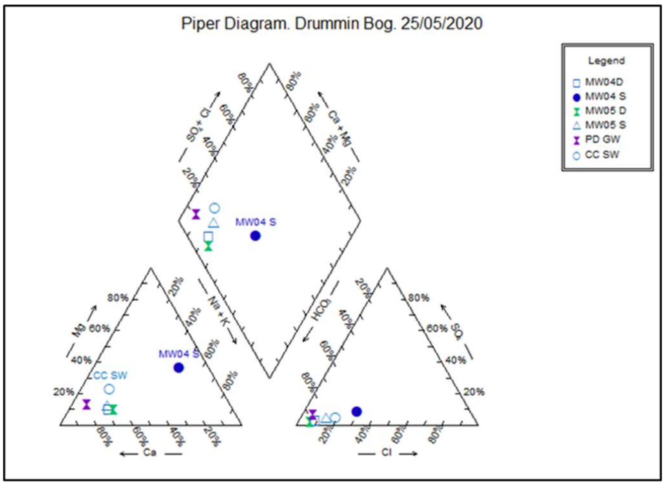


Figure 6.5-2 Ion Bar Diagram

Finally, the data was plotted up on trilinear Piper and Durov Diagrams in **Figures 6.5-3 and 6.5-4** below.



When plotted to a Piper diagram; the results indicate samples which are typical of shallow, fresh ground waters. Sample MW04S has very low Calcium, which is tending to distance it from the other samples.

Figures 6.5-3 Piper Diagram

In the Durov chart the samples are all found to be in the top 80% of HCO3 for alkalinity. The samples for the shallow piezometers and the surface water discharge are lower values for TDS <250mg/L, while the deeper piezometers and the spring sample of PD GW are found to lie between 300 and 600 TDS.

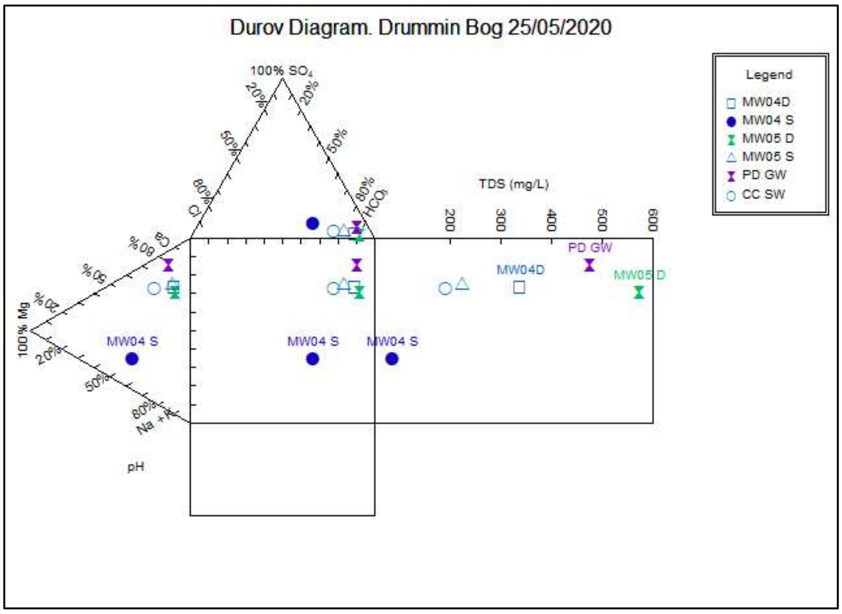


Figure 6.5-4 Durov Diagram

Hydraulic Conductivity 7.0

An important part of the characterisation work on the Drummin Bog AOI was to acquire values for the hydraulic conductivity of the peat. The peristatic pump and sampling equipment on site was to undertake Rising Head Tests.

Two shallow piezometers were chosen, MW02S and MW08S, both were pumped at increments until dry. The discharge water was processed through a flow through cell to get extra information on site water quality. A third piezometer had significant drawdown during sampling and this data was also utilised to attain hydraulic values for MW05D. See **Figure 7.0-1** below for locations.

Figure 7.0-1 Red circled locations indication Rising Head Test Piezometers.

Pumping rates & discharge rates were recorded both manually and electronically using data loggers. When the piezometer was pumped dry, the pump was switched off and recovery commenced being monitored by the data logger. Data sheets can be found in **Supplementary Report Material Folder**. Data analysis was undertaken using Aqtesolv software. The results of the tests indicating values for test locations are contained in **Table 7.0-2** below.

Test	**Units**	**MW02S**	**MW08S**	**MW05D**
Piezometer Depth	*m*	2.2	2.4	4.5
Screen	*m*	1	1	0.5
Target Unit	*N/A*	Peat	Peat	Clay
Pump Discharge	*ltrs/sec*	0.003	0.008	0.003
Recovery Time	*minutes*	235	220	41,760
Bower & Rice	*(m/day)*	0.051	0.10	$1.5*10^{-3}$
Hvorslev	*(m/day)*	0.081	0.12	$1.5*10^{-3}$

Table 7.0-2. Rising Head Test Data Table.

Physiochemical data was also recorded using the YSI unit and flow through cell. All the field physiochemistry data is presented in **Table 7.0-3** for discussion. It is important to recall at this point, that MW01 piezometer was found to be seasonally artesian. Its location is shown in the yellow circle in **Table 7.0-1.** It penetrated the sandy granular fill below the lacustrine clay layer tested in MW05D, which would indicate that the low hydraulic conductivity lacustrine clay unit found in MW05D is acting as an aquitard restricting the flow of water vertically from the peat zone to the clay zone. These values are all comparable to those discussed in the literature review earlier.

The field physiochemistry of the three test sites is given below.

Piezo ID	**Temp**	**DO**	**SPC**	**pH**	**ORP**
Units	**C**	**%**	**µs/cm**	**Units**	**mV**
MW02S	10.8	14.4	78.6	4.43	126.2
MW08S	9.8	11.8	108.6	5.2	72.6
MW05D	10.8	3.3	765	6.95	-135.1

Table 7.0-3 Physiochemical values following pumping at MW02S, MW08S and MW05D

The values for MW05D all indicate a very slow moving anoxic, reducing ground water environment. Water that has taken time to infiltrate this clay unit absorbing lots of ions with an SPC value of 765 µs/cm. Almost no oxygen and a redox value of -135.1mv. In addition to this information it is proven to have a hydraulic conductivity of $1.5*10^{-3}$ m/day. Contrast that with the shallow peat waters of MW02S and MW08S, acidic, low oxygen environments, low SPC suggesting water that has not been long in the peat unit; young water in an oxidised environment and a positive redox value to verify this. Hydraulic testing showing a range of hydraulic conductivity values indicating great flow within the peat test unit.

Another observation is the hydraulic conductivity of MW02S is slightly lower than that of MW08S, there may be two reasons for this. Firstly, MW02S is closer to the edge of the bog than MW08S and the peat is drier and more compacted from drainage and desiccation due to proximity to drains. Secondly, the peat in the area of MW02S would have been artificially compacted in years past by the presence of an excavator working on the drainage channel close by.

Climatic Data 8.0

Climatic (or historical weather data) was collected from the Met Eireann Synoptic Station at Oak Park, Co. Carlow. There are two synoptic stations similar distance from Drummin WS. Oak Park 43km north (inland) and Johnstown Castle, 35km to the south east, 7km from the coast. The location of St Mullins in the valley of the River Barrow, c.4km south-east from Brandon Hill (Elevation 515m), means that it lies in the shadow of the Hill of Brandon as the prevailing rain systems come from the west. The data indicates that Drummin WS is being affected by similar weather influences as Oak Park rather than Johnstown Castle experiences.

Oak Park and Drummin Weather Station Comparison 8.1

It is important to establish accurately how close the relationship between both of the synoptic stations are with Drummin WS. Drummin WS which has a very recent data set can then be placed in context historically giving a more climatic aspect to the data set.

A statistical analysis of maximum and minimum temperature for both stations' data indicates a closer statistical relationship with Drummin and Oak Park rather than Johnstown Castle. For this reason and for the discussion herewith, climatic context of the data in relation of the Drummin Bog (WS) will only be compared to that of Oak Park, Co. Carlow. In order to demonstrate this relationship, the values for max and min temperatures are graphed in **Figure 8.1-1**, these sets of data are based on values recorded from 27th of November 2019 to 30th of June 2020. A statistical correlation of the data indicates a value of 0.96 and 0.92 for maximum and minimum temperatures respectively indicating a very strong positive relationship.

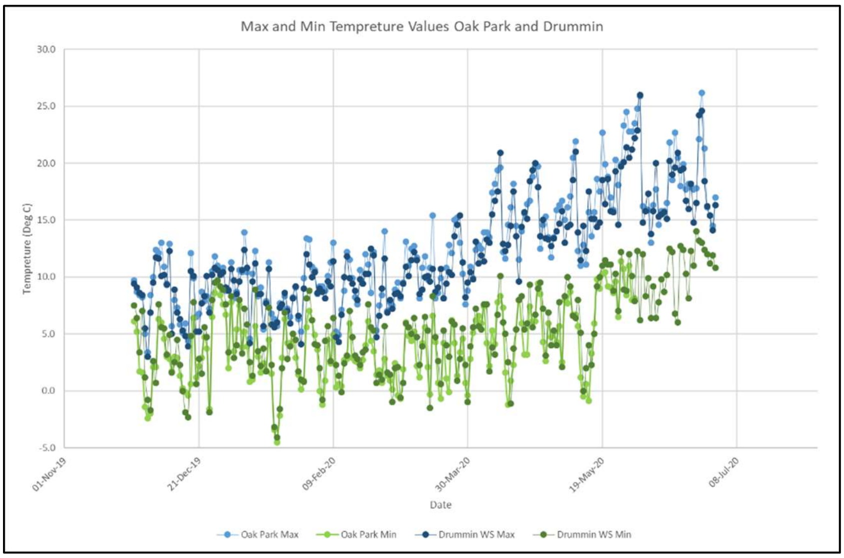


Figure 8.1-1 Max and Min Temperature Values. Oak Park and Drummin Weather Stations.

A similar comparison check was undertaken looking at the precipitation relationship for the same period. And can be seen in **Figure 8.1-2** below. The graph demonstrates clearly that both sites (though 43km apart) experience similar rainfall patterns and shows a correlation value of 0.76, which is very strong, especially considering how spatially temporal rainfall can be. These two checks now offer confidence in using Oak Park data for the historical and climatic context for this research.

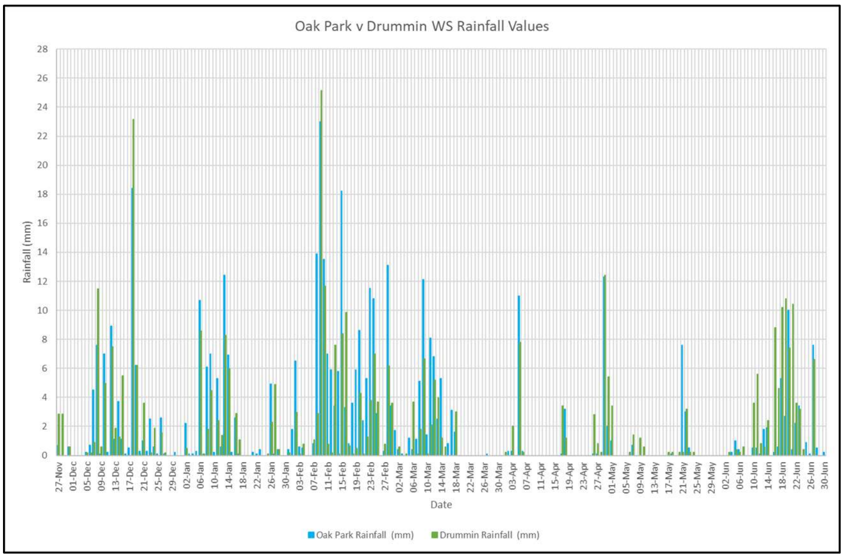


Figure 8.1-2 Precipitation Values, Oak Park and Drummin WS

Oak Park Weather Station Historical Data Sets 8.2

The available data set from Oak Park commences May 1967 to March 1997 and from August 2003 to the present day. Temperature, rainfall, atmospheric pressure and wind speed have all been recorded since 1967, and soil temperature, potential evaporation, evaporation and solar radiation since 1st of January 2008. For the purposes of this research only years of full (12 month) data sets are processed, hence 1968 to 1996 and 2004 to 2019. The data set between March '97 and August 2003 is lost and cannot be found.

Oak Park Temperature Analysis 8.3

A box plot analysis of the maximum temperature values at Oak park since 1968 is presented in **Figure 8.3-1** below. It provides a statistical breakdown of the highest temperatures during the period.

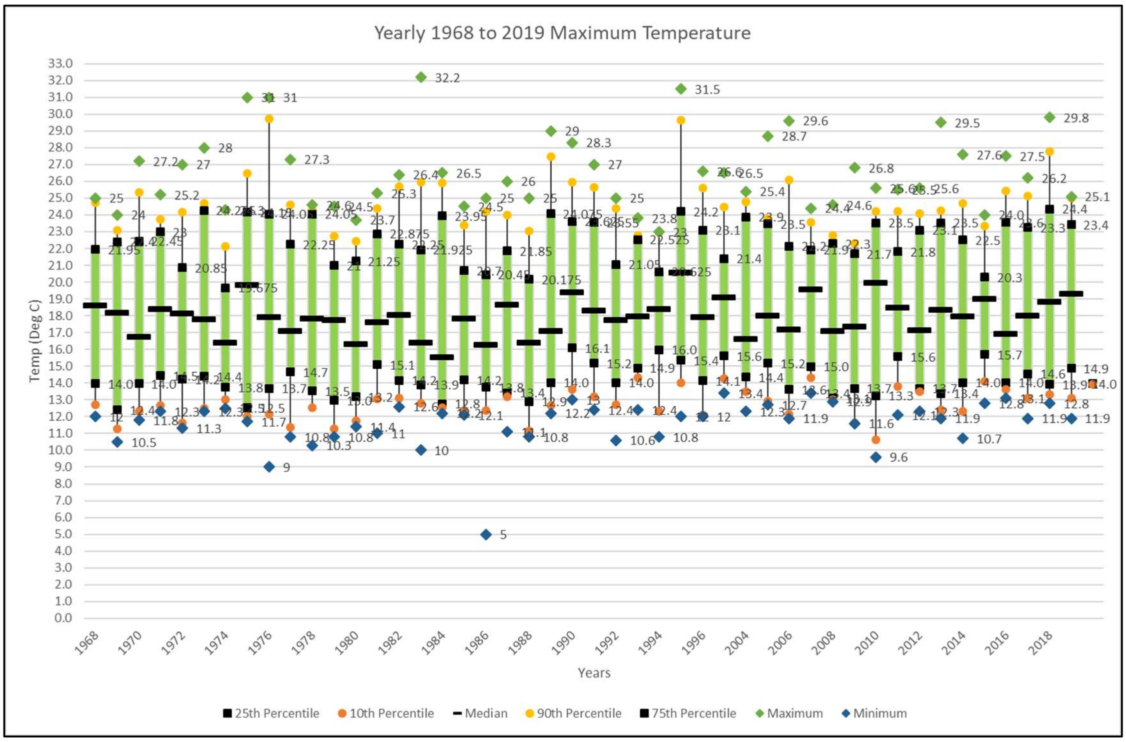


Figure 8.3-1 Yearly Maximum Temperature Values 1968 to 2019. Oak Park

The data shows four occasions when maximum temperatures recorded were above 30°C in 1975, 1976, 1983 and 1995. The data also appears to show a trend the whereby the gaps between 75%tile value and maximum temperature values is narrowing since 1995. Not only is this because the maximum temperature values have reduced slightly but temperatures have generally increased since 1995. Consecutive years appear to becoming generally warmer. For years 2010 to 2019, only one year had a 90%tile temperature value <24°C. Temperatures of 30°C plus are less common but years are trending to becoming consistently warmer. The data sets are found in **Supplementary Report Material Folder**.

An analysis of the minimum temperatures for the same time indicates a subtle increase in average minimum values. In 1978 the average minimum was 1.2, this is the only value >1°C pre 2000. The other years >1°C are 2004 to 2007, 2009, 2011,2013,2014 and 2016. The data can be seen in box plot format in **Figure 8.3-2** below.

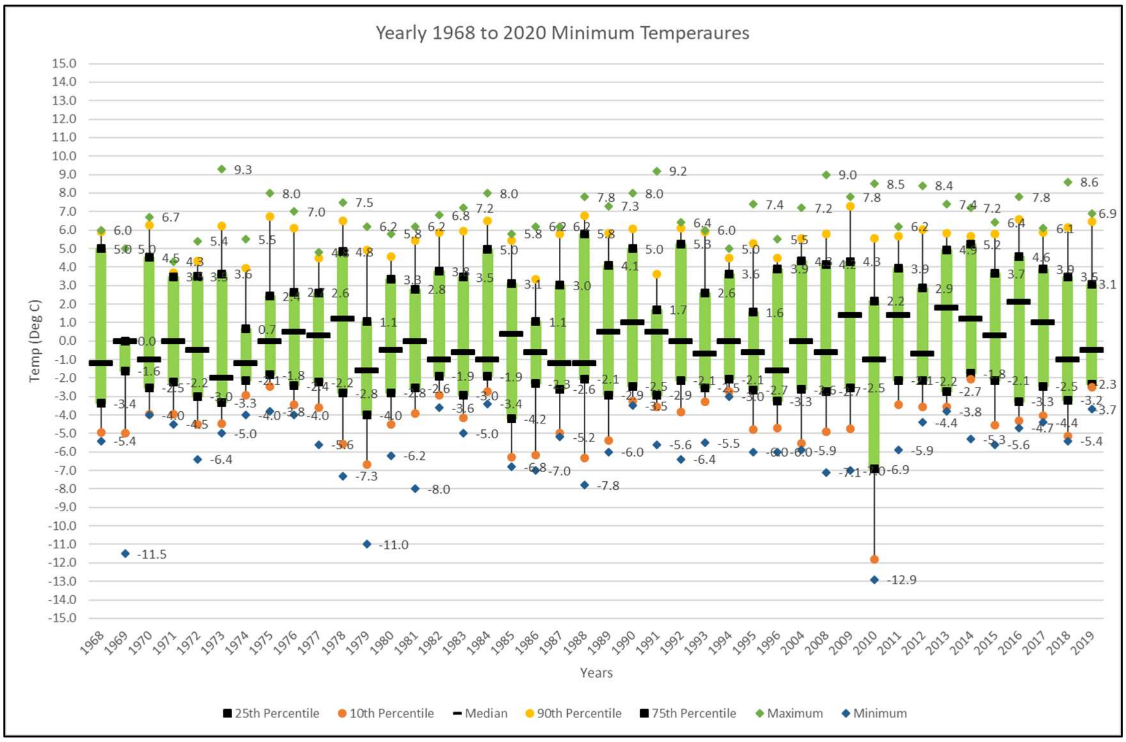


Figure 8.3-2 Yearly Minimum Temperature Values 1968 to 2019, Oak park

Oak Park Precipitation Analysis 8.4

Drummin Bog is in the rain shadow of Brandon Hill to the north-east, protecting it from the full influence of the westerly oceanic prevailing currents. See **Figure 8.3-1 below**. It does not however mean the historical Oak Park data set can't be statistically useful in giving climatic context to the meteorological events at Drummin. The correlation value described earlier is indicative of a strong alignment.

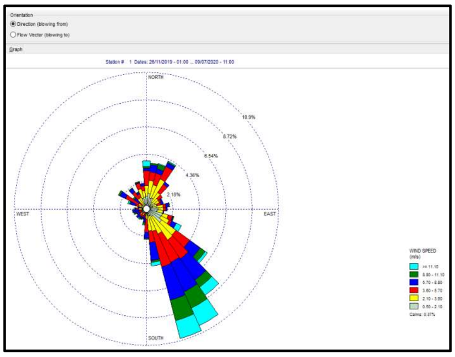


Figure 8.3-1 Wind rose values.

The data from Oak Park suggests that rainfall amounts are increasing and rainfall from erratic events more frequent. On No.12 occasions since 1968 annual rainfall maximum values were >5mm, eight of these were since the year 2000. The data sets are contained in **Supplementary Report Material Folder** and are graphed below in **Figure 8.3-1.** In 2014, 2010 and 2016 rainfall exceeded 6mm, 7mm and 8mm respectively. The figures strongly indicate a steadily increasing trend in rainfall amounts and also erratic events demonstrated by spikes in the graph.

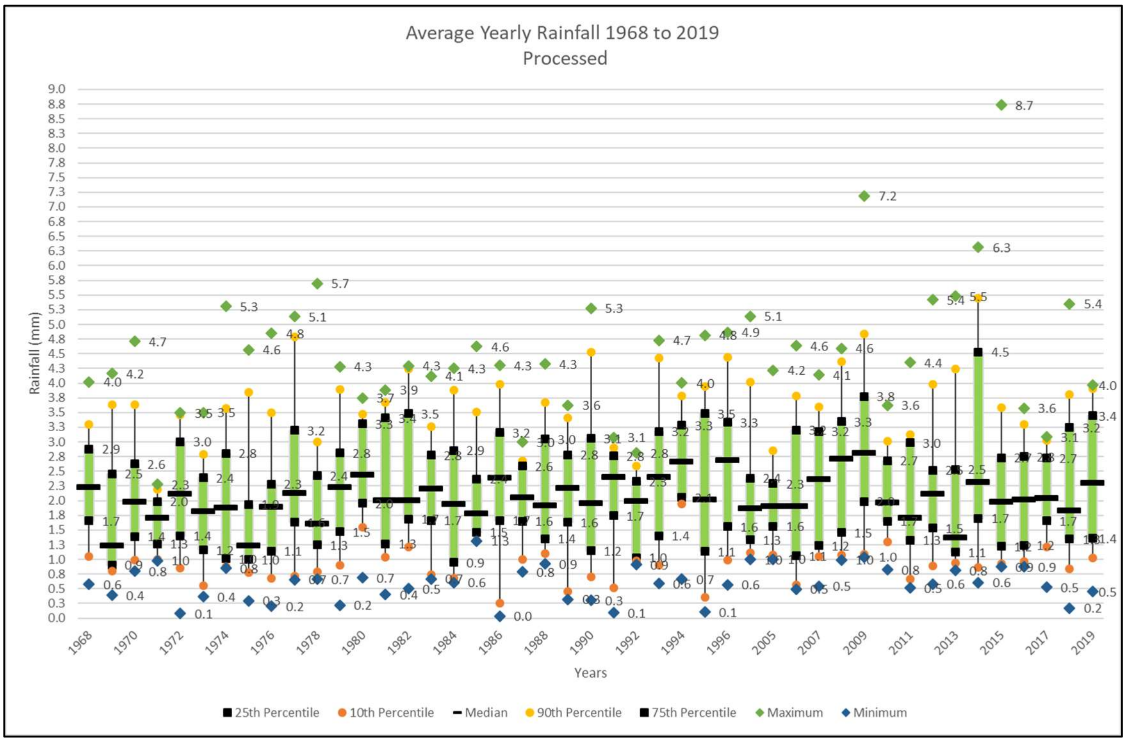


Figure 8.3-2 Yearly average rainfall data, Oak Park

A closer look at the rainfall data and an assessment of months and seasonality also demonstrates the prevalence in recent years for extreme rainfall as can be seen in **Figure 8.3-3** below. 75% of extreme rainfall events were recorded over the 12 months occurred post 2000. Seasonally November to February, August to October and March to July would be the three groupings of similar rainfall values. November has the highest rainfall values. Of note in this graph is a trend appearing in significant rainfall events during Summer months.

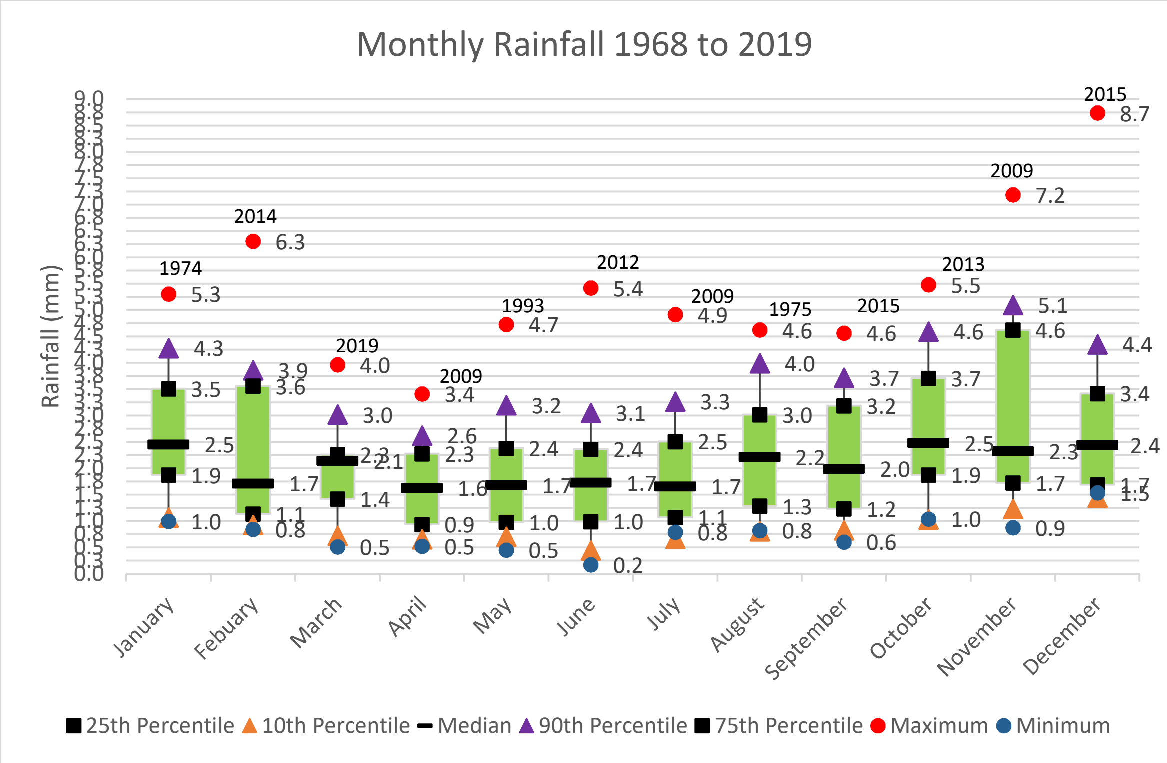


Figure 8.3-3 Monthly rainfall values, Oak Park

<u>Water Balance 9:</u>

The hydrological water balance is the most basic and fundamental of all hydrogeological equations; it is also the most commonly used.

$$P - E - Q \pm \Delta S = 0 \quad \text{or} \quad E + Q \pm \Delta S = P$$

Where P = precipitation (depth/unit time)

E = evaporation (depth/unit time)

Q = discharge (depth/unit time)

ΔS = change in storage of groundwater (depth/unit time)

It is based on the assumption that all the water entering an aquifer system is equal to that leaving it, plus or minus any change in groundwater storage (Brassington 2007). This equation can be manipulated to determine other internal values such as groundwater or various types of evaporation (soil, plants, open water etc). Estimates of recharge derived from inflow, aquifer response or outflow approaches should be incorporated in a water balance for the aquifer system to check the recharge figure is sensible in relation to the observed meteorology, groundwater level variations, abstractions and stream flows (Mistear, Banks, Clarke 2007). Effective rainfall over the study area is calculated using precipitation and potential evaporation (PE) data obtained from Oak Park.

A significant and complementary data set (to the Drummin WS) has been recording temperature and rainfall at Oak Park since 1967 and soil temperature, potential evaporation, evaporation and solar radiation since 1st of January 2008. The Drummin WS data set has been recording since 26th of November 2019. Groundwater level monitoring has been ongoing since 5th of February 2020. While flow monitoring has been undertaken it has not been possible to have the data on an ongoing basis similar to that of weather events and groundwater levels recorded on site until such time as a suitable flow monitoring system can be established. A site with such a large variation in measured flows such as rainfall, groundwater levels and springs (PDGW) cannot however be given a reliable discharge flow based on periodic spot measurements none of which occurred during a wet weather event.

Only one drain (PD GW) has been identified as a consistent inflow into the peripheral Drummin Bog AOI drain, which is sourced outside the study area. There may however be others unseen, after all a significant amount of the local (former bog) landscape has been drained. Evidence of this has already been found looking at historical maps and more modern LiDAR survey techniques.

A method of recording continuous flow is required for the peripheral drain. The channel leading to the coilte culvert is c.100m long and has a good trapezoidal profile and a base channel width of c.1.3m wide and 2m high side walls of c.60° vertical. Based on the spot flow measurements described earlier, a 22.5° v-notch weir needs to be installed in the peripheral drain with a data logger for continuous accurate flow measurements to be taken.

It is important to get an assessment of what kind of flow range is anticipated to be encountered prior to installation of such devices. A V-notch flow plate can have various notch sizes, larger angels for larger flows and vice versa. A size too small may not measure high winter flows accurately as the plate may be over-topped or be washed away; a plate too large may not measure small flows accurately as the weir flow may not clear the nape of the weir accurately. The flows recoded at the coilte culvert outflow are small and do demonstrate considerable variation however, no winter (wet weather) flows have been recorded yet. Further information on v-notch weirs can be found in " BS 1438:2008 Hydrometery – Open flow channel measurement using thin plate weirs. At least 3 months of continuous flow, water level, water flow and meteorological data is required to formulate a reliable water balance budget for the site. Due to the project work load, budget and Covid-19 restrictions it was not possible at this time for the author to properly procure and install a v-notch during the time allotted. It will be completed in the remaining months of 2020.

According to Brassington the maximum volume of water available for recharge is the *effective precipitation*, that is the total rainfall minus the losses from evapotranspiration. On the Drummin Bog AOI, evapotranspiation takes place on the land surface itself. The breakdown of land use within the AOI is 75% (five hectares) of partly drained cutaway bog (200 x 250m) and 25% (approx. two hectares) of mixed woodland and scrub. A significant area of the peripheral drain riparian zone is populated by mixed woodland and scrub. The peripheral drain is thought not only to be acting as a discharge channel from the bog but also acting as a storage and recharge reservoir for this woodland during drier summer months. These items will be elaborated upon later in recommendations.

Climate Change and Drummin Bog 10.

The start of the 21st century is likely to be defined by some of the most extreme and rapid climate changes that the country has experienced, according to the EPA. We have already seen evidence of this and discussed it earlier in Chapter 8. Fluctuating temperatures, flood events and droughts are all happening in quick succession sometime, but all happening with greater regularity, particularly since the year 2000, when climatic statistics are viewed from Oak Park. Before we can discuss the potential effects this may have on the raised bog environment and its impact on planned restoration, it would be useful to apply some method of ranking indices of climate recorded at Oak Park to put the weather data (so recent in Drummin) into a greater historical context.

Standard Precipitation Index (SPI). 10.1

The definition and classification of a period of drought has always been a challenge. The importance of monitoring and assessing water supply from general climate data beginning with precipitation is a good first step. According to McKee et al, there are five important practical issues to any analysis of drought:

- Time Scale
- Probability
- Precipitation deficit
- Application of that deficit to the five water supply variables
- The relation of the definition to the impacts of the drought.

Frequency, duration and intensity however are all functions that depend on time scale. He also states that “all points of view seem to agree that drought is a condition of insufficient moisture caused by the deficit in precipitation over the same time”. The Standardised Precipitation Index (SPI) produced by McKee at al, is based on the difference between mean precipitation for a specified time period, divided by the standard deviation where the mean and standard deviation are produced from past records.

The SPI is calculated as follows:

Yearly sets of precipitation data are prepared, ideally a continuous period of 30 years, in the case of Oak Park 1969 to 1996 and 2004 to 2019. A set of averaging periods are created to determine a set of time scales. The data set is dynamic in that each year a new value is determined from the previous year. Each of the data sets are fitted to the gamma function in order to define the relationship of probability to precipitation. Once that relationship is established from the historic records, the probability of any observed precipitation data point is calculated and used along with an estimate of the inverse normal to calculate the precipitation deviation for a normally distributed probability density with a mean of zero and a standard deviation of unity. Values of precipitation data for year 1969 to 2019 are shown in **Table 10.1-1** below:

Year	SPI Value	Year	SPI Value	Year	SPI Value	Year	SPI Value
1969	0.22	1980	0.00	1991	0.12	2009	1.13
1970	-1.56	1981	0.80	1992	-0.54	2010	2.53
1971	-0.24	1982	0.04	1993	-1.43	2011	-0.37
1972	-1.94	1983	0.60	1994	0.69	2012	-0.69
1973	-0.37	1984	-0.20	1995	1.31	2013	0.19
1974	-1.37	1985	-0.30	1996	-0.20	2014	-0.47
1975	-0.20	1986	-0.19	2004	1.05	2015	2.33
1976	-1.72	1987	0.32	2005	-0.41	2016	0.99
1977	-0.79	1988	-0.83	2006	-0.90	2017	-0.63
1978	0.76	1989	0.04	2007	-1.10	2018	-0.60
1979	-0.74	1990	-0.34	2008	0.15	2019	0.06

SPI Values	Drought Category
>0	Not of Drought Concern
0 to -0.99	Mild Drought
-1 to -1.49	Moderate Drought
-1.5 to -1.99	Severe Drought

10.1-1 SPI Values for Oak Park, 1969 to 2019. (McKee et al).

Positive SPI values indicate greater than median precipitation while negative values indicate less than median precipitation. Drought periods are represented by relatively high negative deviations. Normally the drought is part of an SPI range as demonstrated in **Table 10.1-1**. This data suggested that based on precipitation data from Oak Park, severe droughts are becoming more historical events with none registered since 1976, with an indication that years are becoming wetter.

Since the year 1969 to 2019, according to the SPI there have been three severe drought years, 1970, 1972 and 1976. There have been three years of moderate drought 1974, 1993 and 2007. Values from 0 to -0.99 “mild drought” or greater than zero or “not of drought concern” appear to becoming more frequent indicating wetter years of rainfall events.

Rainfall Anomaly Index 10.2

Due to the variability and seasonality of rainfall recorded at Oak Park, the Rainfall Anomaly Index (RAI) developed by Rooy (1965) is used to classify the positive and negative values in rainfall anomalies. It is considered an index of remarkable simplicity as it requires only precipitation data (Freitas, 2005; Fernandes et al., 2009).

RAI is calculated to analyse the frequency and intensity of the dry and wetter years in this region of Ireland. The RAI developed by Rooy (1965) and adapted by Freitas (2005) is based on the following equations:

$$\text{RAI} = 3\left[\frac{N-\overline{N}}{\overline{M}-\overline{N}}\right], \text{ For positive anomalies}$$

$$\text{RAI} = -3\left[\frac{N-\overline{N}}{\overline{X}-\overline{N}}\right], \text{ For negative anomalies}$$

- Where N= Current Yearly Rainfall,
- N=Yearly average rainfall of the historical series (mm).
- X = average ten lowest yearly precipitation values of historical series (mm).
- M = average ten highest yearly precipitation values of historical series (mm).
    - positive anomalies have their values above average and negative anomalies have their values below average.

In **Figure 10.2-1** below, the average yearly precipitation is graphed against the various yearly precipitation values. What can be observed is an increase in frequency of above average rainfall from the beginning of 2000 onwards. The drier and wetter years can also be visualised by means of a graphical representation of modified Rainfall Anomaly Values (mRAV) in **Figure 10.2-2,** allowing us to identify periods where these events are more intense based on data specific to yearly rainfall values for Oak Park.

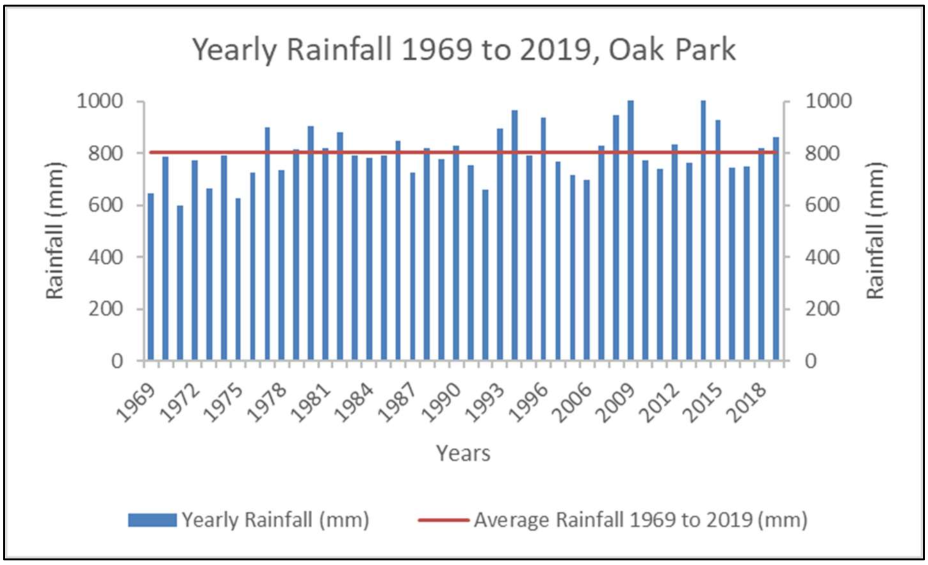


Figure 10.2-1 Annual Average Precipitation, Oak Park

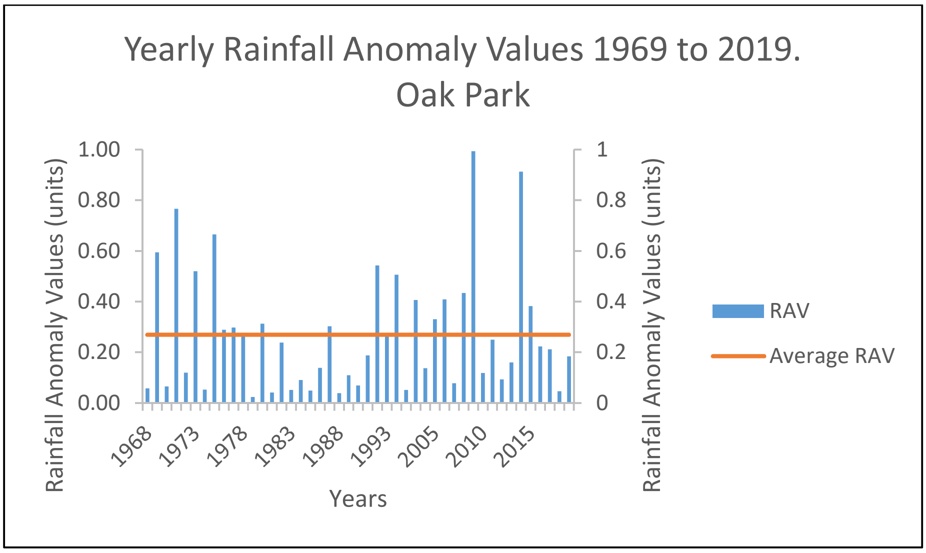


Figure 10.2-2 Rainfall Anomaly Index Values, Oak Park

The modified Rainfall Anomaly Index (mRAI) can be used as an alternative to the Standardised Precipitation Index (SPI) in evaluating future extreme precipitation characteristics. Modified value ranges are shown in **Table 10.2-3** below,

Description	RAI*	mRAI**
Extremely wet	≥3.00	>0.9
Very wet	2.00 to 2.99	0.75 to 0.9
Moderately wet	1.00 to 1.99	0.65 to 0.75
Slightly wet	0.50 to 0.99	0.55 to 0.65
Near normal	−0.49 to 0.49	0.45 to 0.55
Slightly dry	−0.99 to −0.50	0.35 to 0.45
Moderately dry	−1.99 to −1.00	0.25 to 0.35
Very dry	−2.99 to −2.00	0.10 to 0.25
Extremely dry	≤−3.00	≤0.10

RAI* = Original Definition (Van Rooy 1965)

mRAI** = Classification used in this study

Table 10.2-3. (m)RAI Value Ranges.

Modified classification index values are shown in **Table 10.2-4** below.

Year	RAV	Year	RAV	Year	RAV	Year	RAV	Year	RAV	Year	RAV
1968	0.06	1970	0.07	1980	0.31	1990	0.07	2004	0.14	2010	0.12
1969	0.59	1971	0.77	1981	0.04	1991	0.19	2005	0.33	2011	0.25
		1972	0.12	1982	0.24	1992	0.54	2006	0.41	2012	0.09
		1973	0.52	1983	0.05	1993	0.27	2007	0.08	2013	0.16
		1974	0.05	1984	0.09	1994	0.51	2008	0.43	2014	0.91
		1975	0.67	1985	0.05	1995	0.05	2009	0.99	2015	0.38
		1976	0.29	1986	0.14	1996	0.41			2016	0.22
		1977	0.30	1987	0.30					2017	0.21
		1978	0.27	1988	0.04					2018	0.05
		1979	0.02	1989	0.11					2019	0.18

RAV = Rainfall Anomaly Value

Table 10.2-4. mRAI Classification index values.

When observed, the mRAI, we can see that pre 1990 is classed as generally being extremely dry to very dry. Only 1971 is classed as being "very wet". In the 13 years of available records between 1990 to 2009 only three years are classified as being "extremely dry". In records since 2004 the trend has become less "extremely dry", which would indicate an increase in precipitation values in this time period. Also of note are 2009 and 2014 which are classed as "extremely wet", owing to extreme weather events as predicted by the EPA. There is also a trend appearing in the data where 14 years are classified as extremely dry; three of which occur after 2004, in the category "very dry" covering 12 years, seven years occur after 2004.

Conceptual Understanding 11:

The conceptual understanding of the greater Drummin bog area is not fully understood as of this point and won't be without further study of the greater Drummin bog area, especially in context of the reclaimed bog area. A well survey in the area to assess groundwater head elevations to widen out the information from the AOI itself into a broader study area and potential "zone of contribution" in delineating the sources of water feeding into the peripheral drain system to generate a water balance budget is required. It is assumed but not proven that there is more than one drain discharging into the peripheral drain.

The geophysical survey indicated a deep weathered zone of material in the south west section of the site. It is assumed that this depression in the granitic bedrock is the result of an associated fault fracture which are common in this area running in a north-south direction. The bog location is topographical "bottle neck" in the Barrow valley, wedged between Brandon Hill to the east and White Mountain to the west. As ice melt flow increased at the end of the last ice age, significant deposits of sands and gravels were washed in and deposited. Evidence is shown that in the upper Barrow catchment evidence of several ice flows as far south as New Ross. The bedrock faults and fractures in the vicinity of Drummin Bog were filled in with this fine weathered granitic sands and gravels as can be seen in **Figure 11.0-1** below.

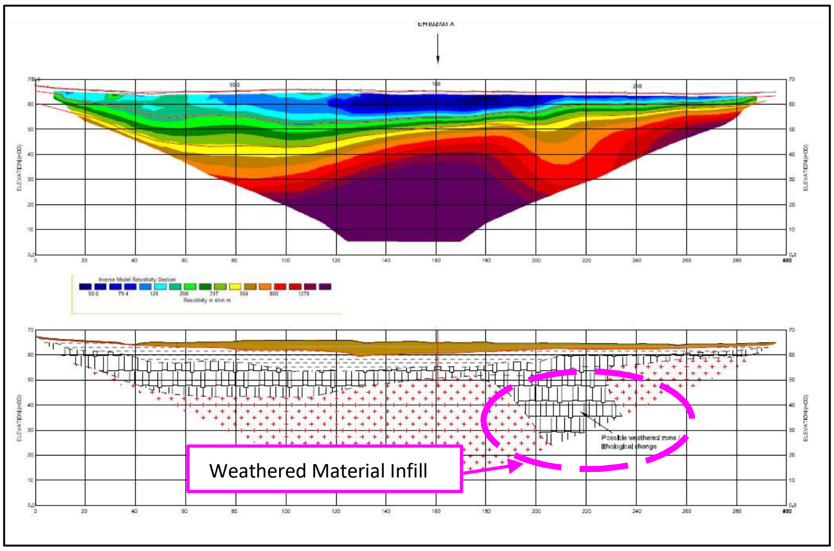


Figure 11.0-1 ERT Geophysical Transect profile.

The location of the bog on the eastern side of the Barrow River and western side of at White Mountain makes the River Barrow a hydrological boundary in terms of surface water drainage from both Brandon Hill to the east and White Mountain to the west. Recharge of water bearing fractures within the igneous rock at the foothills of White Mountain, would flow towards the Barrow River as indicated in **Figure 11.0-2** below.

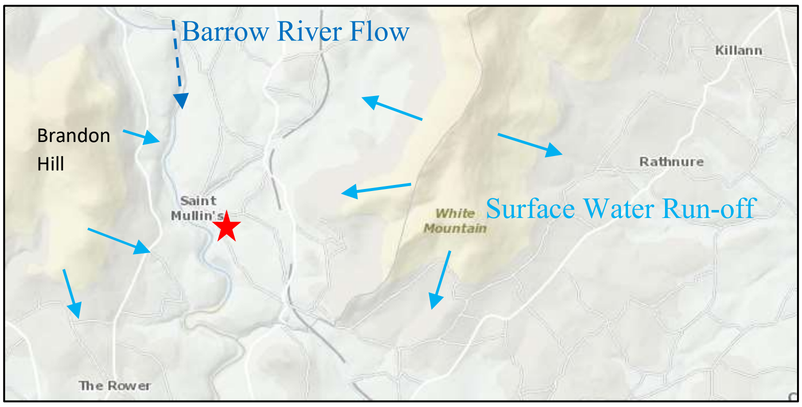


Figure 11.0-2 Rainfall run-off from White mountain and Brandon Hill.

The pressure of this recharge head at the foothills of White Mountain applying a positive hydrostatic pressure on the fracture flow in the granites at lower elevation caused early fen type peats to form.

Evidence of this was noted when observing water levels and MW01; located in the weathered zone mentioned above was found to be seasonally artesian, as the piezometer had penetrated the peat layers into the granitic till filled fissure.

Rich mineralised waters are thought to have come to surface in a series of fractures around the Drummin Bog and south to the Aughanagh River. These waters generated the conditions for fen type peat to grow filling the depressions in the granitic bedrock, eventually giving way to raised bog conditions as the seasonal springs became less effective in feeding the fen a transition to raised bog being fed by precipitation commenced. This raised bog is characterized by its dome shaped profile with peat thicknesses up to 5.7m in the thicker areas measured during this work.

The physio-chemical signatures of the various sampling events verified the different physio-water samples examined. Deeper piezometers into lacustrine clays with almost neutral pH values, very low DO and redox potential and elevated specific conductivity, while the shallow piezometers had low pH and low conductivity indicating waters of a young age from an acidic environment.

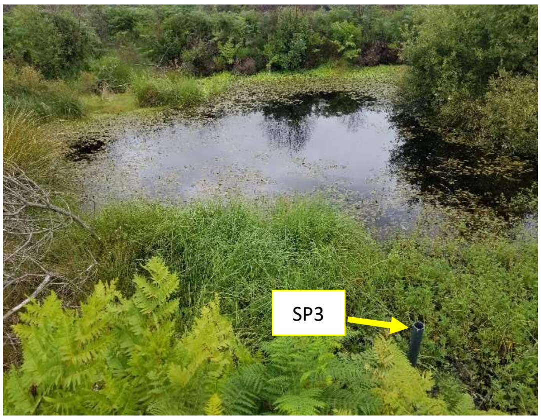


Photo 11.0-3 Drummin Pond and SP3

The rising head data also indicates two different hydraulic environments, the deeper lacustrine clays with a hydraulic conductivity value c. $1.5*10^{-3}$ m/day, while the overlying peat unit was found to vary between 0.05 m/day on the periphery of the bog and 0.12 m/day in the more central piezometer, this can be very characteristic of a raised bog where peripheral drying and drainage causes compaction inhibiting hydraulic movement within the saturated zone of the peat.

Groundwater contours of the site demonstrate that drainage excavation on the bog AOI have led to two contrasting flow patterns. A standpipe (SP3) monitoring a deep excavation at the most elevated point of the bog, See **Photo 11.0-3** above. It is from here, drains cut to the peripheral drain. Based on low flow water levels of 2nd of June 2020 groundwater contours are produced and can be observed in **Figure 11.0-4.**

Figure 11.0-4. Groundwater flow contours. 2nd of June 2020. Drummin Bog.

A cross section based on Appendix 1, Figure 9 is presented in the **Supplementary Report Material Folder.**

<u>Results:</u>

The geophysics and drilling along the same transects gave great insight into the basement geology and the ability to calibrate the peat layers with the drilling was very useful indeed in assisting with the conceptual understanding. It will have important long term benefit also in case future drilling is desired.

The results of this research also indicate that Drummin Bog is surviving and in need of urgent assistance if water levels are to be raised (and maintained) to within a sustainable target level of 0.1m BGL. Initial meteorological monitoring of the site demonstrate that weather events do appear to be extreme reflecting the predictions by the EPA. Those same weather events when extrapolated out over longer time periods using the synoptic station at Oak Park, do however show that the trend is becoming milder and wetter. Where water levels are at or near ground level at MW09, 10 and 11, Sphagnum moss is thriving, but these are localized pockets active raised bog in a large area of dry peat.

While the projections for milder and wetter weather are good for the bog in terms of more rainfall, that rainfall is coming with more intensity and is being lost to the bog via a network of efficient “arterial” drainage channels and ditches.

It is difficult to determine how much water is being lost as the concentration of woodland and scrub is also applying an extra unknown draw-down of water from the peripheral drain, which is not only acting as a drainage channel for water exiting the site but also as a very efficient delivery system of water from within the bog to the dense woodland on the periphery of the site.

The peripheral drain is not the only controlling hydrological boundary on the site. The central bog pond (a deep man-made excavation) causes a localized drawdown of water levels in MW09 and MW04S. This pond is linked directly to the peripheral drain allowing increase of groundwater flux to immediately be drained away and prevent any improved water storage in the peat.

The hydrochemistry on the site is generally very good. MW04S is a cause of concern, however based on the cation-anion balance checks, the analysis is unreliable. The onsite surface flow monitoring has been successful despite being very low during drought periods. The use of the saline conductivity logger has been a very useful tool in accurately measuring a flow which would have otherwise been impossible to measure accurately. Overall the monitoring is working effectively and in sync.

Conclusions:

It is a fact that we cannot control the weather influencing the bog; we know however that there appears to have been a trajectory change in various meteorological patterns which are impacting particularly since the start of this millennium.

The things we can change and influence are two-fold. Firstly, the drainage system on and around the bog. The peripheral drainage channel cuts below the peat in most cases with lacustrine clays and weathered granitic material visible in its side walls of the drain (where exposed). The secondary drainage channels on the bog itself are designed to drain to drain the peat, they do this efficiently; running from high topographical elevations to lower elevations. Several sumps on site link these drains increasing their connectivity. The main bog pond (sump) is a prime example of this and is included in the monitoring both in the pond itself and in the piezometers on its periphery. Attempts to block these drains with sheet piles have failed, indeed once one is blocked it is hard to know if the water just would exit elsewhere.

Secondly the dominance on and around the bog of woodland and thick vegetation is a cause of concern but at this time an unquantifiable concern. It is critical to establish a good reliable data set of flow rates leaving the site. It may possibly be that the woodland and vegetation could be causing severe negative impact of the water levels in the hydrological system of the bog since they surround the system. This issue is accentuated in dryer months when competition for water increases; the peripheral drain is acting as a storage channel from where water is being drawdown by the surrounding trees almost causing its flow to cease.

To rewet the bog and return it to active raised bog (ARB) will involve a multi-level approach and active monitoring will be critical to gauge the successes of the works being undertaken. It is the opinion of the author that single isolated actions on their own will not work. It is also the opinion of the author that monitoring must be continued to gauge action and impact of restoration activities.

<u>Recommendations:</u>

- It is recommended to install a v-notch weir as soon as possible. This will complete the information gap needed to compile a water balance equation.
- The practice of blocking secondary drains on the bog should be reviewed. It may be better to install the sheet piles strategically on the confluences of the AOI raised bog secondary drains and the peripheral drain.

- Pre-installation site surveys would need to be done prior to installing piles in order to ensure correct construction and value for money.
- It is also recommended that the same type of piles be installed to prevent flow exiting the central bog pond; this is a significant water control point. Should water levels be able to be raised and maintained here it can have significant (trickle-down) benefits to peat at lower elevations via gravity feed. Perhaps review its role in the bog landscape from a drainage sump to a water storage sump – reverse engineer the system.
- More data loggers should be deployed to continue to gain a better understanding of the interactions between precipitation and water level values. This will be advantageous also when piling is commenced and rewetting initiated.
- It is recommended that an information campaign be initiated with the local community on an action plan for the bog site in order to get community interest stimulated and buy-in from local stakeholders.
- The state forestry agency "Coilte" should also be approached down the road ahead for the project. The quantity of trees being discussed in this document are not thought significant in a commercial sense but is in the context of a bog area of seven hectares. Their involvement and experience on other similar projects may be would be useful.
- The ongoing Drummin Bog Project work could also have benefits in training local people in various aspects of citizen science which would be beneficial to the data gathering on the site as they would live locally to it and have ownership of it.

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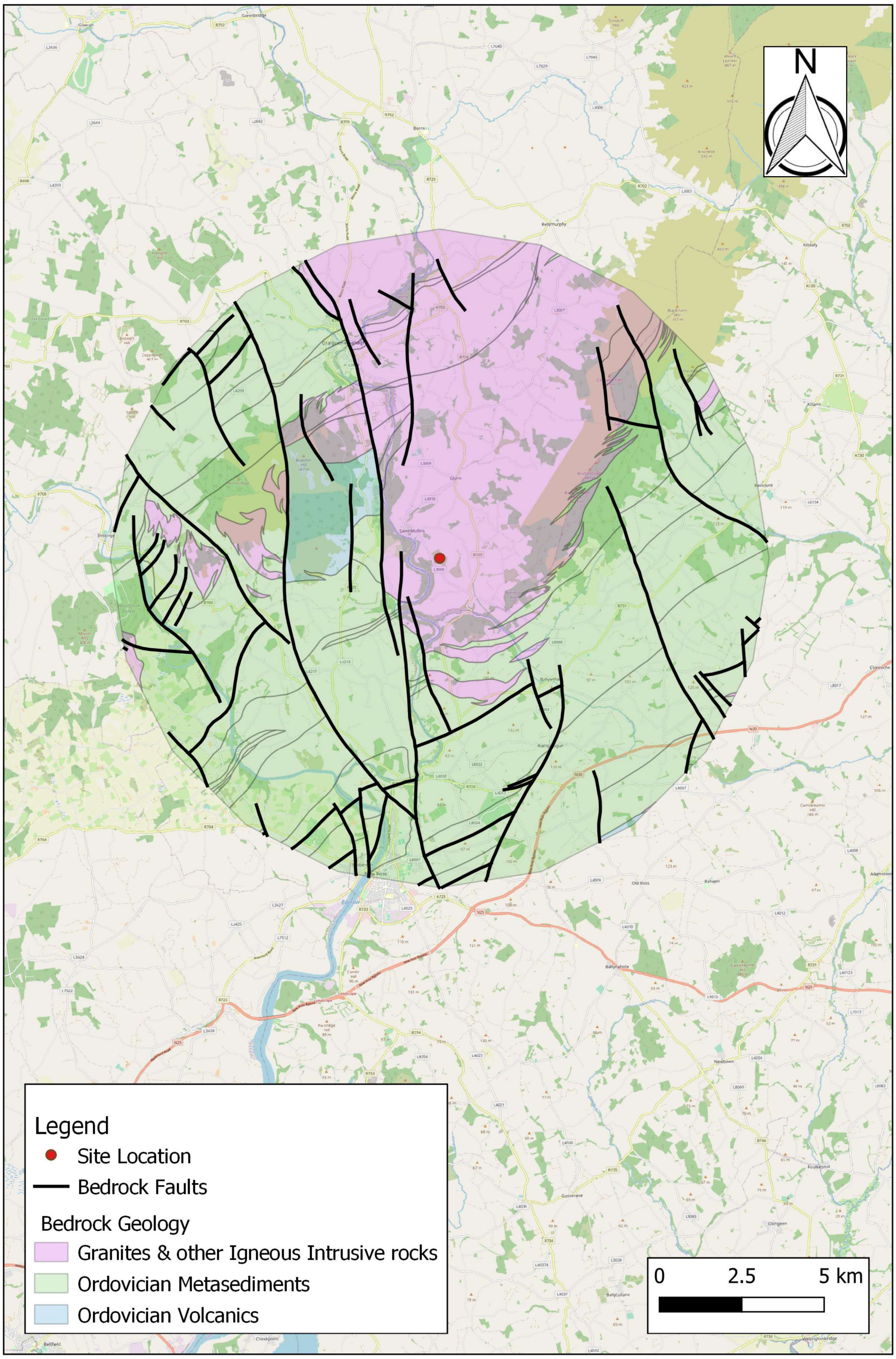
Appendix No.1

Environmental Setting – Figures 1-6

Monitoring Locations Elevations – Figure 7

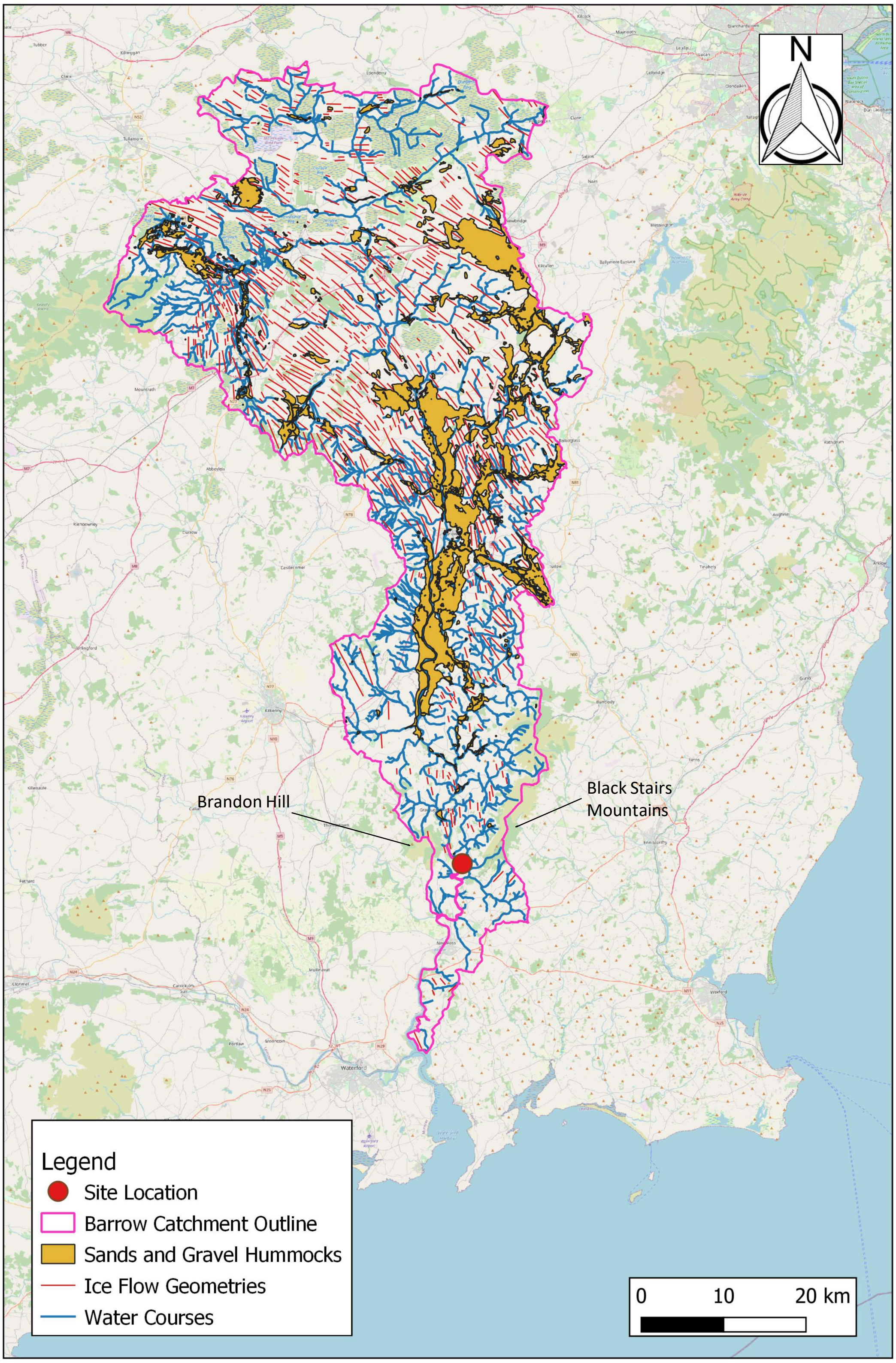
LiDAR Darin Survey – Figure 8

Monitoring Location Network– Figure 9



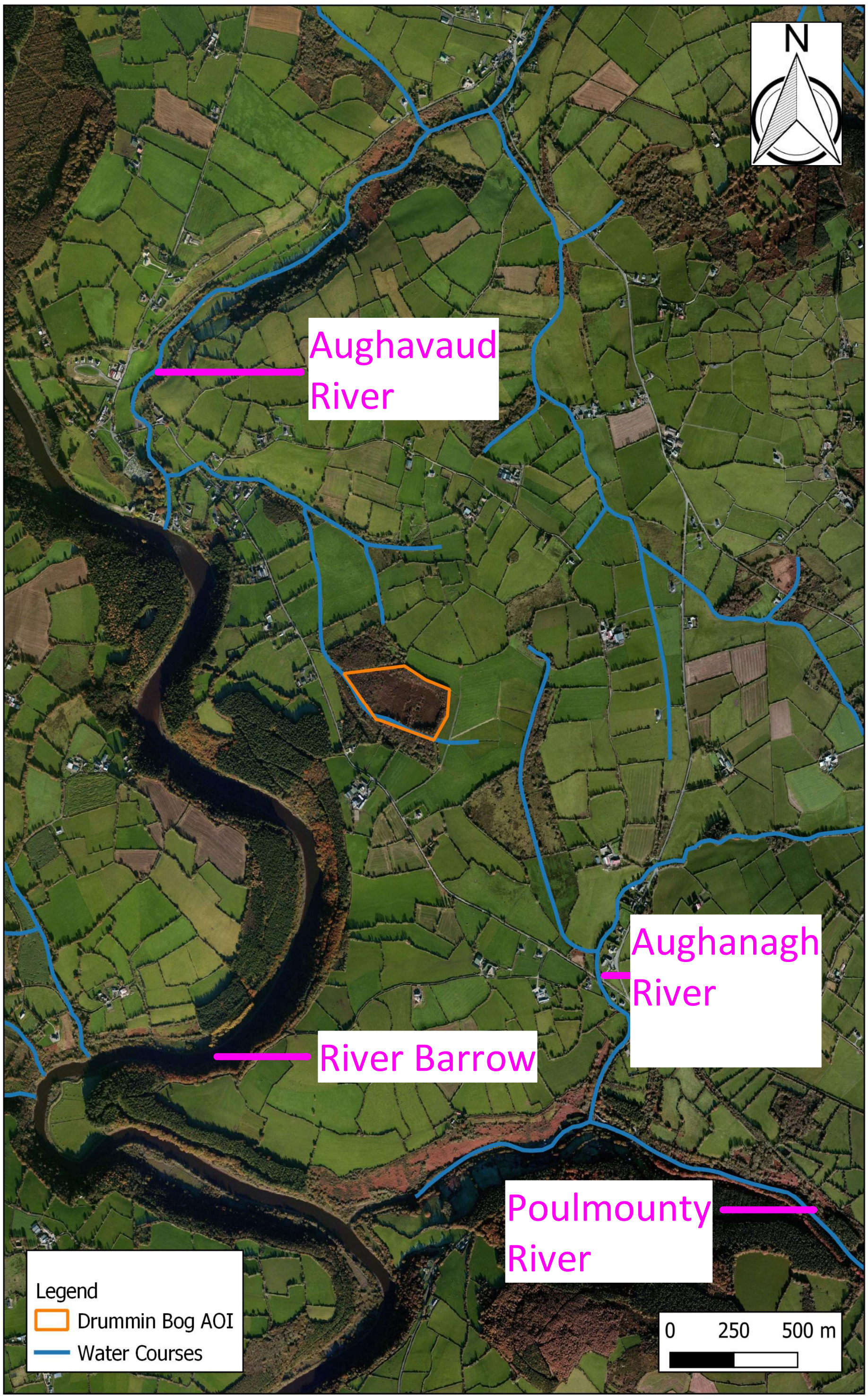
Newcastle University

Title: Bedrock Geology. 10km Site Radius	*Drawn By:* James Lalor
Date: 1st of August 2020	*Student ID B504488844*
Source : Geological Survey of Ireland	*Figure 1.*

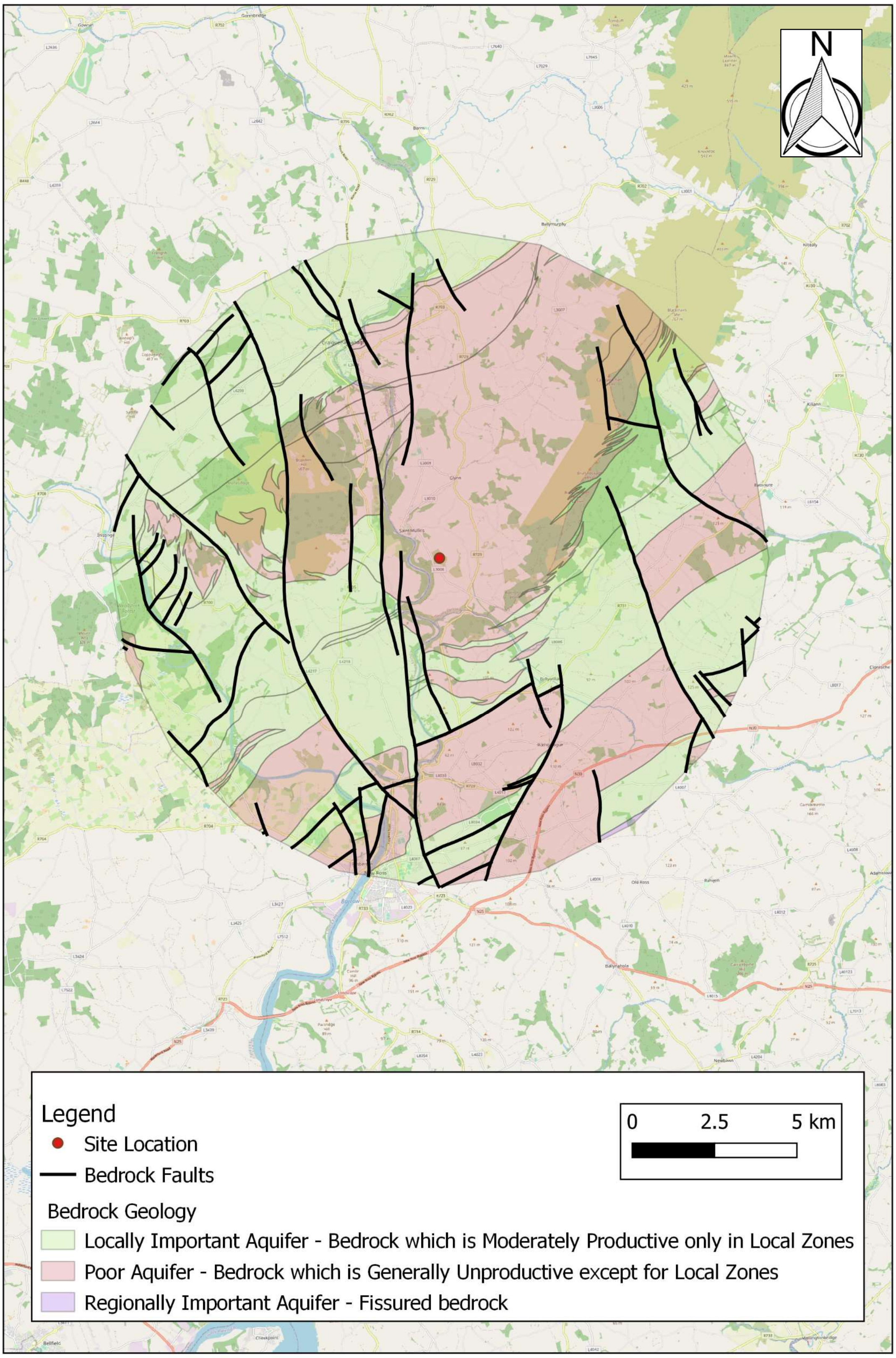


Title: Catchment Glacial Features.	*Drawn By:* James Lalor
Date: 1st of August 2020	*Student ID B504488844*
Source : Geological Survey of Ireland	*Figure 2.*

Newcastle University

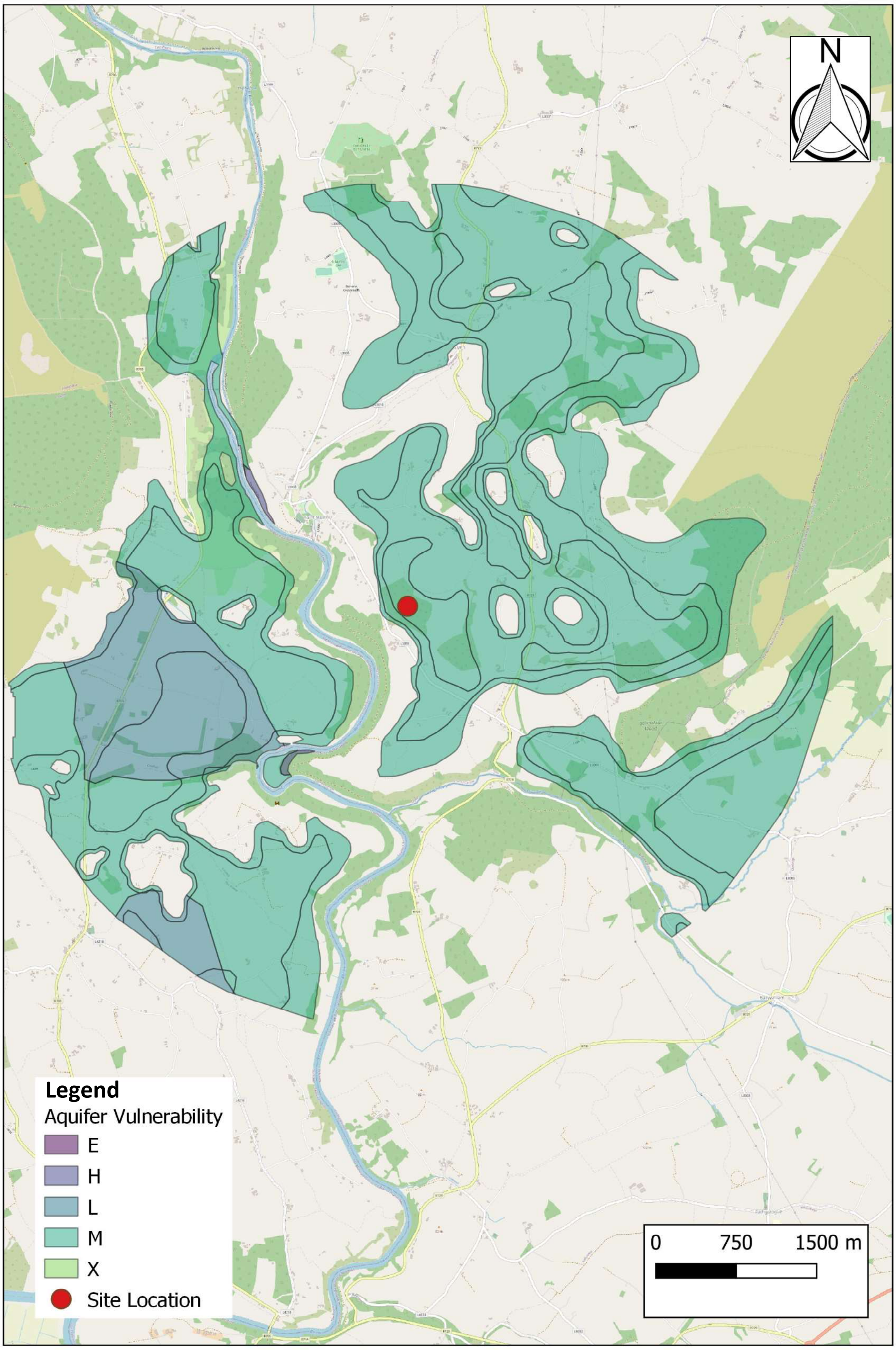


Title: Local Hydrological Boundaries	*Drawn By:* James Lalor
Date: 1st of August 2020	*Student ID B5048884*
Source : Geological Survey of Ireland	*Figure 3*



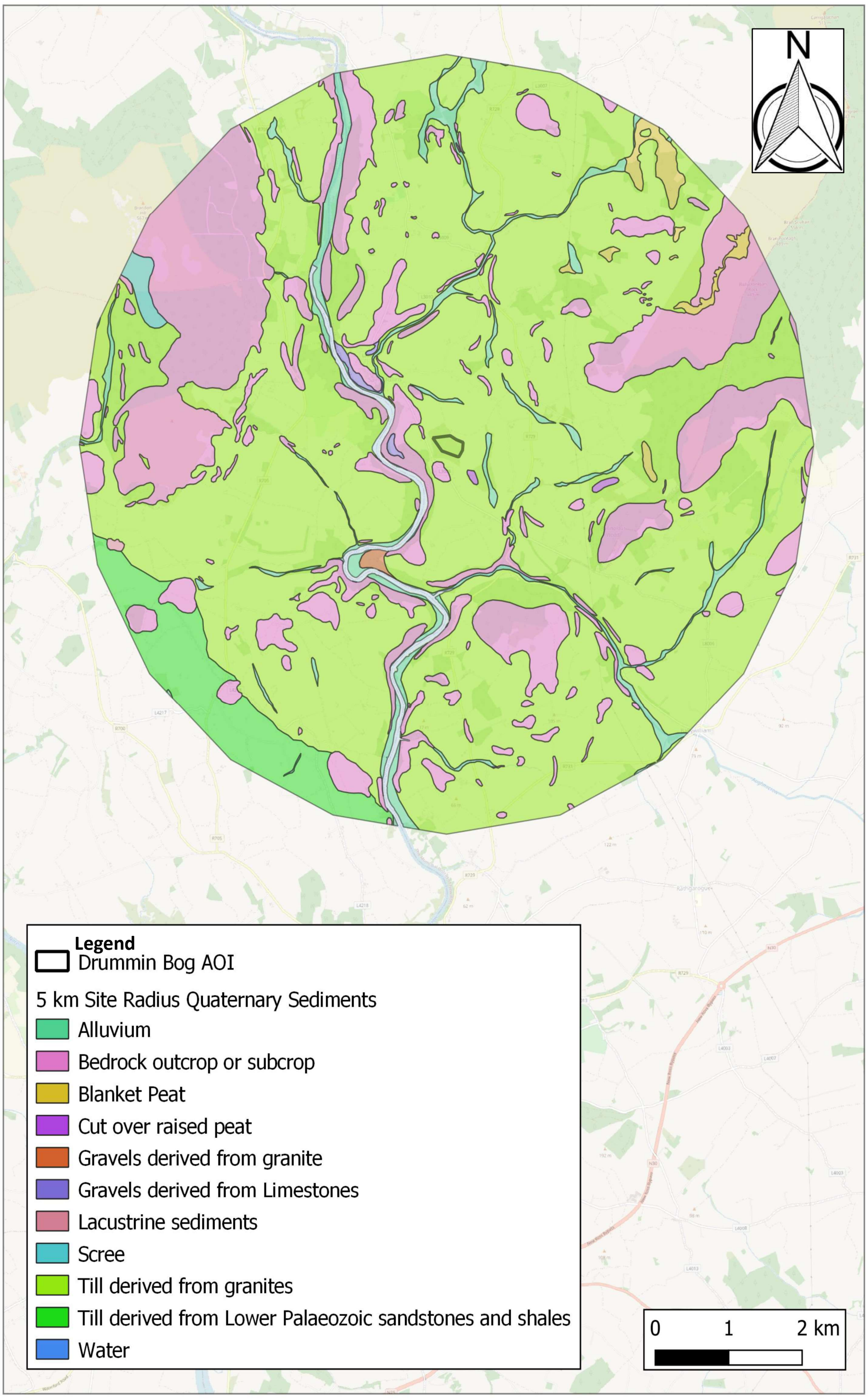
Title: Aquifer Bedrock Geology. 10km Site Radius	*Drawn By:* James Lalor
Date: 1st ofAugust 2020	*Student ID B5048884*
Source : Geological Survey of Ireland	*Figure 4.*

Newcastle University



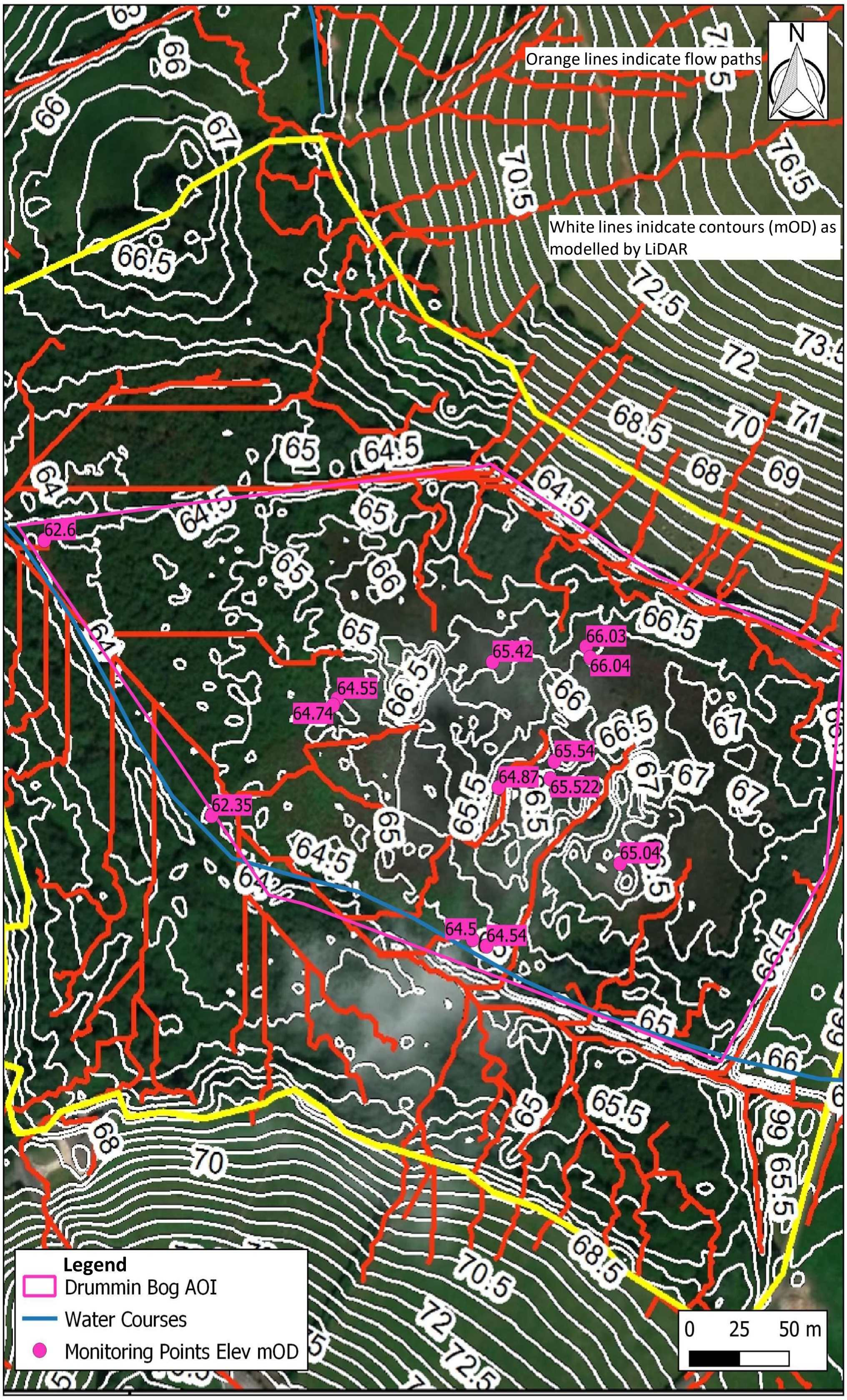
Title: Aquifer Vulnerability. 5km Radius	*Drawn By:* James Lalor
Date: 1st ofAugust 2020	*Student ID B5048884*
Source : Geological Survey of Ireland	*Figure 5.*

Newcastle University

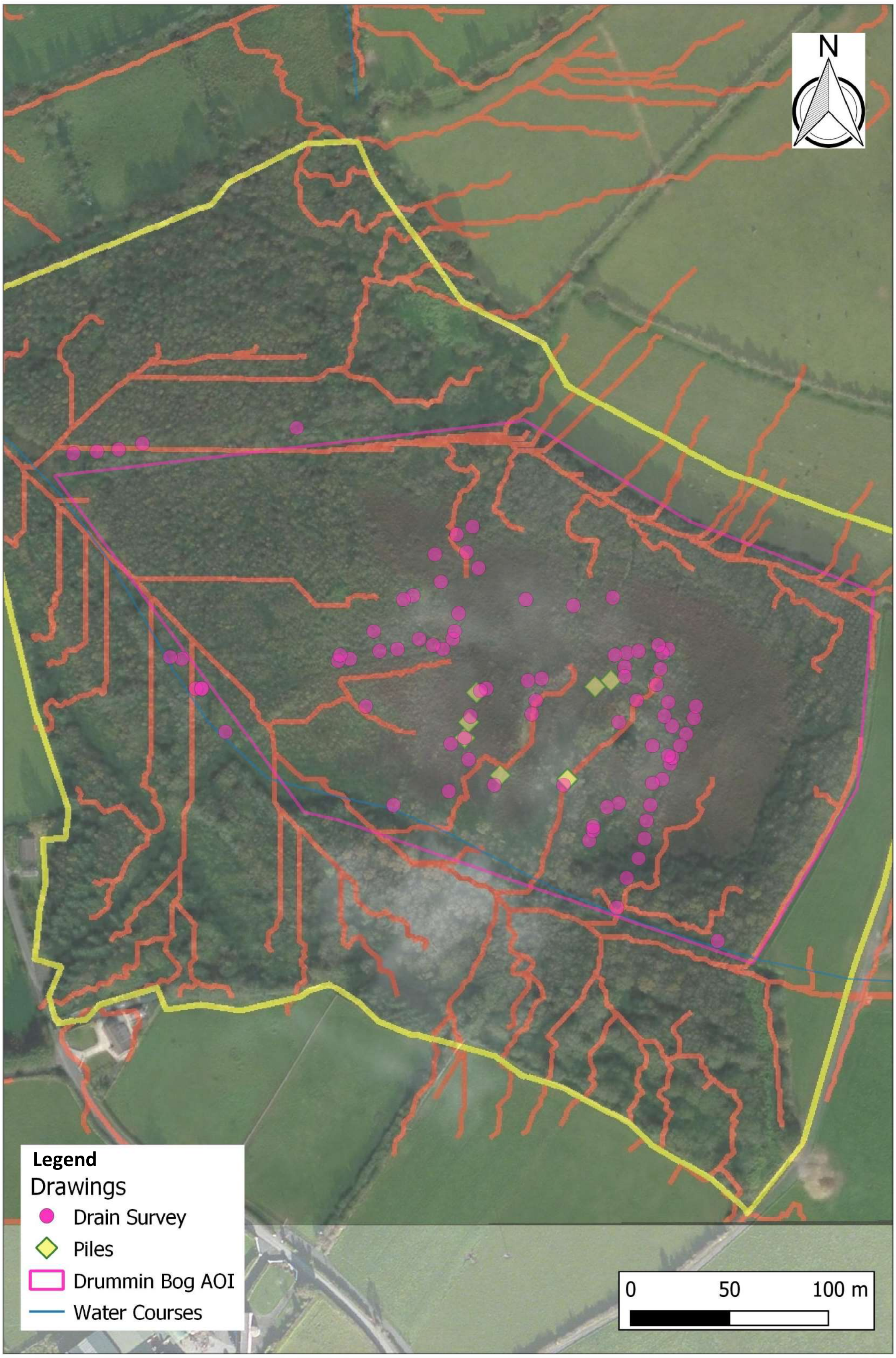


Newcastle University

Title: Quaternary Sediments. 5km radius	*Drawn By:* James Lalor
Date: 1st of August 2020	*Student ID B5048884*
Source : Geological Survey of Ireland	*Figure 6.*

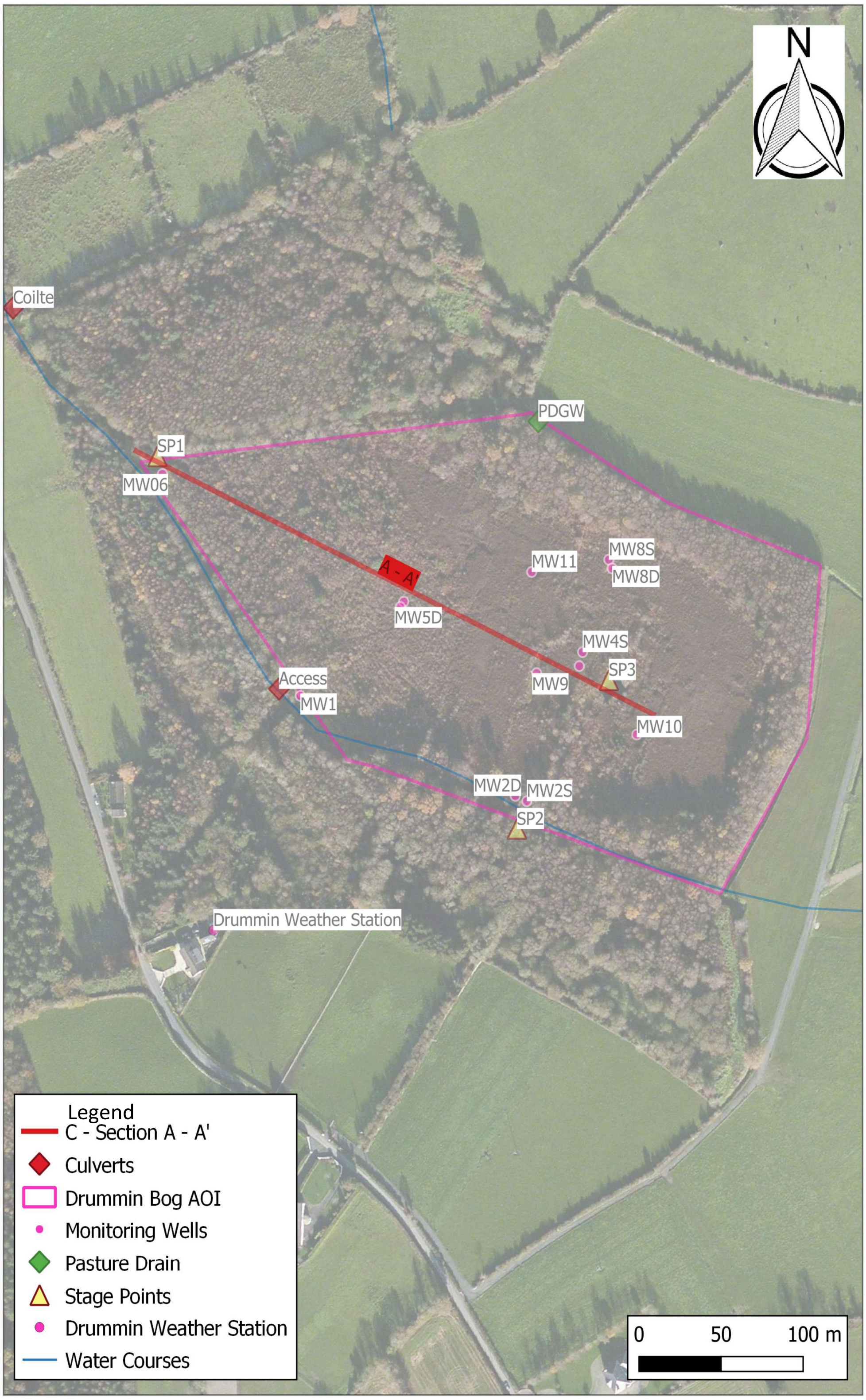


Title: Monitoring Well Elevations mOD.	*Drawn By:* James Lalor
Date: 1st of August 2020	*Student ID B504488844*
Source : Geological Survey of Ireland	*Figure 7.*



Title: LiDAR drain survey checks	*Drawn By:* James Lalor
Date: 1st of August 2020	*Student ID B504488844*
Source : Geological Survey of Ireland	*Figure 8.*

Newcastle University



Title: Site Orientation	*Drawn By:* James Lalor
Date: 1st of August 2020	*Student ID B5048884*
Source : Geological Survey of Ireland	*Figure 9.*

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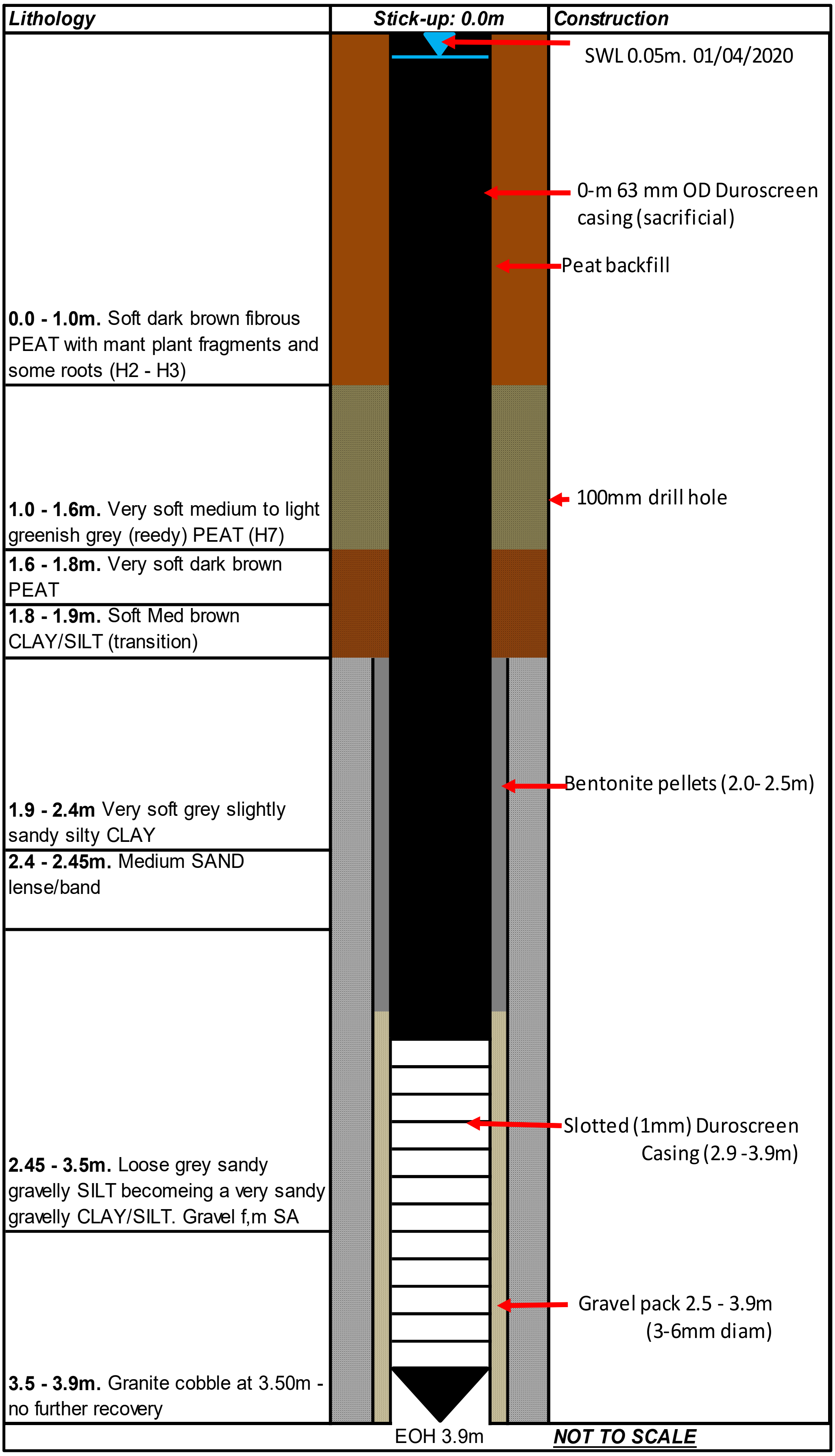
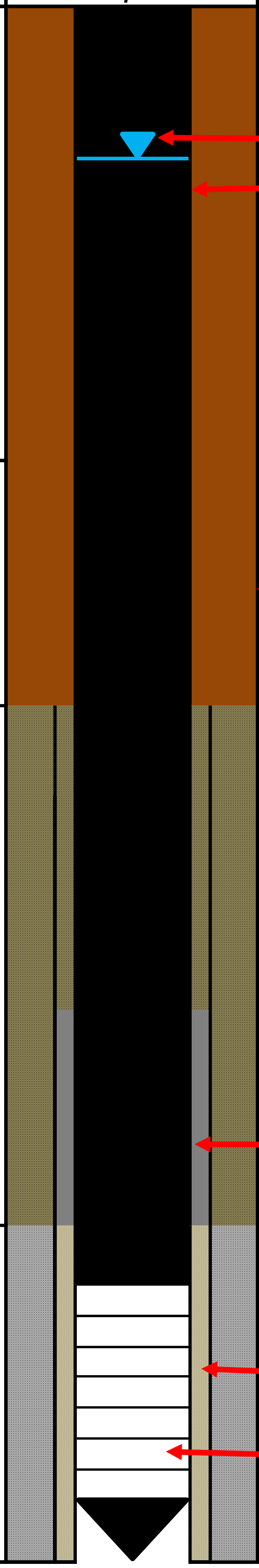
Appendix No.2

Piezometer Logs



Well No. :	MW 01. Colar Elevation = 62.45m OD	*Supervised by: JL/ML*
Date Drilled:	20th of January 2020.	*Depth (mBGL) : 3.9*
Co ordinates:	673685 637167	*Drillers: Doran GE Ltd*

Lithology	Stick-up: 0.29m	Construction
0.0 - 2.1m. Soft dark brown, very woodyPeat (H7), very large wood fragments at 0.9m, 1.8m and 1.9m.		
2.1 - 3.1m. Very soft light brown becoming greenish brown PEAT (H7).		
3.1 - 3.9m. Very soft liquifying grey clayey organic SILT with pockets of soft greenish brown PEAT.		
3.9 - 4.6m. Loose, very silty fine SAND.		



NOT TO SCALE

Well No. : MW 02 Deep. Collar Elevation = 64.85m OD	*Supervised by: JL/ML*
Date Drilled: 21st of January 2020.	*Depth (mBGL) : 4.6*
Co ordinates: 673805 637096	*Drillers: Doran GE Ltd*

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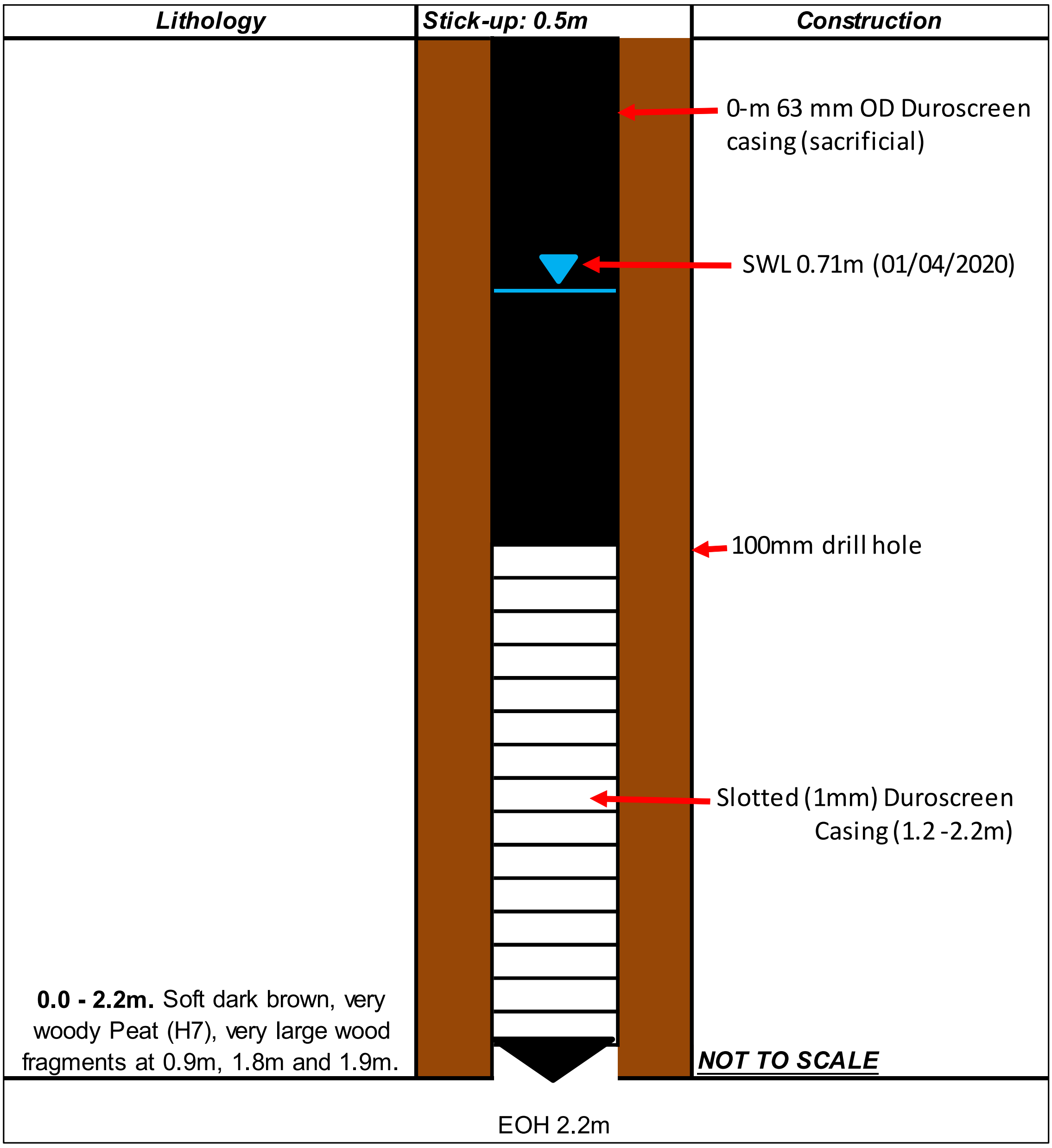
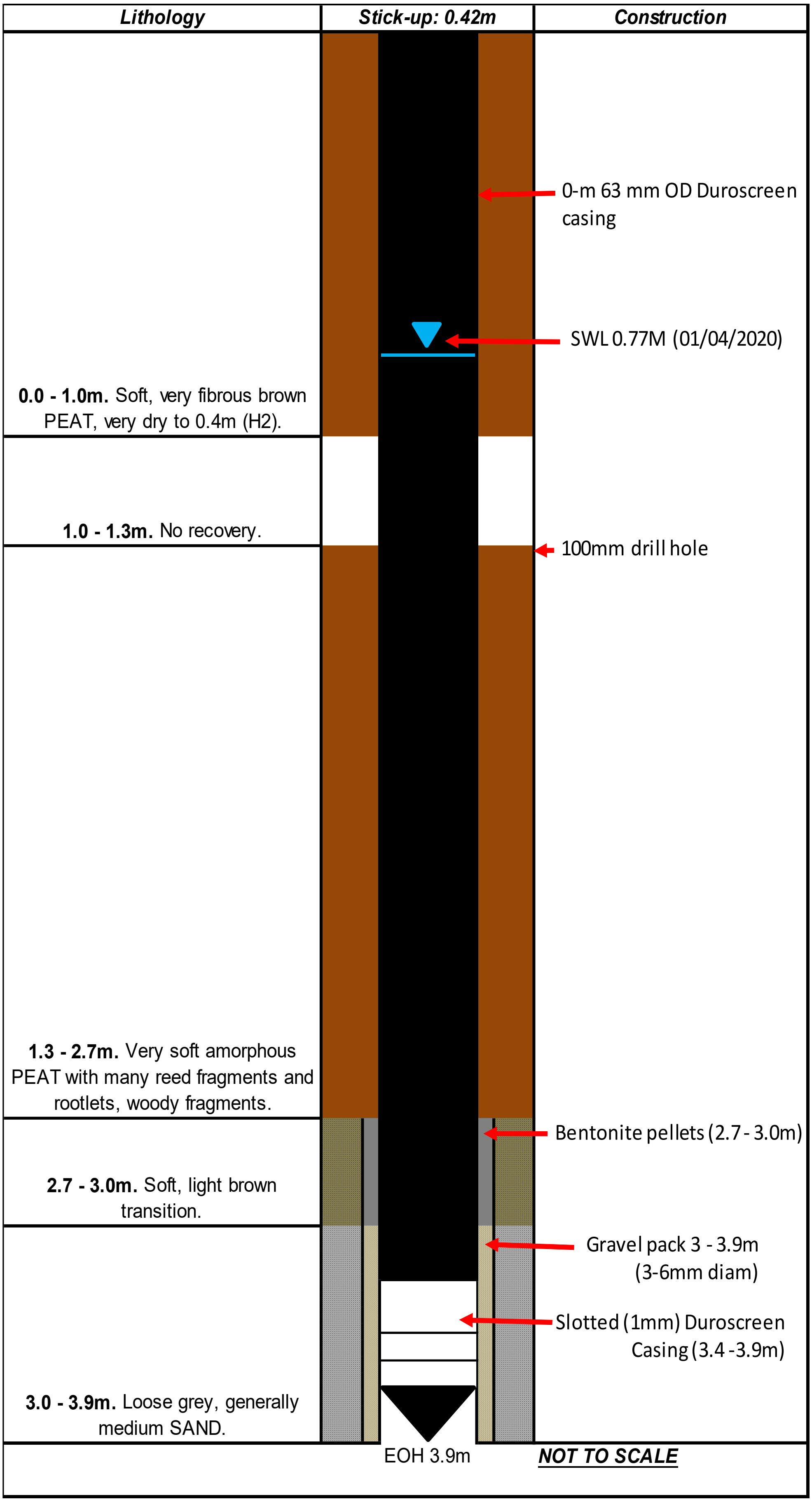


Well No. :	MW 02 Shallow. Collar Elevation = 65.04m OD	*Supervised by: JL/ML*
Date Drilled:	23rd of January 2020.	*Depth (mBGL) : 2.2*
Co ordinates:	673823 637107	*Drillers: Doran GE Ltd*

Newcastle University



Well No. : MW 04 Deep. Collar Elevation 64.98m OD	*Supervised by: JL/ML*
Date Drilled: 22nd of January 2020.	*Depth (mBGL) : 3.9*
Co ordinates: 673855 637184	*Drillers: Doran GE Ltd*

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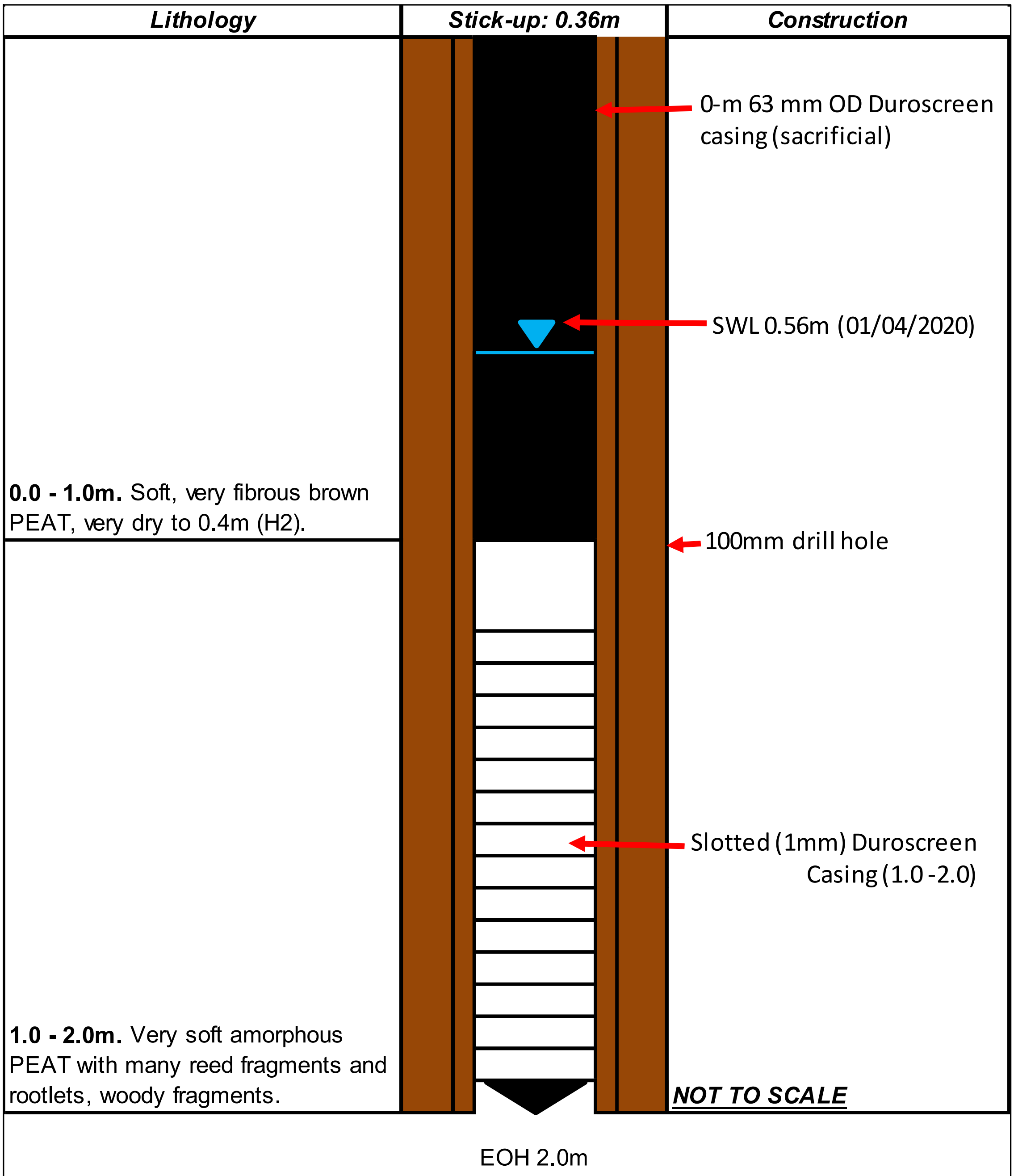


Well No. : MW 04 Shallow. Collar Elevation = 65.95m OD	*Supervised by: JL/ML*
Date Drilled: 22nd of January 2020.	*Depth (mBGL) : 2.0*
Co ordinates: 673857 637192	*Drillers: Doran GE Ltd*

Lithology	Stick-up: 0.11m	Construction

0.0 - 1.0m. Soft (dry) woody amorphous PEAT with many woody fragment and roots. Cobble sized wood fragmenet at 0.5m. (H6)

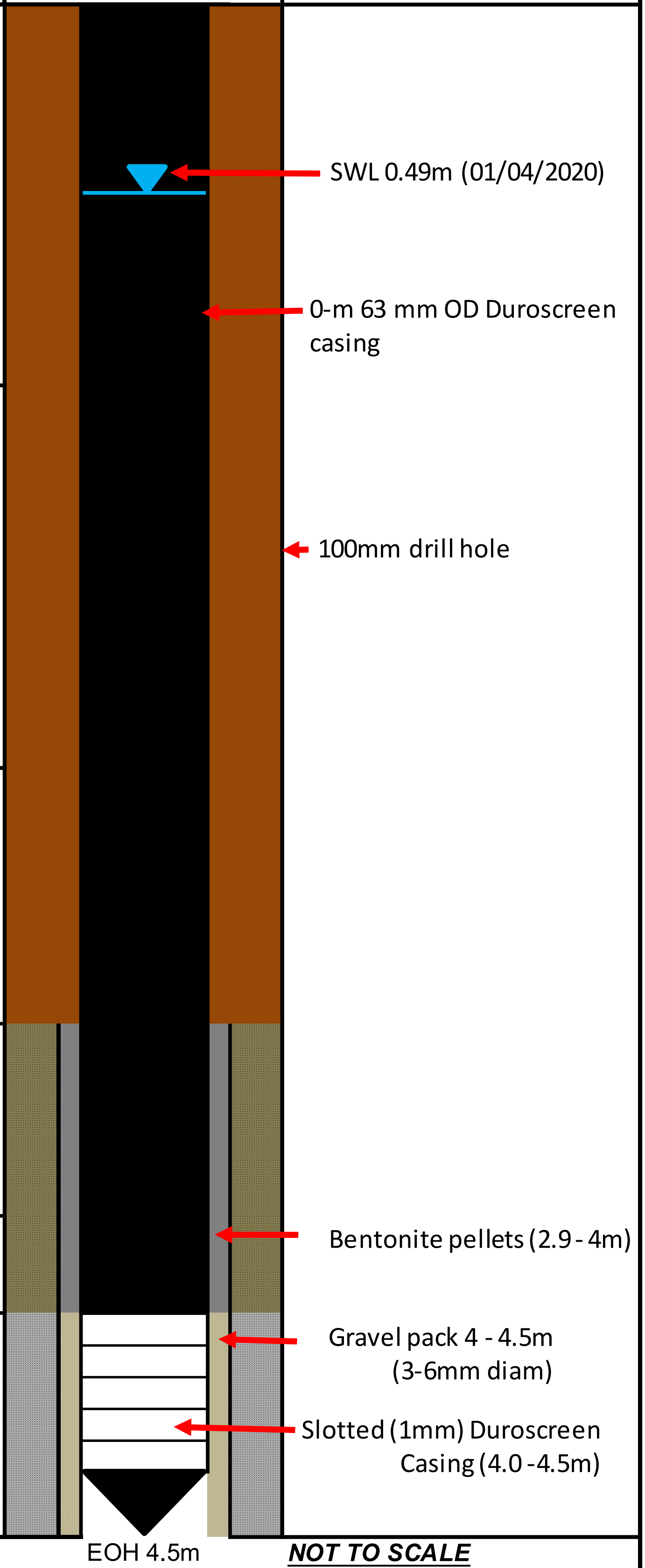
1.0 - 2.0m. Very soft wet black amorphous PEAT with some woody fragments (H7). Large cobble sized wood fragment at 2.0m (base of core)

2.0 - 2.9m. Soft dark brown very woody PEAT. Wood fragment gravel sized possibly birch. (H3)

2.9 - 3.6m. Very soft olive green fibrous PEAT

3.6 - 4.0m. Very soft greyish green silty PEAT/ very organic SILT (micaceous). grading into...

4.0- 4.5m. Very soft grey silty organic CLAY

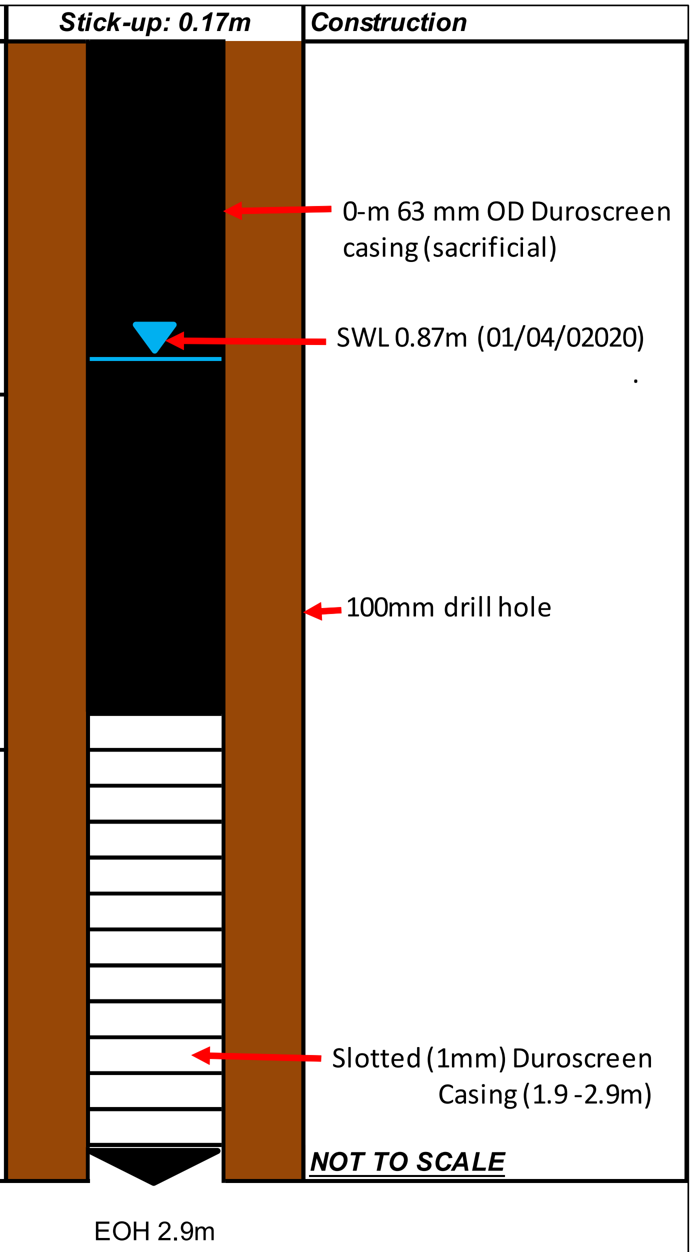


NOT TO SCALE

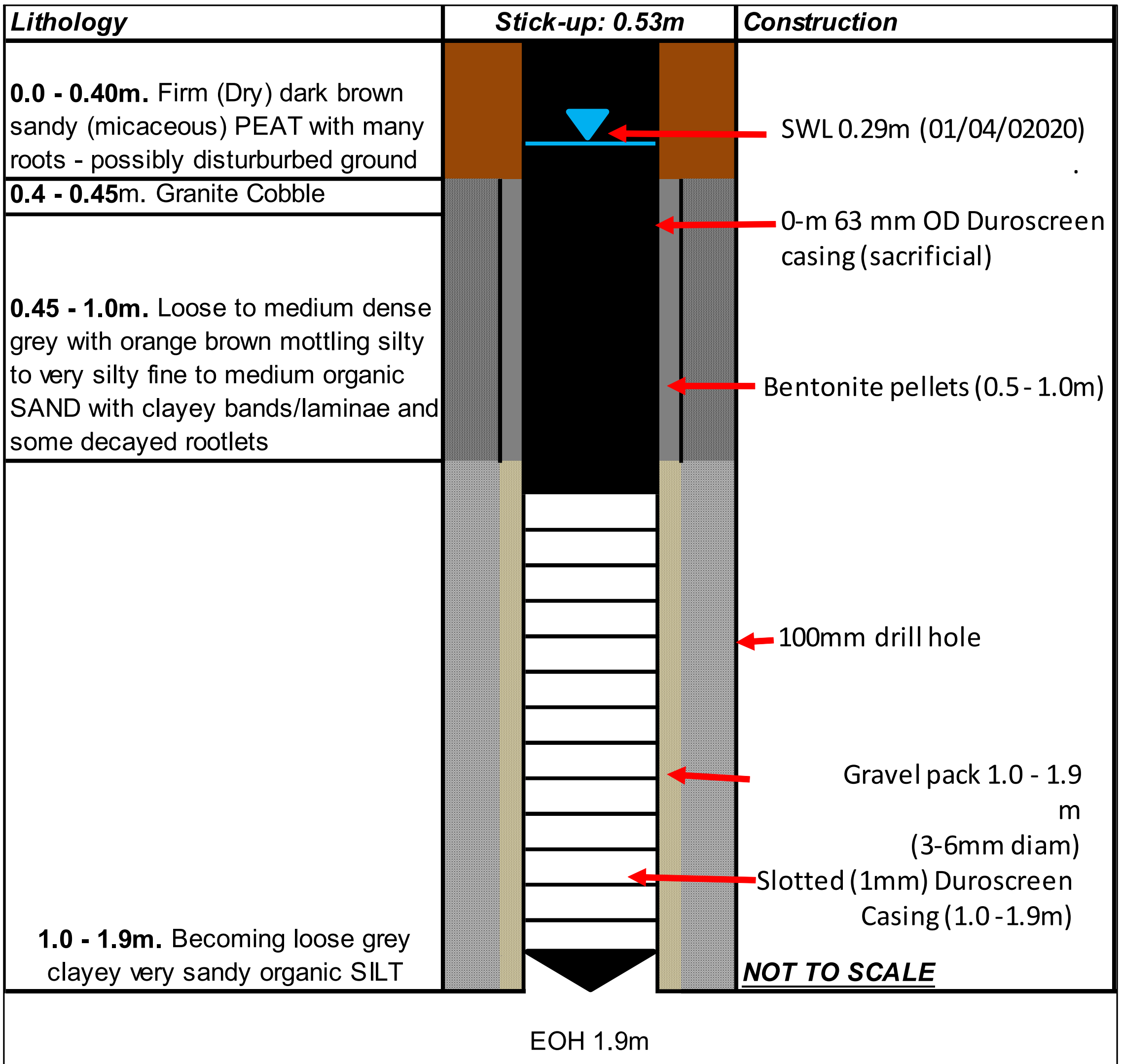
Well No. :	MW 05 Deep. Collar Elevation = 64.74m OD	*Supervised by: JL/ML*
Date Drilled:	21st of January 2020.	*Depth (mBGL) : 4.5*
Co ordinates:	673748 637221	*Drillers: Doran GE Ltd*

Newcastle University

Lithology
0.0 - 1.0m. Soft (dry) woody amorphous PEAT with many woody fragment and roots. Cobble sized wood fragmenet at 0.5m. (H6)
1.0 - 2.0m. Very soft wet black amorphous PEAT with some woody fragments (H7). Large cobble sized wood fragment at 2.0m (base of core)
2.0 - 2.9m. Soft dark brown very woody PEAT. Wood fragment gravel sized possibly birch. (H3)



Well No. :	MW 05 Shallow. Collar Elevation = 64.82m OD	*Supervised by: JL/ML*
Date Drilled:	21st of January 2020.	*Depth (mBGL) : 2.9*
Co ordinates:	673746 637218	*Drillers: Doran GE Ltd*



Well No. : MW 06. Collar Elevation = 62.60m OD	*Drawn By:* James Lalor
Date Drilled: 20th of January 2020.	*Depth (mBGL) :* 1.9
Co ordinates: 673598 637303	*Drilled By: Doran GE Ltd*

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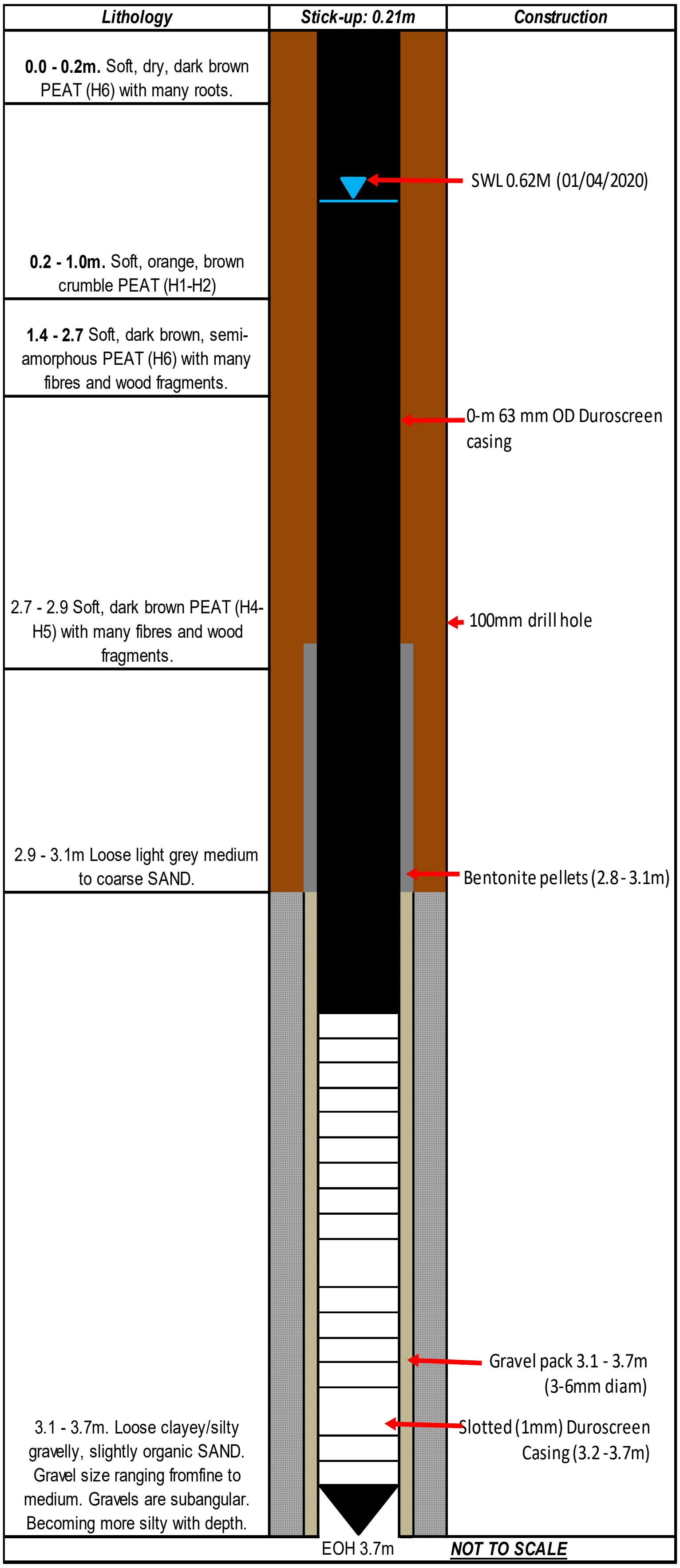

Well No. : MW 08 Deep. Collar Elevation = 66.32m OD	*Supervised by: JL/ML*
Date Drilled: 22nd of January 2020.	*Depth (mBGL) : 3.7*
Co ordinates: 673875 637240	*Drillers: Doran GE Ltd*

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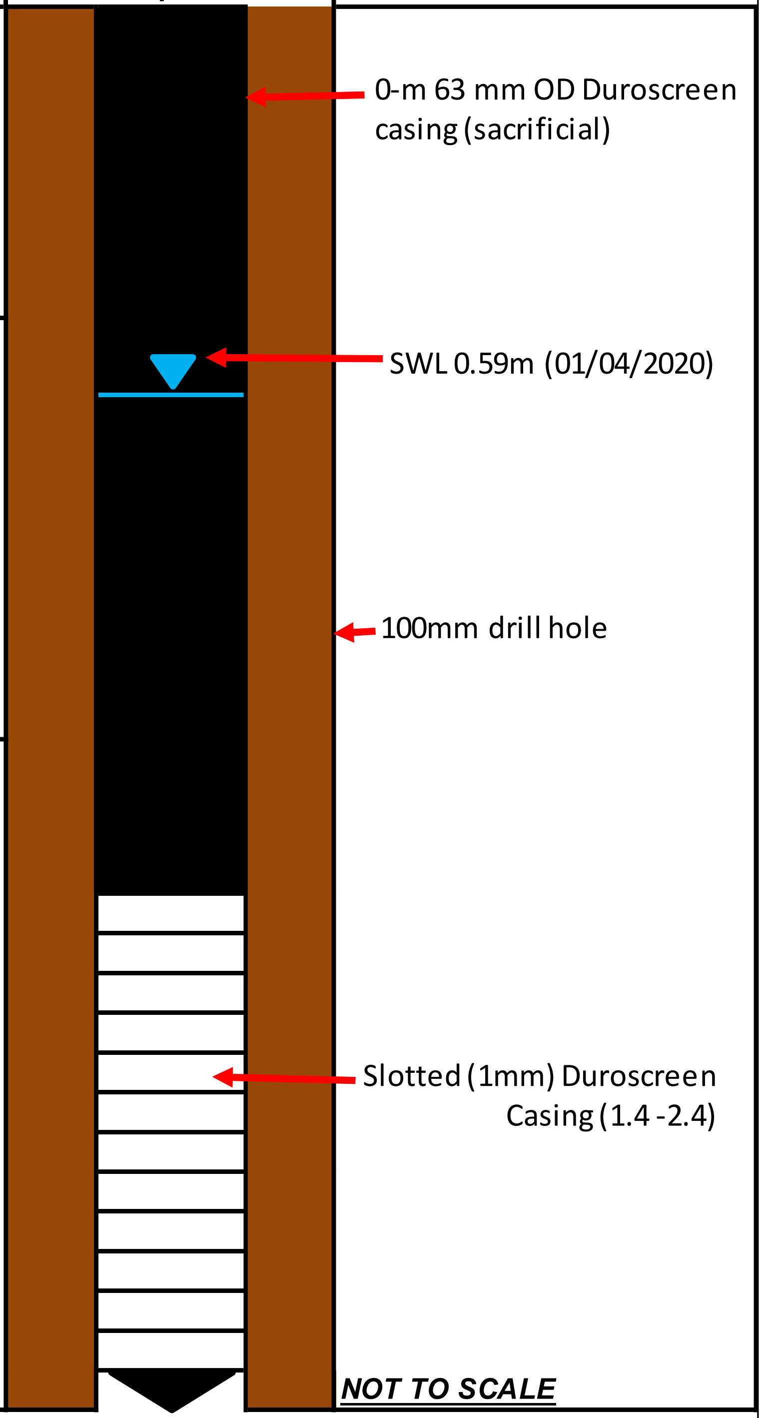
Lithology	Stick-up: 0.14m	Construction

0.0 - 0.2m. Soft, dry, dark brown PEAT (H6) with many roots.

0.2 - 1.0m. Soft, orange, brown crumble PEAT (H1-H2)

1.4 - 2.4 Soft, dark brown, semi-amorphous PEAT (H6) with many fibres and wood fragments.



EOH 2.4m

Well No. :	MW 08 Shallow. Collar Elevation = 66.15m OD	*Supervised by: JL/ML*
Date Drilled:	23nd of January 2020.	*Depth (mBGL) : 2.4*
Co ordinates:	673873 637245	*Drillers: Doran GE Ltd*

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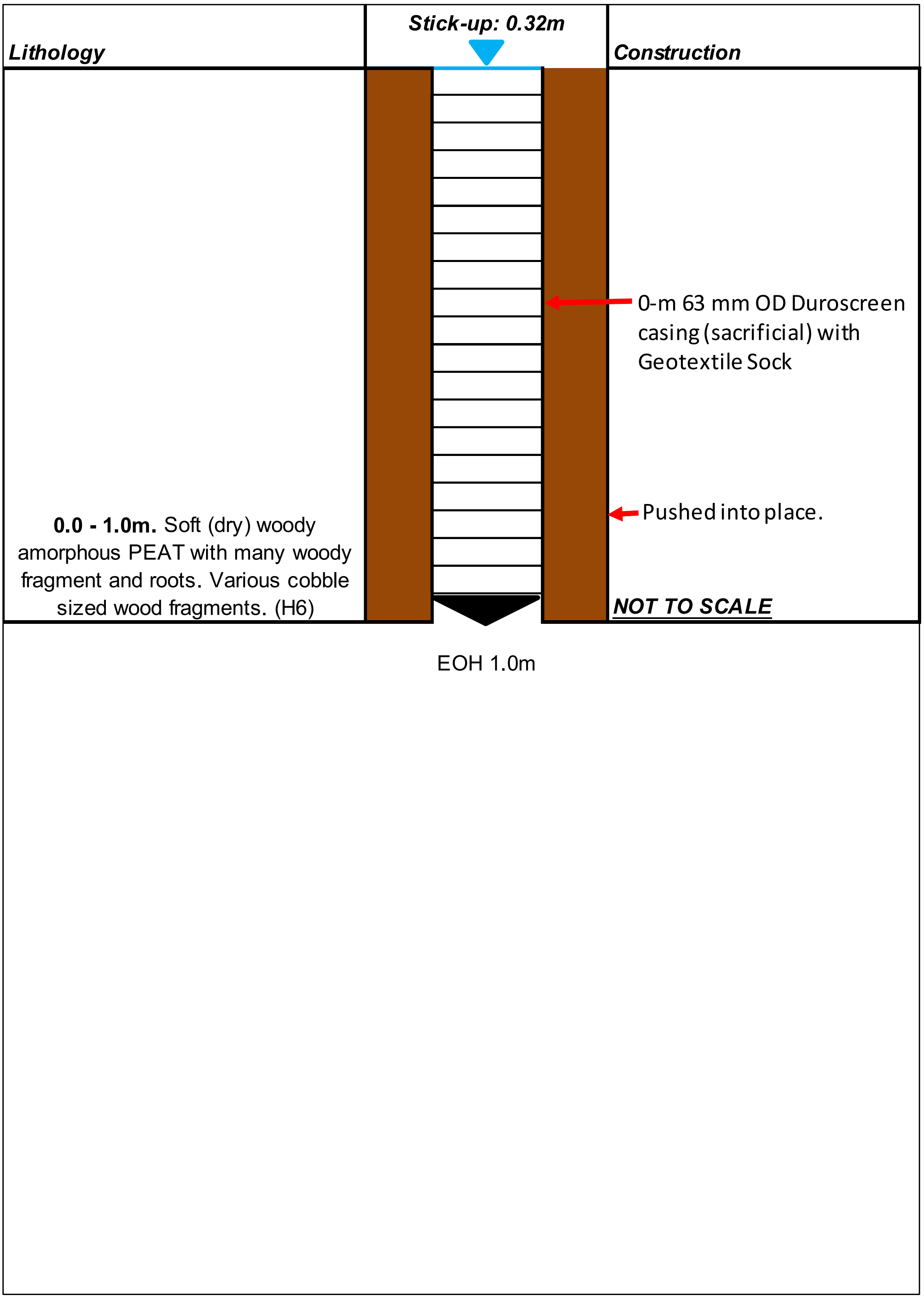

Well No. :	MW 09. Collar Elevation = 65.22m OD	*Supervised by: JL/ML*
Date Drilled:	2nd of June 2020.	*Depth (mBGL) : 1.0*
Co ordinates:	673829 637180	*Push-in-piezo*

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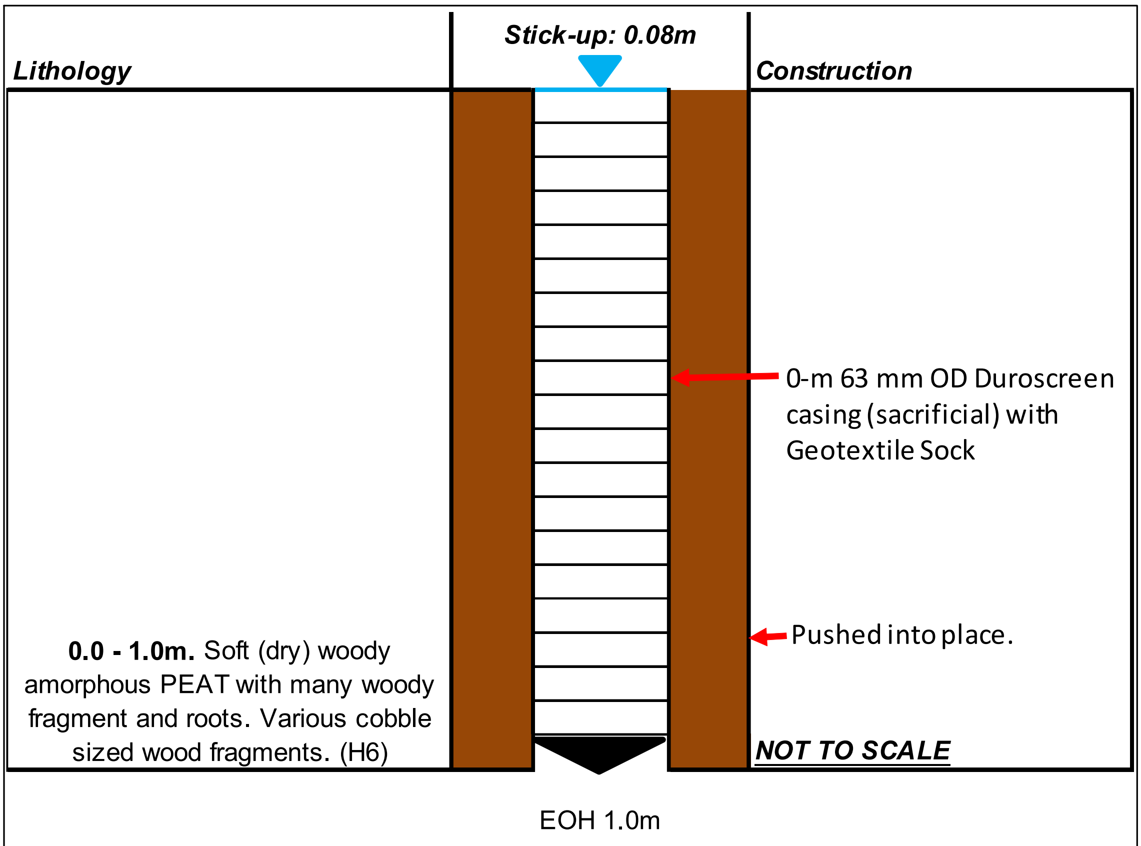

Well No. :	MW 10. Collar Elevation = 65.14m OD	*Supervised by: JL/ML*
Date Drilled:	2nd of June 2020.	*Depth (mBGL) : 1.0*
Co ordinates:	673890 637145	*Push-in-piezo*

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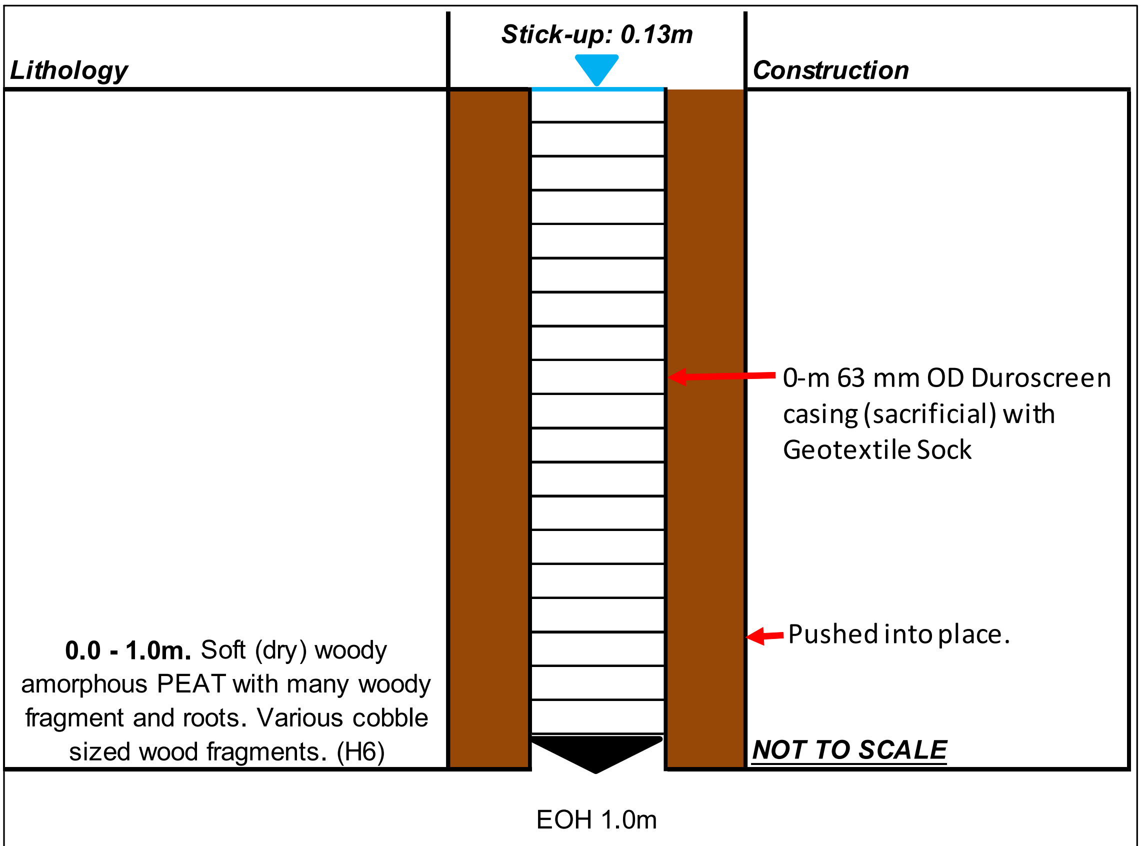

Well No. : MW 11. Collar Elevation = 65.52m OD	*Supervised by: JL/ML*
Date Drilled: 2nd of June 2020.	*Depth (mBGL) : 1.0*
Co ordinates: 673826 637238	*Push-in-piezo*

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