Report on Restoration Potential for Altikeeragh Blanket Bog ASSI.

April 2023

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Introduction

This report outlines the works undertaken to develop a peatland restoration plan for Altikeeragh Blanket Bog ASSI, Northern Ireland (Altikeeragh), based on work co-ordinated by Dr. Raymond Flynn of the School of the Natural and Built Environment, Queen's University Belfast between September 2021 and March 2023. The work contained in this report builds upon the March 2022 Interim Report, provided by Dr. Flynn to Causeway Coast and Glens Heritage Trust (CCGHT) describing findings of works carried out as part of the preliminary investigations of the site and contained in Appendix 1.

This report provides details of further investigative works carried out at Altikeeragh between the publication of the Interim Report and March 2023 with a view to providing a framework for restoration measures at the site. Figure 1, taken from the 2022 report, summarises the location of the site.

Figure 1: Location map for Altikeeragh Blanket Bog ASSI, Northern Ireland. Aerial Image: ESRI.

Previous Work

The March 2022 Interim Report describes work completed from 2021 until the time of writing, providing details of the following:

1. Completion of a citizen science programme to determine existing dam locations, and construction materials used to make them, across the northern half of the site.
2. Completion of a citizen science programme to investigate peat depths across the northern half of the site to assess peat thickness, as a prelude for assessing the possibility of using locally available materials for restoration works.
3. Completion of a drone-based topographic survey of Altikeeragh and its immediate surroundings
4. A detailed investigation to assess the capacity of existing composite peat dams, with overflow pipes to retain water (, completed as a Civil Engineering student project by Beth Taylor, QUB)
5. Installation of a remotely accessible weather station to continuously measure precipitation and other meteorological parameters.
6. Installation of groundwater monitoring wells (piezometers) to allow monitoring of baseline water table levels in the peat
7. Procurement and installation of automated groundwater level loggers, installed in piezometers across the northern side of the site.

Key findings from these investigations were as follows:

1. The citizen science programme undertaken at the site revealed, through probing, that significant thicknesses of peat (>2m at all uncut, or high, bog locations) across that part of the bog investigated. (See Figure 3 in Appendix 1).
2. Citizen science dam surveys revealed dams located in artificial drains of contrasting dimensions across the site. Dam material ranged from peat, often with overflow pipes passing through them, to interlocking plastic sheet piling. (See Figure 3, Appendix I for locations)
3. Location of drains and their measurement of drain dimensions proved challenging in many cases due to extensive infilling by vegetation.
4. The drone-based survey of the site permitted additional linear features to be identified across the site. (See Figure 2)
5. Drains generated localised subsidence, which varied with drain depth and decline in water level. Linear features identified in drone survey data often (but not always) corresponded to artificial drainage.
6. Drain widths varied from ~1m to in excess of 5m. Depths proved difficult to measure due to infilling with vegetation but where they could be measured, they typically were between 1.0 and 1.5m deep
7. A survey of those drains identified by the citizen science programme revealed they operated with variable levels of efficiency, from those with a strong capacity to retain water, as reflected by water level differences across them following periods of wet weather, to ineffective (i.e. no water level difference across them).
8. Work, subsequently completed by Taylor (2022) as part of her Civil Engineering project, revealed that peat dams containing overflow pipes could retain further water by blockage of pipes, yet excessive water level differences ran the risk of rupturing peat around the outside of pipes, generating additional leakage.

9. The weather station at the site proved effective for measurement of the amount and timing of precipitation. By contrast the installation of a solar radiation monitor limited quantification of evapotranspiration from July 2022 onwards. The weather station remains active on site.
10. Manual water level measurements made in the piezometers installed across the site revealed consistent elevated water levels, typically no greater than 20cm of the ground surface, apart from those located adjacent to open drains approaching the margins of deep drains on steeper sloping ground.
11. Water level loggers, successfully monitored groundwater levels on a semi continuous basis (every hour).

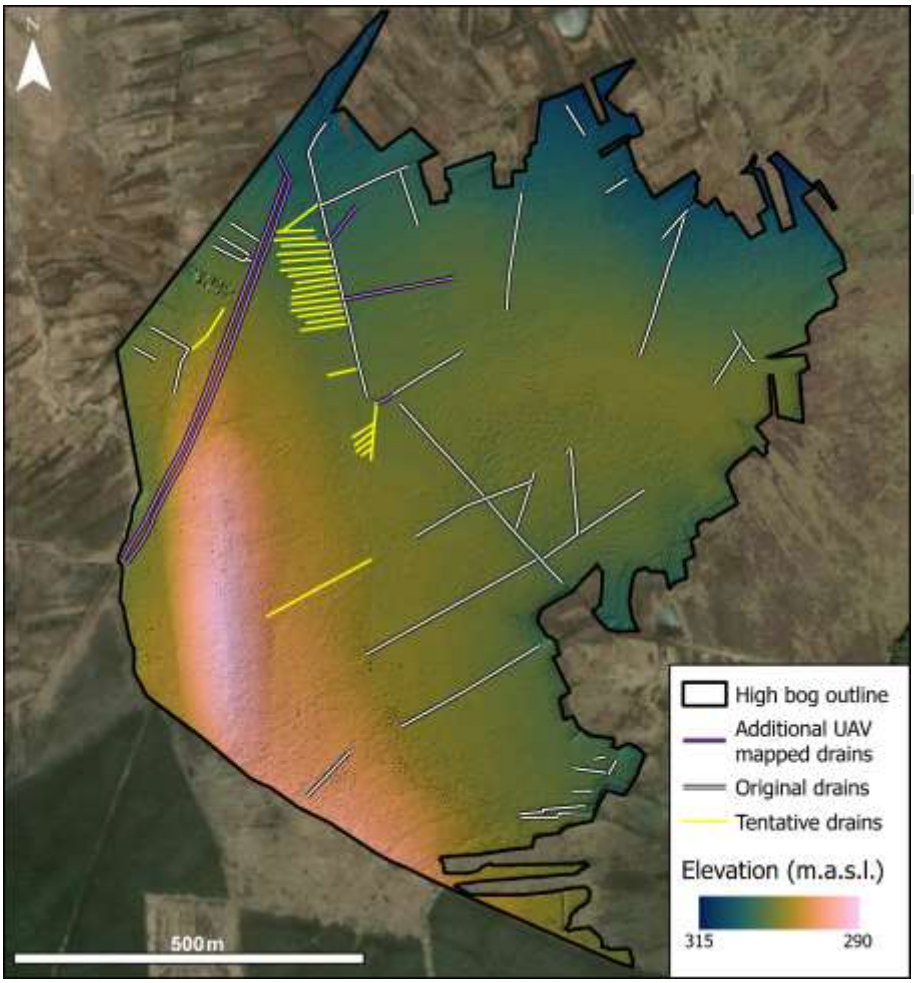

Figure 2: Location of prominent lineaments, identified as possible drains, based on drone-based topographic survey. Altikeeragh Blanket Bog, ASSI.

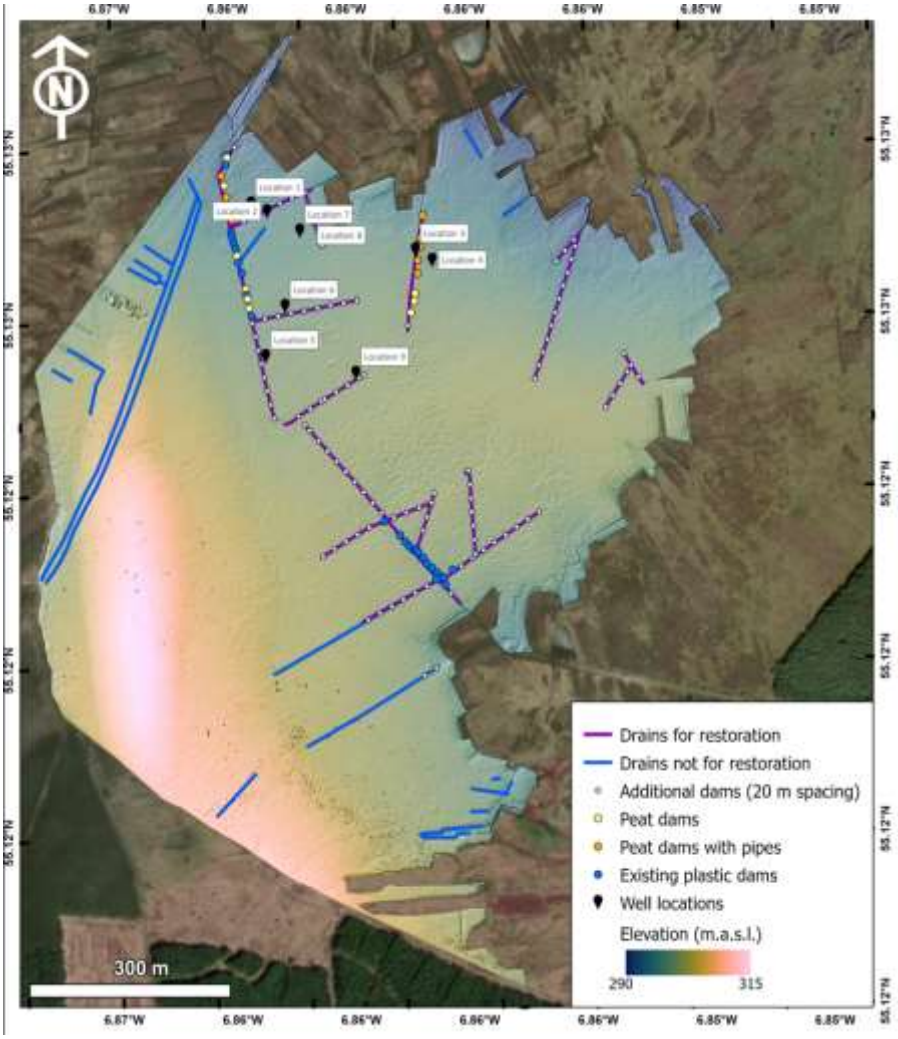

Figure 3: Drone based topographic survey model of Altikeeragh ASSI showing the locations of water level monitoring points, drains and (existing and proposed) dams. The paler area on the western side of the site reflects a more steeply sloping ridge.

Further Investigative Activities (March 2022-March 2023)

Peat Coring

Localised coring, using a 1m x 10mm diameter gouge auger, encountered peat up to 4m thick across that part of the site surveyed by the citizen science programme, thus corroborating programme findings. The results of the coring suggested peat decomposition (of humification) increased with depth from H1-2 (determined using the Von Post classification system) at the ground surface to H6-7 approaching the base of the peat. Where recovered, substrate material consisted of pale grey silty

clay with some granular gravel; this was interpreted as glacial till. Material descriptions were consistent with peat substrate material observed in outcrop on adjacent cutover, which consisted of similar fine grained material, containing rock fragments (clasts) up to boulder size, dominated by metamorphic rock. High levels of refusal / grinding at the base of peat during coring further suggest comparable deposits occur below the high bog.

Further Drain /Dam Surveying

Subsequent to the citizen science dam survey, expansion of the area of interest led to a survey of drains across the remainder of the site. The results of the drone-based topographic survey allowed location of additional potential drains to be identified, and verified by ground truthing. Surveying included measurements of drain dimensions and materials making up any new dams encountered, and the nature of drain infilling material.

The results of the drain survey, apart from corroborating the findings of the citizen science survey, allowed the functioning of dams to be more confidently evaluated. Findings revealed highly variable levels of water retention in more recently encountered dams, with the presence of many plastic dams approaching the southern side of the site proving particularly ineffective due to a failure to appropriately seal them. Nonetheless the plastic materials (, often accompanied by associated supporting cross members,) proved mechanically robust and had potential for inclusion in dam remediation.

A survey of the contact between the high bog and surrounding cutover revealed the contact (or facebank) to regularly exceed 2m in height, leading to significant drops in water levels, and associated subsidence around the bog margins. This, in turn, has led to steeper slopes in a 50m-100m strip around the bog margins. High bog artificial drainage in this area often lacks infilling material, in part reflecting the ability of more steeply sloping drain beds to prevent the establishment of infilling vegetation. Moreover, widespread (>30%) areas of bare peat the steeply sloping surrounding ground reflect its inability to host peat-accumulating vegetation; similar topographic conditions occur on the N-S trending ridge, occurring on the western side of the site.

By contrast, those drains encountered in the centre of the site frequently contained infilling vegetation and occurred in areas with abundance of standing open water and/or evidence of former pool complexes. This is further reflected in the gentle sloping ground conditions encountered in this area.

Although drain dimensions varied across the site from a single ENE-WSW trending drain up to 5m wide (and infilled), approaching the north western boundary of the site, to a smaller number of 1m wide drains encountered around the high bog margins, the majority of drains measured 1-2m in width. Depths (, where measurable,) were up to 1.5m deep. Critically, ground truthing investigation of tentative drains, as identified by lineaments failed to reveal the presence of identifiable drains based on differences in vegetation, and notably infilling by *Sphagnum sp*. mosses. More generally, extensive systems of smaller feeder drains (aka grips), often encountered elsewhere in bog drainage schemes, have not been observed at Altikeeragh; this may explain the relatively good condition of the bog compared to other blanket bogs across northern Ireland.

Groundwater Monitoring

Continuous groundwater monitoring, initiated by Taylor (2022) in December 2021 in the vicinity of a dam on the northern side of the site, was expanded to allow monitoring of wider baseline hydrogeological conditions across the northern part of the site. This consisted of the installation of monitoring wells and data loggers at nine locations (Figure 3, Table 1). Initial monitoring wells, with screens installed to 1m below ground allowed, the range of water table fluctuations to be sampled. Wells were located adjacent to drains to allow for collection of baseline data to compare with responses following to future restoration works, while measurements at Location 7, situated away from drains, aimed to allow drain side well responses to be compared to background conditions.

Piezometer Label	Easting (ITM)	Northing (ITM)	Position	Well ID (mm)	Screen Length (mm)	Logger
Alt-1	672431	931782	Location 1	32	80	2398
T1	672434	931778	Location 1	32	80	
T2	672428	931774	Location 1	32	80	
Alt-2	672455	931771	Location 2	32	80	1970
T3	672447	931777	Location 2	32	80	
T4	672453	931783	Location 2	32	80	
Alt-3	672677	931716	Location 3	32	80	2393
Alt-4	672702	931701	Location 4	32	80	3989
1E	672698	931701	Location 4	32	80	
1G	672701	931699	Location 4	32	80	
Alt-5	672453	931563	Location 5	32	80	2404
1C	672451	931567	Location 5	32	80	
1H	672454	931567	Location 5	32	80	
Alt-6	672482	931635	Location 6	32	80	1798
1F	672482	931642	Location 6	32	80	
1A	672485	931637	Location 6	32	80	
Alt-7	672504	931743	Location 7	32	80	2402
T5	672510	931740	Location 7	32	80	
T6	672510	931747	Location 7	32	80	
Alt-8	672523	931760	Location 8	32	80	7196, baro
T7	672525	931765	Location 8	32	80	
T8	672521	931769	Location 8	32	80	
Alt-9	672588	931539	Location 9	32	80	2392
1B	672586	931536	Location 9	32	80	
1D	672583	931540	Location 9	32	80	

Table 1: Monitoring well construction table. Altikeeragh ASSI.

The results of monitoring over the earlier part of 2022, to the start of the hydrological start of April, revealed little difference in water levels between locations. By contrast differences proved larger during the summer period (until the end of September 2022), when the impacts of evapotranspiration begin to play a more significant role on the bogs water budget (, or the difference in water entering and leaving the bog).

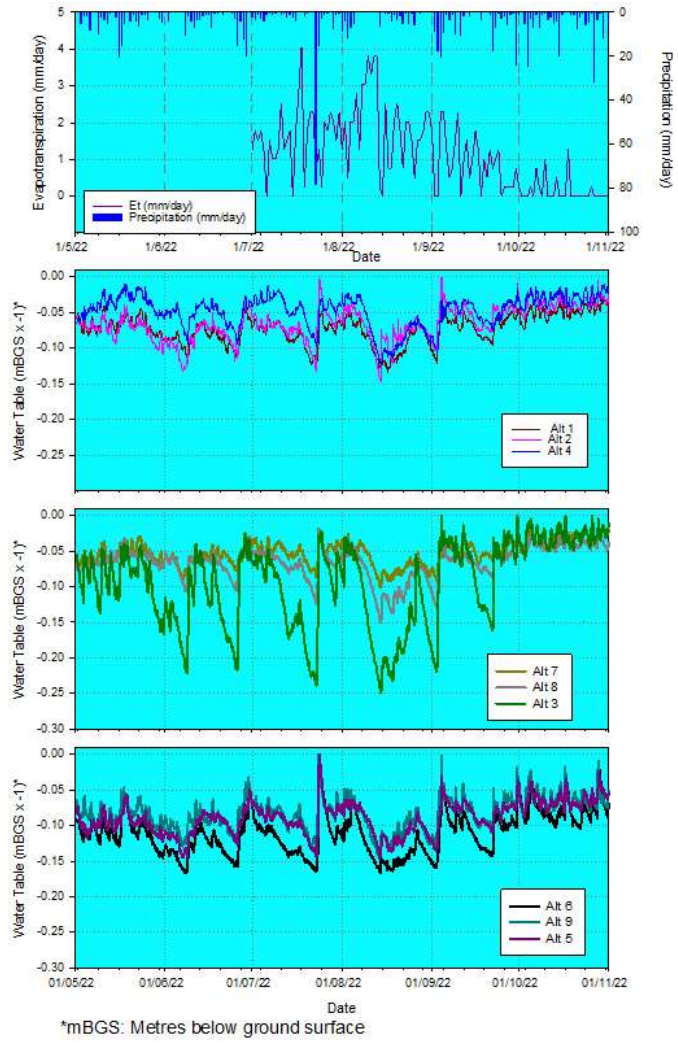

Figure 4: Rainfall, evapotranspiration and groundwater level fluctuations for Altikeeragh Blanket Bog, ASSI 1st May 2022 to 1st November 2022. Note: mBGS-metres below ground surface.

Figure 4 summarises water levels fluctuations for the summer and early winter period of 2022 and reveals a strong relationship between precipitation and groundwater levels. Critically frequent rainfall helps maintain the elevated groundwater levels, which can drop significantly during drier periods, particularly in the vicinity of drains. The range of water level fluctuations varies substantially, with the range of fluctuation proving greatest at Location 3 and Location 8, where the piezometers occur immediately adjacent to a drains containing little infilling vegetation. These contrast with background conditions at Location 7 and Location 4, where the impacts of drains are

considered lowest. Elsewhere drain levels fluctuate slightly more than at Location 7 and Location 4. This is reflected in the water level exceedance plots, presented in Figure 5, where conditions at Location 7 and Location 4 resemble those encountered in peat accumulating raised bog plant communities.

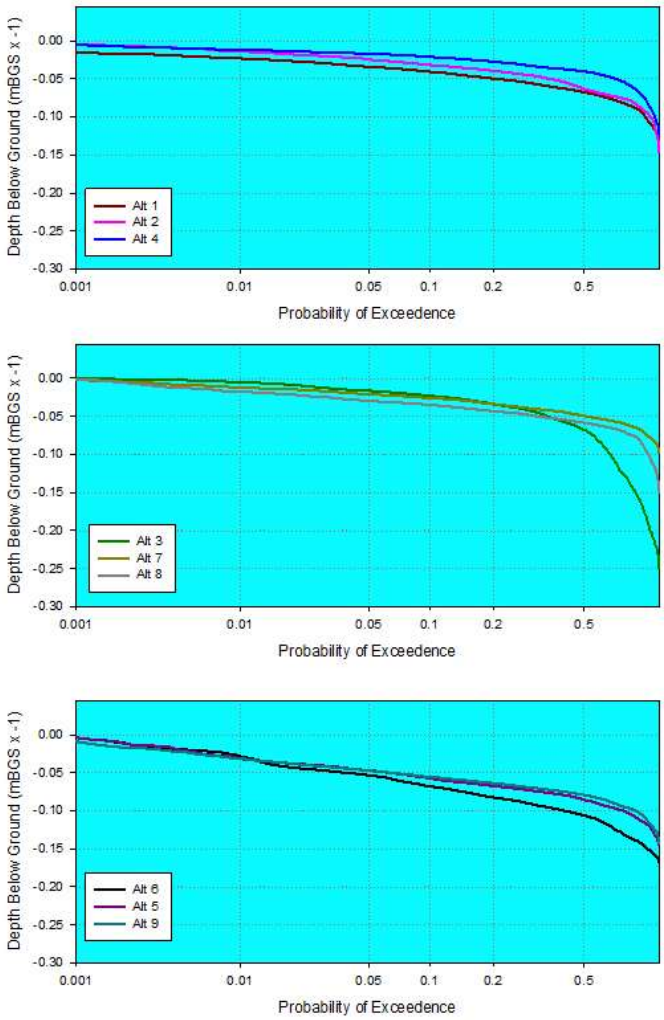

Figure 5: Water level exceedance plots for monitoring wells at Altikeeragh ASSI. Data from 1st May 2022 to 31st October 2022. Note: mBGS-metres below ground surface.

Peat Hydrogeological Profiles

The results of citizen science probing programmes, and subsequent coring, revealed significant thickesses of peat underlying Altikeeragh. However, the properties of this peat could prove crucial for determining its effectiveness in restoration works. In light of the findings of the summer

monitoring programme, further investigations, carried out from October 2022 to January 2023 aimed to understand the role of flowing ground water on peatland vegetation. To this end an innovative programme of water level monitoring, using three monitoring wells at each monitoring location, aimed to assess the variability of groundwater flow rates with depth, and whether the upper layers of peat at Altikeeragh could form suitable damming material. This was achieved by evaluating the variability (and rate of removal) of salt tracer over time and relating this to the hydraulic gradient (or slope of the water table) operating across the immediate area. The resulting data thus provide a means for assessing how easily water can flow through the upper layers of peat and whether it would prove effective as a material for retaining water.

Figure 6, presenting the results of the testing, show that following the injection of tracer significant declines in concentration were observed at all locations over a relatively short time period. However, further examination reveals that concentrations increase with depth , indicating that water flowed faster closer to the ground surface.

Further examination of the hydraulic gradient across the test locations (Figure 7) revealed that with the exception of wells located immediately adjacent to drains, the magnitude of hydraulic gradient does not vary significantly (although the direction of flow does vary substantially at the control location).

Overall results suggest that the uppermost metre of the peat encountered at those locations tested has high permeability, i.e. water may flow through it relatively easily. This is particularly the case in the uppermost parts of the peat, while groundwater flow rates (and permeability) decline with depth. This issue requires consideration in selecting materials for restoration measures, where the construction of peat dams with less permeable peat will prove less effective at retaining water. More generally, findings indicate that use of in-situ peat for restoration works at Altikeeragh should focus on material obtained from greater than 1m below ground surface.

Implications for Restoration

The findings of the hydrological investigations completed at Altikeeragh aid in developing a peatland restoration plan for the site. Drone data (Figure 2) show that conditions in the centre of the bog contrast with those approaching the margins and the western side of the high bog, where, in both cases, steeper ground limits the re-establishment of peat accumulating vegetation. Restoration activity in both of these areas promises to prove challenging, given that establish restoration prove most effective on flatter ground. By contrast areas with gentler slopes prove more amenable to established restoration techniques.

In flatter areas, groundwater monitoring revealed that water table regimes differed across the bog, with conditions proving most variable in the vicinity of drains. Although the impact of the drains on water levels declines with distance, water level duration curves reveal that differences can remain between the control well and wells closer to drains, where water levels proved lower during prolonged dry periods. This can affect the development and survival of peat accumulating plants.

Restoration processes need to re-establish hydrological supporting conditions for peat accumulating vegetation. Central to this process is the maintenance of water levels as close to the ground surface as possible. This is typically considered as within 10cm of the ground surface for more than 90% of the time. Monitoring data from Altikeeragh and elsewhere demonstrate that this objective can be hindered by artificial drainage. Consequently restoration efforts should aim to reduce (and ideally eliminate) the influence of artificial drainage on bog hydrology.

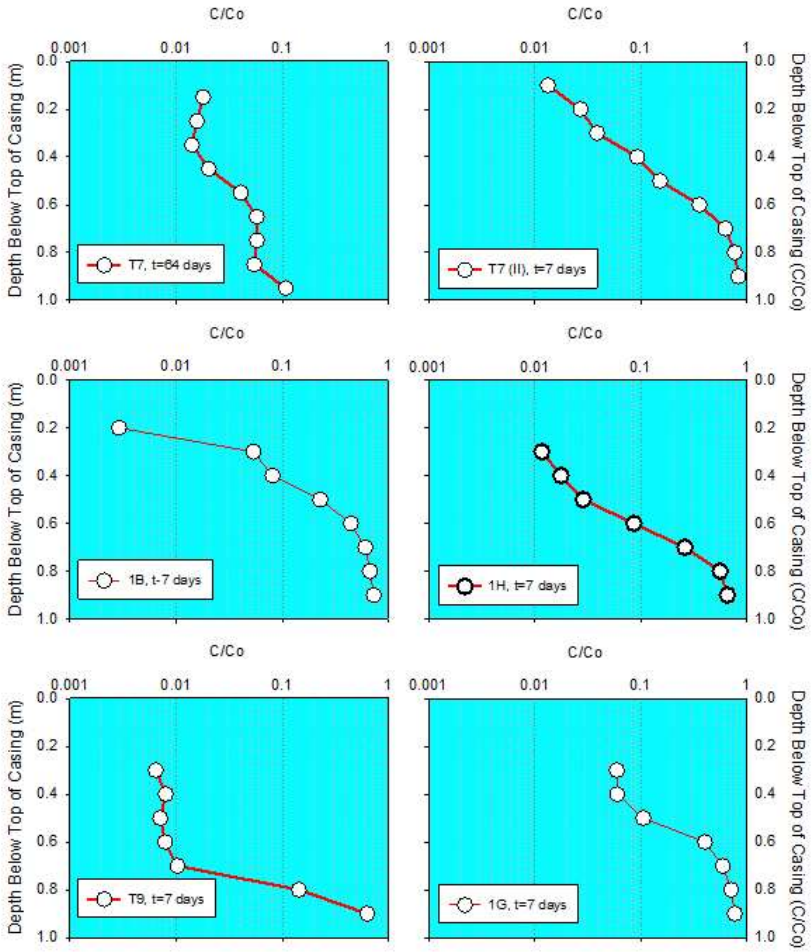

Figure 6: Results of tracer dilution tests(27 Jan 2023 to 3 Feb 2023) at selected monitoring wells, Altikeeragh ASSI. Note the logarithmic scale on the X-axis reflecting the more rapid loss of tracer (and greater groundwater flow rates) in the uppermost parts of the peat. Peat from this shallower part of the bog should not be used for peat dams in restoration works.

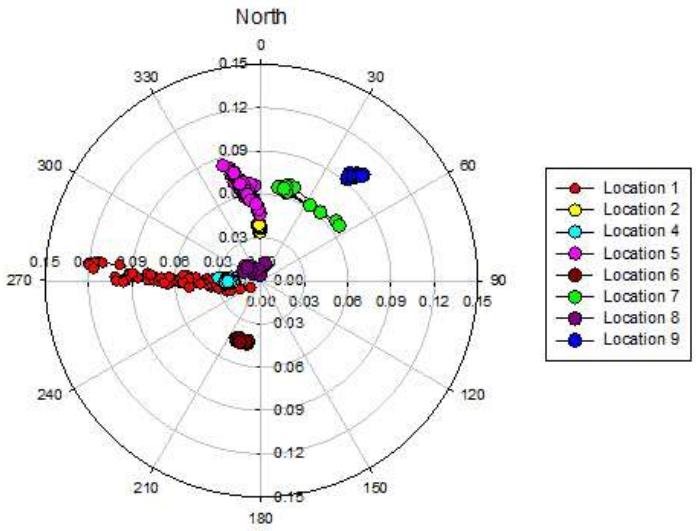

Figure 7: Variation in hydraulic gradient at hydrogeological monitoring points, Altikeergh ASSI. The magnitdue of gradient proved greatest at Location 1 and Location 5, both of which are located within 2m of active drains.

A number of methods exists to tackle the effects of drainage, of which damming and wave damming/zippering require consideration for the restoration of the high bog at Altikeeragh. (See Figure 8 and Figure 9 for schematic illustrations of these methods.) The Nature Scot web site contains details of the basis and implementation of these measures (https://www.nature.scot/doc/peatland-action-technical-compendium-restoration-4-artificial-drains)

Critically, restoration activities need to aim to reduce the impact of drainage and allow for the re-wetting on adjacent areas. Although wave damming and zippering (Figure 9) prove effective in areas of extensive gipping, (i.e. areas with narrow drains), the limited number of drains of suitable dimensions renders this approach of limited relevance at Altikeeragh.

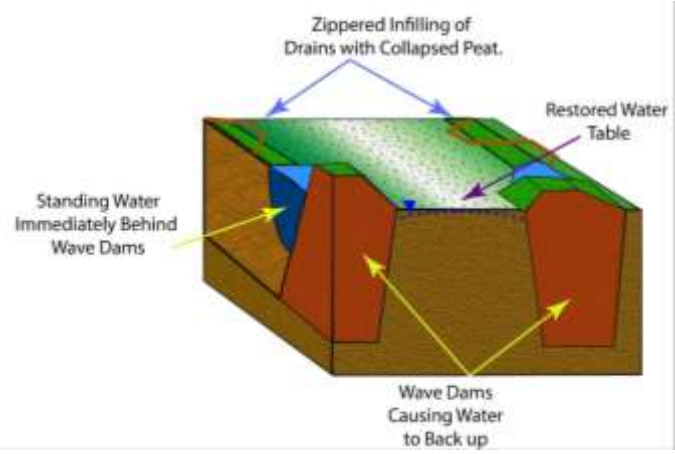

Figure 8: Figure 9: Schematic illustration of the application of wave dams and zippering to artificial drains. The approach is best applied on drains 1.5m wide or less (depending on drain depth), and thus of limited relevance to conditions at Altikeeragh.

By contrast installation of dams at regular intervals across all drain types shows considerable potential to raise water levels, should appropriate measures and materials be employed. Detailed guidance on this issue can be obtained from https://www.nature.scot/doc/peatland-action-technical-compendium-restoration-4-artificial-drains.

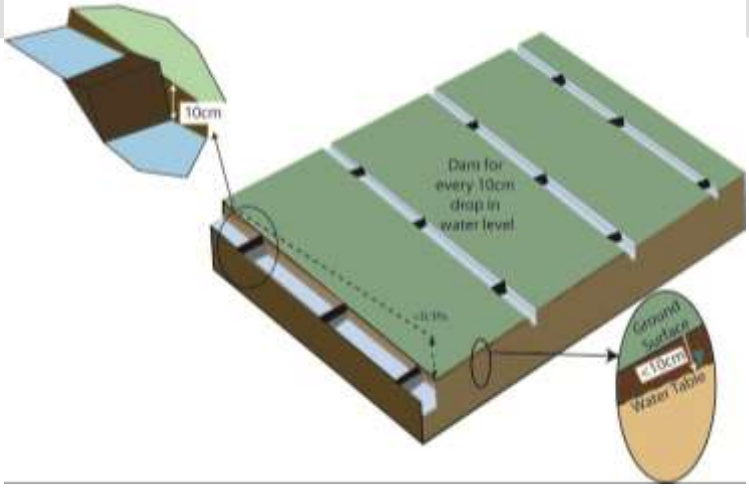

Figure 9: Schematic illustration of the impact of drain damming. Dam can consist of a number of materials, including plastic, timber and peat. Note that the objective of damming is to raise water table levels in the areas separated by drains.

In addition to the recommendations made in the Nature Scot documentation, the following site specific issues need to be considered as potentially relevant to restoration works:

1. Any machinery employed in restoration efforts should aim to minimise its impact on the bog surface.
2. Much of the high bog at Altikeeragh proves particularly soft. Any machinery employed in restoration works needs to factor this issue in. More specifically issues of ground pressure need to be addressed. Table 2 provides a summary of anticipated ground pressures for machines more commonly employed in restoration works.
3. The use of wide track vehicles may prove necessary for restoration works. This may require the removal and replacement of gates and fencing at the site entrance at Ballyhackett Road to allow machinery to enter, given the narrow dimensions of the access ropute.
4. The current dam infrastructure performs at various levels of effectiveness, with many proving ineffective. Nonetheless, the presence of existing dams may be exploited to enhance restoration efforts. More notably the following are proposed :
   (a) Existing peat dams can be employed following the temporary removal of any covering vegetation mats, before, where present, piping passing through them is permanently removed. This should then be followed but the addition, and mechanical compaction, of further peat to raise dams approximately 1m above the surrounding banks. Damming should extend a minimum distance of 1m to either side of the drain bank, where the dam should taper down to the ground surface. Vegetation mats should then be replace on the repaired dam.
   (b) Interlocking plastic sheet pile dams should remain in place (with any upstanding elements cut back to 50cm above bank height or lower. (Elements that fail to reach base of the drain should either be hammered down or removed.) These should form the core of peat dams.
5. Given the properties of the shallowest peat on site, all (on-site) peat to be used for damming, should be derived from more than 1m below ground surface. Borrow pit excavations should thus remove the vegetative cover (to be set aside) before removing the uppermost metre of peat to access deeper peat. It may be necessary to excavate deeper peat from nearer bog margins, should material in central areas prove too soft (and compressible). Shallow peat should then infill the borrow pit.
6. Works should avoid existing hydrogeological monitoring infrastructure (i.e. monitoring wells)
7. Works should ideally be undertaken in later summer / early autumn when conditions on site are anticipated to be drier and ecological impacts will be minimised, e.g. on nesting birds.
8. It is recommended that further maintenance works be undertaken approximately 6 months after completion of initial works to assess (and if necessary repair) any dams that have experienced significant subsidence or erosion.
9. Where drains have infilled with vegetation, this should only be removed locally to avoid inadvertent increases in the hydraulic efficiency of drains (and thus their capacity to remove water).
10. Should machinery be unable to access part or all of the site manual installation of rigid plastic or (plastic coated) timber piles can be undertaken, bearing in mind that overall material costs may considerably exceed those of peat (while machinery costs would be considerably less). Works undertaken using these materials should follow guidelines proved by Nature Scot.

	Track length point to point	minus length track not on ground	track width	Number	Area covered (m2)	Machine weight (kg) x 1000	Ground pressure kg/m2	Ground pressure lbs/sq inch
Small track digger	3	0.4	0.6	2	3.12	6	1923.08	2.74
Standard	3.5	0.6	0.7	2	4.06	13	3201.97	4.55
Fitted bogmaster 1	4	0.8	1.2	2	7.68	13	1692.71	2.41
Fitted bogmaster 2	5	0.8	1.5	2	12.6	15	1190.48	1.69
Oak mats, standard	5	0	1	3	15	13	866.67	1.23
Oak mats bmaster 2	5	0	1	4	20	15	750	1.07

Table 2: Summary of ground pressures to be anticipated for contrasting restoration machinery. Data courtesy of Bryan Irvine (DAERA)

Dam Locations

Given the nature of the artificial drainage configuration and the topographic conditions encountered at Altikeeragh, the potential for restoration is considered greatest in the central part of the site, where the drainage network on flat (and wet) ground is densest. Figure 3 presents proposed locations for a restoration network incorporating both exiting dams (to be renovated) and new dams. The co-ordinates for the dams are provided in the spread sheet accompanying this report. Critically damming should also focus on installations as close to the (visible) drain starting points. The spread sheet provides co ordinates for works, accurate to approximately 2-4m..

In addition systems of dams with different spacings are proposed, ranging from every 10m to every 50m. Although damming every 10m is anticipated to prove more effective than every 50m, the associated benefit is not directly proportional. The precise number of dams installed will ultimately depend on available resources.

Concluding Remarks and Ecosystem Services

Overall, hydrological monitoring at Altikeeragh suggests that the site has considerable potential to restore to peat accumulating conditions. Topographic and hydrological data suggest that the central part of the site displays the greatest potential for restoration works.

Benefits for restoration can be anticipated to extend beyond those of terrestrial biodiversity, with an improvement in ecosystem services provided by the bog. These include

- Slowing of runoff from the bog through damming can be expected to stabilise flow to streams draining Altikeeragh, including those areas supplying the Northern Ireland Water drinking water reservoir at Ballyrees. (See Appendix II)
- Restoration of conditions at the site can also be expected to reduce organic carbon and ammonia loads to receiving water bodies, thus helping improve aquatic ecosystem health while improving the quality of raw water entering Ballyrees (See Appendix II for supplying catchment locations).
- In a similar light, the increase and stabilisation of water levels can be anticipated to reduce greenhouse gas emissions from the site and improve its carbon sequestration capacity.

Consequently the benefits of restoration activities at Alikeeragh extend to affect the wider environment. Quantifiying these effects will provide an evidence base for the benefits of blanket bog restoration at Altikeeragh and other blanket bogs across Northern Ireland, with the site providing a useful and quantifiable indication of how conditions may be anticipated to change following restoration works. This issue proves particularly relevant, given the relatively pristine condition of the site.

Consequently Altikeeragh acts as an important flag ship site for blanket bog restoration across Norther Ireland. Given the scientific approach adopted in the study, the following are recommended (should funds prove available) to improve the benefits and knowledge base that will arise around restoration works.

1. Hydrological monitoring of precipitation and evapotranspiration should continue throughout and following any restoration. This will entail not additional equipment costs, although the station will require routine maintenance.
2. Hydrogeological monitoring of groundwater levels should continue for the foreseeable future, with data loggers being downloaded every six months. Manual water level

measurements should be made immediately prior to downloading. At current settings, the loggers may be anticipated to function satisfactorily for the next five years.

3. If possible runoff should be monitored in one or more of the streams draining the site, ideally before the start of restoration works to allow the impact of restoration of flow stability to be quantified. This would entail additional expense for the installation of one or more flumes and monitoring devices, yet would allow the bog's water budget to be more confidently assessed.
4. The quality of the water draining the site should be monitored to assess how restoration would affect key water quality parameters, notably ammonium and dissolved organic carbon. This has critical implications for both aquatic ecosystem health and raw water quality entering Ballyrees Reservoir.
5. Hydrological monitoring should be accompanied by a programme of terrestrial ecological monitoring on the bog, and aquatic ecological monitoring on streams draining it. Ideally surveying should be undertaken before restoration works. This will allow wider ecological benefits of restoration to be better quantified and linked to blanket bog hydrological parameters.

Appendix I

March 2022 Interim Report

Interim Report on the Status of Baseline Hydrological Measurement at Alitkeeragh Nature Reserve ASSI

Introduction:

The following interim report outlines activities carried out at the 180.5 ha Altikeeragh Blanket Bog ASSI (Altikeeragh) (Figure 1) by QUB personnel to assess the potential of the site to host restoration measures. Blanket bog habitat, encountered across Altikeeragh has experienced significant impacts from human activity, which have affected its ecology. Impacts have included cutting and associated drainage around bog margins, while a system of drains on the uncut (high) part of the bog have impacted high bog hydrology. The work presented in this report forms the first part of a two-part report, with this section describing work completed to 31st March 2022. Works completed in the period between April 2022 and September 2022, and the findings of the investigation will be described in a subsequent report.

Figure 8: Location map for Altikeeragh Blanket Bog ASSI, Northern Ireland. Aerial Image: ESRI.

Peat-accumulating uncut high bog forms a priority habitat that can provide important ecosystems services to water, biodiversity and the atmosphere. However, damage to the blanket bog across Altikeeragh has resulted in the loss of peat-accumulating conditions. Work carried out by Flynn et al. (2021) on Irish blanket bog has demonstrated that this can result in degradation and/or loss of ecosystems services, while in some cases habitat degradation may result in bogs providing ecosystem disservices. Reinstating peat accumulating habitat allows for the restoration of services,

yet may require direct human intervention. Previous blanket bog restoration programmes across Britain and Ireland have had limited success, largely as a consequence of works engineering being undertaken without underpinning science informing appropriate measures. Scientific data provide relevant data to allow these options to be developed in a more unbiased and scientifically defensible manner. Critically restoration needs to be underpinned by an understanding how water behaves (hydrology) and how it can influence plant communities (ecohydrology).

To date the favoured means of ecohydrological restoration for peatlands across Britain and Ireland has involved drain blockage by damming at fixed intervals along its course to cause water to back up; this aims to generate a water table rise in adjacent peat. Investigations completed by Cushnan (2017) have demonstrated that for peat-accumulating *Sphagnum* species to re-establish and begin to form peat once again, water table levels need to be within 10cm and 15cm of the ground surface for over 90% of the time; levels below this threshold are incapable of supporting peat-accumulating vegetation.

Published studies quantifying levels of success in re-establishing peat-accumulating vegetation prove scarce, while those studies that have been published often focus on the re-growth of vegetation in drains. Although regrowth of peat accumulating vegetation in drains proves important, it needs to be recognised that restoration measures should aim to re-establish peat forming conditions on the ground beyond the drain. Put another way, re-establishment of hydrological supporting conditions for peat forming vegetation within drains, although necessary, may prove insufficient to raise the water table sufficiently on surrounding peat to allow for re-expansion of active (peat accumulating) blanket bog and the *Sphagnum sp.* that dominate it. Moreover, the elevated permeability of living *Sphagnum sp*., encountered within drains, implies that even though drains have infilled with vegetation they can still support flowing water at rates which may prove significantly higher than those in the surrounding peat, thus facilitating significant through flow and impacts on surrounding water tables. Assessing how well drain blockage achieves these goals underpins investigations at Altikeeragh.

The following sections describe investigative measures and instrumentation installed at Altikeergh to evaluate the effectiveness of current and proposed restoration activity. Works aim to identify those areas where further measures may be limited/unnecessary, while trying to optimise the success of the forthcoming restoration programme at those parts of the site where further intervention is required. More generally, activities aim to provide critical baseline data against which the impact of restoration activities can be compared and quantified. Moreover, comparing these data provide a justification for monitoring the success of restoration measures, and adjusting them with time, should outcomes prove unsatisfactory.

Baseline Survey

To develop and implement a restoration programme for Altikeeragh, Causeway Coast and Glens Heritage Trust engaged Queen's University Belfast personnel (Flynn, Graham) to undertake a baseline study of site conditions at Altikeeragh to characterise the hydrological regime. This employed site-specific investigation methods, followed by the installation of a hydrological monitoring network. Data to be generated by the network will provide the underpinning needed to assess to what degree restoration works have achieved the goal of restoring a hydrological regime, needed for the re-establishment and expansion of peat accumulating conditions. Works consisted of a series of elements, described below.

<u>Preliminary Drain Survey</u>

Preliminary investigations completed by Dr. R. Flynn (SNBE, Queen's University Belfast) in August 2021 noted the presence of a number of high bog drains across Altikeeragh, which varied in width and depth, but mostly having a width of approximately 75cm and a depth of approximately 1m. Although some drains contained flowing water, dams across others, installed by NIEA contractors in YEAR, limited water flow. Dam construction and materials varied, but consisted largely of drains made from humified (decomposed) peat and/or interlocking plastic sheet piling. Observations of water levels on either side of dams suggested that their efficacy varied significantly, with many displaying evidence of leakage. Typical failure mechanisms consisted of the following

1. Incomplete interlocking plastic sheet piling: Plastic sheet piling, driven into the peat failed to span the fill width of a drain, resulting in by-pass of interlocking piles.
2. Leakage through plastic sheet piles: Ineffective interlocking of plastic sheet piling results in excessive water loss through dams. Although damming may slow the decline of water levels in the drains, flow through the dams results in a failure to maintain elevated water levels for sufficiently long period to keep water tables at target elevations to support *Sphagnum sp.*
3. Surface bypass of peat dams: Surface water flows around peat dams installed into drains, resulting in an inability to maintain elevated water levels. This typically occurs following temporary backup of water, leading to erosion of peat and the establishment of flow paths around a dam. These can deepen with time, resulting in a gradual loss in drain efficiency.
4. Subsurface flow through/around peat dams: Inappropriate installation of peat plus and/or the use of excessively permeable peat can result in excessive seepage of water through peat dams. In addition, this installation of 4" (100mm) plastic pipes, passing through dams, ensured that drain levels cannot exceed maximum levels which may prove too low to prevent the re-establishment of peat accumulating vegetation.

Aerial Survey

Although a valuable sequence of aerial images exists for Alitkeeragh, the resolution of available digital data has proven insufficient to allow for confident identification of key hydrological features. To address this issue, Conor Graham (SNBE, QUB) undertook an unmanned aerial vehicle (UAV) survey of Altikeeragh and its immediate surroundings. Processing of these data has permitted more confident identification of drains, particularly those on high bog areas, which many have subsequently infilled with vegetation (yet remain hydraulically active).

Figure 2 presents a hillshaded image of the area covered by the UAV survey. The use of hill shading has permitted more confident identification of both key drains and the outline of that part of the site where peat cutting/marginal drainage has not taken place; this corresponds to approximately 75ha of the site, with remaining areas consisting of blanket bog cutover or isolated fragments (<1ha) of high bog.

Further analysis of the hillshaded image has allowed for tracing of the principal drains crossing the site and a preliminary identification of the locations of existing high bog dams, installed as part of previous restoration works. In additional, digital topographic data collected (Resolution) during the survey permitted estimations of both ground elevation and slope across the site. Based on survey findings a limited area of Altikeeragh, considered most promising for the re-establishment of peat accumulating conditions, based on the slope and proximity of marginal drainage.

Commented [RF1]: Aisling/Andrew to provide.

Commented [RF2]: Still awaiting feedback from Conor on this.

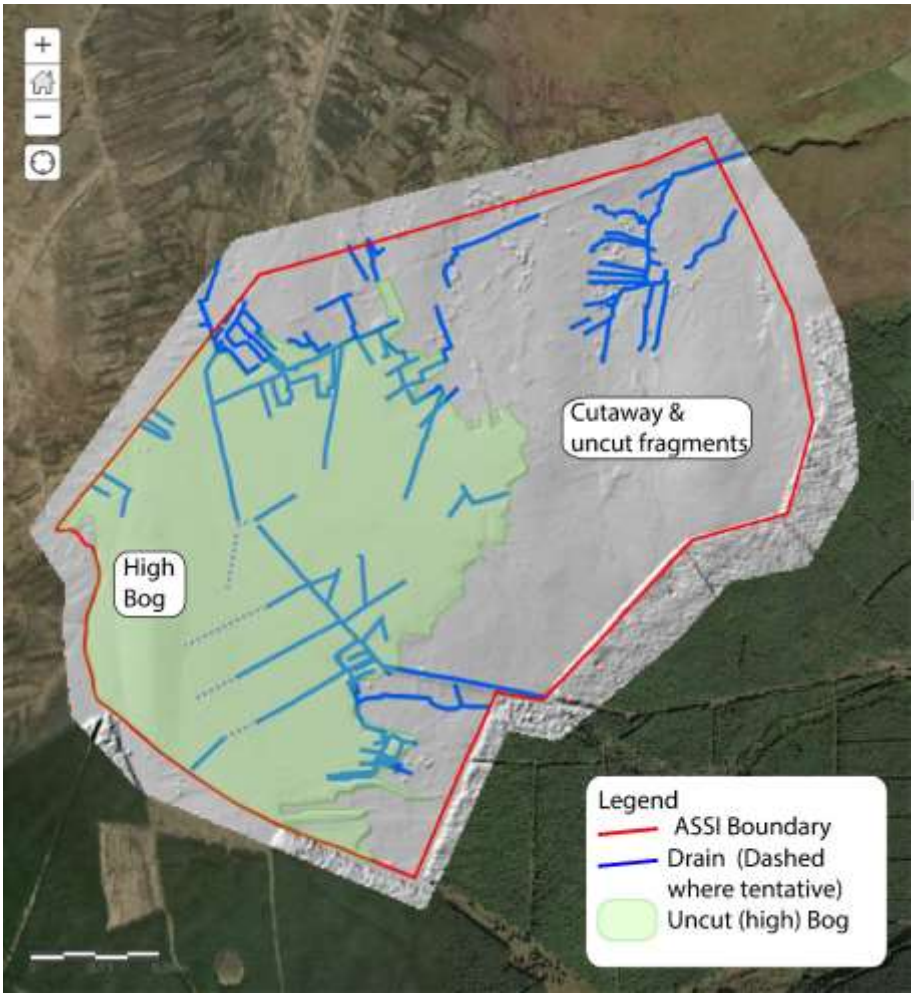

Figure 9: Hillshade digital elevation model of Altikeeragh ASSI, generated from UAV imagery. Use of these processed data have permitted the area of high bog to be estimated at 75ha.

Citizen Science Survey

To facilitate an improved understanding of the location of dams, and their condition, across the northern part of Altikeeragh, a citizen science-based programme, completed on 31/10/21, employed number volunteers to record drain location, drain type and drain condition across the northern part of the site, targeted for restoration. In addition, a secondary element of the citizen science programme involved a programme of coring at regular intervals to assess peat thicknesses (to determine if peat exceeded 2m in thickness).

Figure 3 presents the results of the survey, showing those locations where dams had been placed across drains (and their constituent materials).

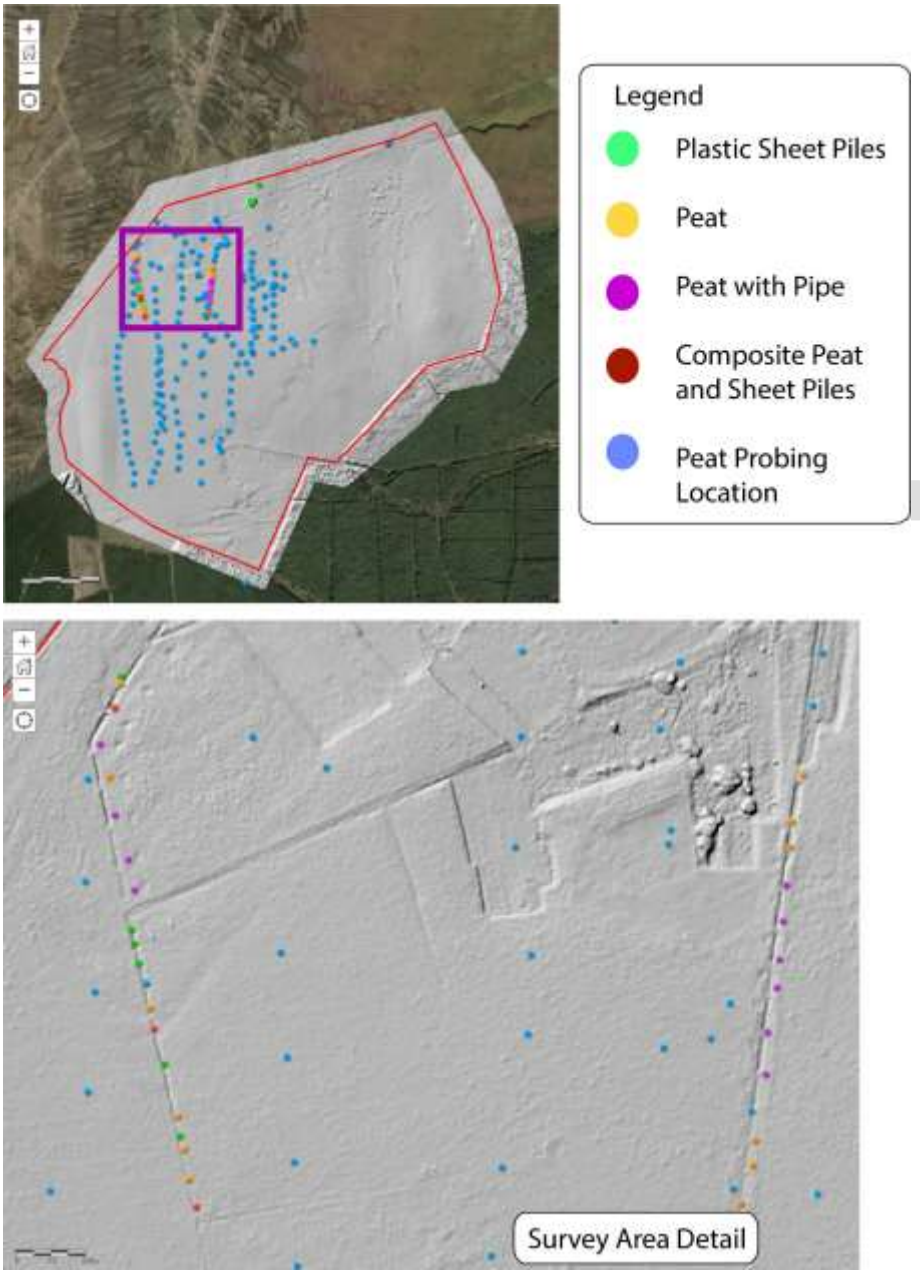

Figure 10: Hillshaded digital terrain model of Alitkeeragh ASSI, presenting the drain dam/composition and peat probing location data collected by citizen science programme. Note that the position of dams, off the course of drains, reflects the lower resolution of the global positioning systems (on mobile phones) employed by citizen science volunteers.

Dam Efficiency Investigations

Dam survey data revealed the presence of a number of peat dams containing 100mm (4") pipes installed through their centre. The presence of the pipes was considered to present a potential opportunity to undertake a preliminary programme of inexpensive restoration measures in which blockage of the pipes could raise groundwater levels in the peat to allow evaluation of peat to limit the transmission of groundwater. No data existed on the evaluation of this method. To address this short coming, Ray Flynn and Beth Taylor (SNBE, QUB) investigated the capacity of dams to retain water following blockage, based on rates of tracer dilution passing through peat over one to two week periods. The north-western end of the survey area, detailed in Figure 3, acted as the pilot area for investigation. Completion of dilution testing prior to and following blockage of the drain permitted the contrast in seepage rates to be examined. Finding of the research are anticipated in April 2022.

Hydrological Network

Linking groundwater level responses to prevailing hydrological conditions proves fundamental for assessing the capacity of Altikeeragh to facilitate conventional restoration measures. Installation of a mobile weather station in December 2021 has permitted high resolution monitoring of precipitation and the parameters needed to determine evapotranspiration. These data have been made available on an open access platform at the following site: Personal Weather Station Dashboard | Weather Underground (wunderground.com)

Results to Date

Aerial Survey: The findings of the aerial survey have proven valuable in identifying drain and dam locations, while also facilitating the identification of those areas most suited to restoration through dam blockage. Full use of the topographic data generated has yet to take place.

Weather Station: The Divis portable weather station continues to successfully record meteorological conditions at Altikeeragh at approximately half hourly intervals. Further modification of the system is under investigation to assess the potential to automatically provide potential evapotranspiration measurements to complement precipitation data, given the potential of the former parameter to to act as a major element of blanket bog budgets during the summer period (Flynn et al., 2021)

Drain Survey: Findings of the drain survey suggest a limited number of drains have been blocked on Altikeeragh, with the two principal drains crossing the northern end of the site containing a variety of damming materials. Observation suggest that the capacity of these features to retain water varies significantly, with some proving completely ineffective. Conversely, other dams have proven more effective at retaining water. However, as preliminary monitoring data suggest, some of these are incapable of maintaining the water table above the threshold level to support the survival of peat accumulating plant communities during drier periods. In all cases where target hydrological conditions have not been met, upgrading/replacement of dams will prove necessary.

Dam Efficiency.

Preliminary findings of the dam efficiency study suggest that water moves through the peat at variable rates at Altikeeragh, with flow proving greater during wetter periods. Conversely, declines in water table occur during prolonged dry periods. Measurements suggest that the peat in the Dam Efficiency Study Area consists of an upper more permeable layer, through which water flows rapidly.

This is underlain by a lower permeability unit, which transmits groundwater at a considerably lower rate. At the study area, flow through the upper more permeable unit has allowed water levels to decline below the threshold for peat accumulating vegetation, despite blockage of pipes passing through the peat dam. Profiling of monitoring wells installed into the peat have revealed that this upper 20-50cm of peat proves highly permeable. Consequently, measures to raise the water table will need to limit discharge through this upper layer to maintain the water table at a sufficiently high level to facilitate re-establishment of peat accumulating vegetation. On-going measures at Altikeeragh will aim to establish the distribution and depth of this layer. This in turn will inform the depth of peat to be replaced in installing/upgrading existing dams across the site.

Forthcoming Work for Summer/Autumn 2022

The findings of the investigations completed to date form a core element of future works. More specifically the findings have informed the investigation programme to be completed in the next (approximately) five to six months to provide essential summer baseline hydrological data to monitor the impact of evapotranspiration on bog water table levels during the summer period. This will involve installation of monitoring wells and data loggers (to be provided by CCGHT) in the vicinity of the area targeted for restoration works at the end of the summer. This will thus provide a means to more widely monitor water table fluctuations, while also facilitating the measurement of key peat properties, notably it hydraulic conductivity and how this varies across the restoration area. These findings will in turn underpin the design and selection of appropriate restoration strategies, most appropriately suited to the re-establishment of hydrological supporting conditions needed to support active (peat accumulating) blanket bog.

Appendix II

Catchments for

Northern Ireland Water Reservoir

at Ballyrees

General
Catchment Management

Title : Ballinrees WTWs upland subcatchments
Note :

Centre X-Y: 275,182 429,044 **Plotted by** : Allenr@WATER
Scale : 1 : 50000 **Date** : 10 February 2022 **Time** : 15:04:58 General A4 Landscape

northern ireland water
Delivering what matters