1. INTRODUCTION

1.1 BACKGROUND

Hydro-Environmental Services (HES) were requested by MKO to respond to a further information request issued by Galway County Council on 19th April 2023 for the proposed Derryclare Wild Western Peatlands Project, Co. Galway (Planning Ref P23/60).

This report responds to Item 3 of the further information on queries relating to the geological, hydrological and hydrogeological environments.

1.2 STATEMENT OF QUALIFICATIONS

Hydro-Environmental Services (HES) has extensive hydrological and hydrogeological experience relevant to this project. Upland hydrology, forestry and windfarm related drainage design are core areas of business for HES. HES routinely completes environmental impact assessment reports in terms of hydrology and hydrogeology for proposed developments on peatlands (forestry and renewable energy projects). HES also specialises in the area of wetland hydrology, ecohydrology and bog restoration and has worked with National Parks and Wildlife (NPWS) on several bog and wetland restoration projects. HES has extensive experience in surface water drainage design and surface – groundwater interactions.

HES have worked on over 100 wind farm projects in Ireland and Northern Ireland. Many of these were situated on peatlands and required assessments of existing drainage features, streams and water quality data. HES work at all stages of wind farm developments including feasibility stage, layout design & preliminary drainage design/planning stage, and also at construction management stage. Wind farm drainage design/management requires experience both as a civil/drainage engineer, a hydrologist and as a hydrogeological specialist. HES have these combined experiences and expertise which are also relevant to this project.

HES's experience covers the key area of water quality and drainage controls and mitigation during all phases developments. HES work at EIAR/planning stage to assist with development of the optimal site layout which involves development of hydrological constraints maps and interaction with geotechnical and ecological specialists and with site designers. HES also provide a follow-on consultancy service (if planning is granted and the development proceeds to construction) of detailed drainage design and construction management for drainage during development/construction stage. This practical on-site experience is invaluable as it has led to the development of improved preliminary and detailed drainage layouts and also many improvements/optimisations to standard peatland drainage mitigation measures.

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1.3 SUMMARY OF KEY MATTERS RAISED

HES have reviewed the Galway Co. Co. RFI (dated 19th April 2023) along with the submission made by National Parks and Wildlife (NPWS) (dated 12th April 2023). The key issues raised by the Planning Authority and NPWS regarding drainage management and surface water quality are largely contained within request Item 3 and are summarised in **Table A**.

Table A: Summary of FI request Item 3

Key Matter Raised	Item Ref
The Local Authority requests robust scientific evidence that the proposed methodologies of drain blocking, damming, drain reprofiling, stump flipping, surface smoothing, mulching and cross-tracking do not pose risks of water quality impacts.	3 (a)
Insufficient baseline water quality monitoring.	3 (b)
Information gap in relation to the rainfall data utilised to demonstrate the pluvial impact of water drainage.	3 (c)
Additional detailed should be presented in the Flood risk Assessment including the additional loading to existing surface water features and the ability of harvest blocks to accommodate the predicted rainfall.	3 (d)

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2. RFI ITEM RESPONSE

2.1 ITEM 3 (A)

Item 3 (a) of the RFI issued by Galway County Council on 19th April 2023 is reproduced below:

> *"The Irish Peat Conservation Council (IPCC) raised concerns within their initial scoping response regarding the adequacy of current "best practice approaches" to assessing peat strength and stability, these have been found wanting, owing to numerous landslides across the country. This in combination with the concerns raised by the DHLGH regarding using untrialled and untested methods of peat restoration in an upland area of the west of Ireland; the applicant is requested to provide sufficient supporting evidence demonstrating the trailing and testing of the proposed methods, including the provision of likewise case studies, providing the Local Authority with robust scientific evidence that the proposed methodologies of drain blocking, damning, drain reprofiling, stump flipping, surface smoothing, stump mulching and cross-tracking and do not pose detrimental risks of peat disturbance, peat erosion, peat stability and water quality impacts as a direct result of the development. The supporting evidence should be comprehensive and include the appropriateness of the proposed drain blocking using dams on slopes of greater than 6 degrees, the project proposes these works on slopes of 10 degrees which is contrary to current recommendations and untested in Ireland. Please comprehensively address this concern."*

2.1.1 Item 3 (A) Response

With respect to potential water quality effects which may arise from drain blocking, damming, drain reprofiling, stump flipping, surface smoothing, stump-mulching and cross-tracking, detailed mitigation measures are presented in the EIAR Chapter which ensure the protection of surface water quality and compliance with WFD objectives. A detailed Hydrological Monitoring Plan for the project is also attached in **Appendix I**.

Issues with respect to slope stability and associated implications for the project viability have been considered carefully at all stages of this project. A detailed Peat Stability Risk Assessment (PSRA) has been completed by Fehily Timoney (FT) for the Proposed Project. The PSRA is attached to the EIAR as **Appendix 7-1** and concluded that the site has an acceptable margin of safety, is suitable for the proposed peatland rehabilitation works and is considered to be at low risk of peat failure. The PSRA also includes recommendations and mitigation measures for rehabilitation works in peatlands, all of which will be implemented to ensure that the proposed works adhere to an acceptable standard of safety.

2.2 ITEM 3 (B)

Item 3 (b) reads as follows:

> "The applicant should have monitored the water quality within and connected to the site in more detail to ascertain baseline quality information to inform both the EIAR and in the assessment of risk in relation to the Appropriate Assessment. Baseline data should be collected over an appropriately representative period, combining both manual and automatic monitoring triggered by flow and submitted in support of the application."

2.2.1 Item 3 (B) Response

The baseline surface water quality of the site is presented in Section 9.3.6 and Section 9.3.13 of the EIAR.

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Section 9.3.6 presents surface water quality data obtained specifically for the EIAR study. The data presented in this section comprises of grab samples (2 no. rounds of 5 no. samples completed by RPS on 10th August and 8th October 2022) and field hydrochemistry (14 no. locations monitored by HES on 22nd and 23rd of November 2022). We acknowledge that the results presented in Section 9.3.6 represent water quality data from grab sampling.

However, long-term water quality data for the baseline environment is also presented in Section 9.3.13 of the EIAR. In this section, the Water Framework Directive (WFD) status of the waterbodies within and connected to the project site is discussed. Under the WFD, waterbodies can be awarded 1 of 5 no. status ranging from "Bad" status to "High" status. Waterbodies are assigned a status based on monitoring of biological elements (*i.e.* fish, macro-invertebrates etc.) and supporting elements (hydromorphology, nutrients, dissolved oxygen etc.). Each of these elements contribute to the overall WFD status of a waterbody, with the lowest common denominator rule being applied, whereby the lowest scoring element denotes the overall status of a waterbody. The EPA completes extensive monitoring work in support of the WFD and the frequency of monitoring is outlined in **Table B** and corresponds to the minimum monitoring frequencies as recommended in Annex V of the WFD.

Table B refers to 2 no. types of monitoring programme completed by the EPA: Surveillance Monitoring (SM) and Operational Monitoring (OM). Surveillance Monitoring provides a comprehensive and long-term picture of water body status while Operational Monitoring assesses any changes in the status of the waterbody.

According to www.catchments.ie there are a total of 10 no. National Water Monitoring Stations located on Derryclare Lough downstream of the project site (refer to **Figure A** below). Therefore, the "High" status achieved by the Derryclare lake waterbody has been assigned following water quality monitoring at these stations as per the frequencies outlined in **Table B**. Given the wide range of parameters and the frequency of monitoring completed by the EPA in order to assign a WFD status to Derryclare Lough, we consider that the WFD status provides sufficient water quality information for this waterbody and any additional sampling would be superfluous. Whilst we note that there are no National Water Monitoring Stations located on Lough Inagh, we consider that the grouping of its WFD status with that of Derryclare Lough is adequate. Given the close proximity and similarity of these two lake waterbodies, any additional sampling at Lough Inagh is unnecessary. We acknowledge that there are no EPA monitoring stations on the small streams which drain the site but additional monitoring has been completed to address this issue – see below.

Therefore, the WFD status of the lake waterbodies in the vicinity and downstream of the site are assigned based on the results of an extensive monitoring programme which combines biological, hydromorphological, physico-chemical monitoring. Consequently, it can be concluded that the WFD status of the lake waterbodies presented in Section 9.3.13 presents the results of long-term monitoring in the vicinity of the site and is sufficient for the EIAR process.

Furthermore, additional monitoring has been completed since October 2022 in order to provide additional information relating to the baseline hydrological environment. This additional monitoring comprised of monthly grab samples at 5 no. locations (4 on local streams within the site and 1 on Lough Inagh) and Biological Quality Surveys at 4 no. streams within the site. The results of the biological surveys ranged from High (Q4-5) to Moderate (Q3-4). The high status was achieved in the upper reached of a watercourse and the status of this watercourse decreased further downstream. Meanwhile, the results of the monthly grab samples from January to April show that the recorded parameters in the local watercourses and Lough Inagh are typically below the respective EQS apart from elevated concentrations of zinc. The waters have low alkalinity, are very soft, have low nutrient concentrations and

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are acidic with low pH values. The full results of this monitoring is presented as an appendix to the monitoring plan (attached as **Appendix I**).

Furthermore, it is fully intended to complete a detailed monitoring plan in advance of the proposed works. This monitoring plan includes general water quality monitoring during the Pre-Construction and Post-Construction phases, with more intensive monitoring completed during the Construction Phase. During the Pre-Construction Phase it is proposed to record key hydrochemical parameters (temperature, conductivity, and turbidity) through the use of automated probes at 15 minute intervals. In addition, monthly grab samples will be taken for phosphorous and annual biological monitoring will be undertaken. The data from the Pre-Construction monitoring will furthermore aid the characterisation of the baseline hydrological environment. The detailed monitoring plan is attached as **Appendix I.**

Therefore, given the combination of the monitoring completed as part of the EIAR study (field hydrochemistry and grab sampling) and the long-term monitoring completed by the EPA as part of the WFD process, we consider that the baseline water quality information presented in Chapter 9 is sufficient for the EIAR process. Furthermore, once permission is received for the Proposed Project, additional water quality monitoring will be completed in advance of any works and this data will be used to further characterise the baseline hydrological environment.

Table B: Frequency of monitoring for each quality element in the national surface water WFD monitoring programme (EPA, 2021)

Water Quality Element	**Water Category**	
	Rivers	**Lakes**
	Biological	
Macroinvertebrates Fish Aquatic Plants	Every 3 years (annual monitoring of macroinvertebrates in priority areas)	Every 3 years
Phytobenthos	Annual (SM))	Twice per annum every 3 years (SM)
Phytoplankton	-	Twice per annum (SM)
	Hydromorphology	
Hydromorphology	Every 6 years	Every 6 years
	Priority Substances	
Priority Substances	12 times per annum every 6 years	12 times per annum every 6 years
	Physico-Chemical	
Nutrients Oxygen Conditions Acidification	5 times per annum (OM) 12 times per annum (SM)	4, 6 or 8 times per annum (OM) 12 times per annum every 3 years and as per OM frequency in other years (SM)
Specific Pollutants	12 times per annum every 6 years	12 times per annum every 6 years

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Figure A: National Water Monitoring Stations (www.epa.ie)

2.3 ITEM 3 (C)

Item 3 (c) reads as follows:

> "It is noted that the rainfall data utilised to demonstrate the pluvial impact of water drainage across the site relies on data from a monitoring station in Claremorris and data collated from Met Eireann from 1965-1985, where the extents of extreme rainfall as a result of climate change would not have been recorded. This information gap alongside the relatively high levels of existing peat saturation combined with the proposed drain blocking, removal of trees & exposure of bare peat needs to be adequately analysed and studied to determine the risks posed and mitigation required to protect peat stability on-site and avoid any resultant impact on Population and Human health, biodiversity, land, soil and water quality as well as in the adjoining SAC. The applicant is requested to provide site specific standard rainfall data from recent monitoring carried out over an appropriate period across the application site, this should collate alongside the peat depths, saturation levels in corresponding months and results of the FRA. (requested on item d)."

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2.3.1 Item 3 (C) Response

Rainfall Data

The RFI suggests that the rainfall utilised in the EIAR chapter was from a monitoring station in Claremorris and relied on data collated from Met Eireann from 1965 to 1985. This statement is incorrect.

The data from Claremorris weather station was utilised solely with respect to average potential evapotranspiration. Average potential evapotranspiration data is only available for 14 no. weather stations in the Republic of Ireland. Whilst we acknowledge that this weather station is located ~54km northeast of the project site, it is the closest weather station for which evapotranspiration data is available. As stated in Section 9.3.2, the annual potential evapotranspiration at Claremorris is 408mm/yr. Other weather stations on the Atlantic Coast for which potential evapotranspiration data is available include Bulmullet and Shannon Airport, located ~80km northwest and ~100km to the southeast of the project site respectively. The annual potential evapotranspiration at these locations is 527mm/yr and 543mmm/yr. Despite the differences in potential evapotranspiration between these 3 no. rainfall stations, the data from Claremorris is chosen due its proximity to the project site.

With respect to the rainfall data presented in Section 9.3.2 of the EIAR, the rainfall data was sourced from the nearest available rainfall station, *i.e.* Ballynahinch rainfall station, located ~7km to the southwest of the project site. We recognise that Ballynahinch station closed in 1985. However, Met Éireann have modelled the 30-year average rainfall for this station for the period from 1981 to 2010 (www.met.ie). The 30-year annual average rainfall for the period from 1981 to 2010 for Ballynahinch rainfall station was utilised in the assessment of runoff and pluvial effects associated with the Proposed Project.

In addition, Section 9.3.2 of the EIAR presents rainfall return periods for the project site. Rainfall return periods were sourced from Met Éireann (www.met.ie) which uses a depth duration frequency model to estimate point rainfall frequencies for a range of durations for any location in Ireland. Site-specific rainfall return periods specific to the project site are presented in the EIAR.

Nevertheless, we also recognise that the standard average annual rainfall (SAAR) of 1,211mm/yr referenced in the EIAR underestimates the actual rainfall at the project site. Met Éireann now provide a grid of SAAR for the entire country for the period of 1991 to 2020. Based on these site-specific modelled rainfall values, the SAAR at the project site ranges from 2,283 to 2,489mm/year, with an average of 2,429mm/yr.

An updated water balance is provided below, assuming an average annual rainfall of 2,429mm/yr.

Effective rainfall (ER) = SAAR – AE
= 2,429mm/yr – 387mm/yr
ER = 2,042mm/yr

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Groundwater recharge coefficient estimates from the GSI (www.gsi.ie) vary across the project site from 4% where the project site is overlain by peat to 85% where bedrock outcrop is present. Due to the extensive coverage of blanket peat at the site, the low permeability of the bedrock aquifers and the sloping nature of the topography, a recharge coefficient of 10% is taken for the project site. Based on this coefficient, an estimate of 204.2mm/year average annual recharge is given for the project site. This means that the hydrology of the project site is characterised by very high surface water runoff rates and very low groundwater recharge rates. Therefore, conservative annual recharge and runoff rates for the project site are estimated to be 204.2mm/yr and 1837.8mm/yr respectively.

SAAR and Implications for Peat Stability Assessment

The rainfall depths referenced in Chapter 9 of the EIAR has no direct implications for the Peat Stability Risk Assessment (PSRA) completed for the Proposed Project. The completed PSRA does not use standard annual average rainfall (SAAR) as an input parameter in the peat stability calculations. The slope stability calculations are completed assuming a fully saturated peat profile (i.e. the water table is conservatively assumed to be at ground level), and a surcharge of 10kPa (*i.e.* an additional surface load) is applied to each analysis point. This surcharge is equivalent to 1m of stored peat or 1m of water (simulated) above ground level (given the similar density of peat and water). Therefore, the peat stability risk assessment accounts for additional water load (from seasonal and temporal rainfall events) in this manner, and not directly by use of the SAAR rainfall value for the site.

2.4 ITEM 3 (D)

Item 3 (d) is reproduced below:

> "The application site including post operational needs to be fully assessed against the increased flood risk posed by the change of use of the land, including the changes to the management of the existing water courses and drainage flows within the application site. The FRA should examine the additional loading to the existing surface water features within the site, the ability of each harvest block to accommodate the predicted rainfall, including saturation rates of the peat, the structural capacity of the proposed dams (at the various locations) to accommodate predicted extreme pluvial events, as well as assessing the adequacy of the proposed silt traps and fencing and any additional mitigation measures which may be required)."

2.4.1 Item 3 (D) Response

Flood Risk

The purpose of the Proposed Project is to restore and rehabilitate the project site to Atlantic Bog and heathland habitats.

The project site was planted with coniferous forestry plantations in the 1960s. In order to facilitate the forestry operations at this time, the site was drained by inserting forestry drains, typically mound and ribbon drains, into the peat surface at ~15-20m intervals. The effect of this "draining" was that the water table in the peat bog was lowered, with water making its way into the forestry drains which in turn discharged into local watercourses and into Lough Inagh and Derryclare Lough. Following the change in land use at Derryclare to forestry, the Derryclare site retained less water than in its original undrained "natural" state. Furthermore, due to the current imposed forestry drainage system the local watercourses (*i.e.* mountain streams) likely respond more rapidly to rainfall events and likely have flashier hydrographs than would have occurred in its natural state.

With respect to the hydrological and hydrogeological environment, the overall aim of the Proposed Project is to restore the hydrological regime as much as practicable to its original state. Restoration and rehabilitation will place the existing peatland environments on a path towards naturally functioning peatlands.

Improvements in runoff volumes can be achieved through rehabilitation and restoration. The plans involve the rewetting of the drained peatlands (by increasing the saturation rates of the peat) through restoration works such as drain blocking, surface smoothing and re-profiling. These works will reduce surface water runoff from each harvest block, and on a wider scale increase the water storage capacity of the overall site. This will result in the hydrograph of nearby watercourses being less flashy, with a more gradual response to rainfall events. Therefore, these measures will reduce and delay the hydrograph peak on each of the local watercourses, and also reduce the flood risk downstream of the site.

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Furthermore, irrespective of the volumes of runoff from the project site, all runoff from the site enters either Lough Inagh or Derryclare Lough. These are a series of large, interlinked lakes, and they have a huge ability to buffer rainfall runoff. As a result, the potential for an increase in downstream flood risk as a result of the proposed project is negligible.

<u>Structural Capacity of Dams</u>
As detailed in Chapter 4 of the submitted EIAR, the slopes and sizes of the drains will be the deciding factors in selecting the dam material types and also the spacing of the dams.

The selection of dam materials will be based on the existing best practice bog restoration techniques and guidelines. Peat dams will only be used on a shallow slopes (<10° gradient), with plastic dams being used on steeper slopes. The spacing of dams will also improve the structural capacity of the dam by decreasing the loading an any one dam. The dam spacing should be between 7.5 m and 20 m on flatter ground, however, the frequency of dams should increase to between 5 m and 7 m on steeper sloping ground.

<u>Adequacy of Silt Traps and Silt Fencing</u>
As detailed in the EIAR, silt fences and silt traps will be installed at the outfalls of existing drains before the commencement of any works. In areas that are particularly susceptible to erosion (*i.e.* steeper slopes), it may be required to install double or triple silt fences. These measures follow all existing best practices and guidelines in relation to felling and bog restoration and will ensure the protection of downstream surface water quality.

With respect to the adequacy of these features, silt traps and silt fences are widely used during peatland restoration for the prevention of suspended solids entrainment in runoff. Silt traps/fences are incorporated into the Construction Phase for water quality protection only, and they serve no function in long term water attenuation within the Rehabilitation Plan. During the Construction Phase silt traps/fences will be regularly inspected to ensure that they are functional and turbidity will be measured downgradient of the works areas. Necessary repairs and maintenance will be completed when required following inspections. In the event that elevated turbidity concentrations are recorded downstream, all upstream silt traps and silt fences will be inspected and no additional works will be completed until necessary repairs are made and downstream turbidity concentrations return to baseline levels.

No additional mitigation measures are deemed necessary.

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Appendix I:
Derryclare Wild Western Peatland Project, Co. Galway.
Proposed Hydrological Monitoring Plan

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DERRYCLARE WILD WESTERN PEATLANDS PROJECT, CO. GALWAY
PROPOSED HYDROLOGICAL MONITORING PLAN

Prepared for:
Coillte Nature

Prepared by:
Hydro-Environmental Services

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1. INTRODUCTION

1.1 BACKGROUND

Hydro-Environmental Services (HES) were requested by Coillte Nature to prepare a Hydrological Monitoring Plan for the Derryclare Wild Western Peatlands Project, Co. Galway.

The monitoring plan defines hydrological monitoring proposals associated with the Derryclare Wild Western Peatlands Project. The aim of the project to restore and rehabilitate ~281 hectares (ha) of Atlantic Bog and heathland that is currently planted with lodgepole pine and Sitka spruce forests and managed for commercial forestry.

The hydrological monitoring plan will be implemented throughout the lifetime of the proposed project including a period of pre-construction monitoring, monitoring during the construction phase and operation phase (i.e. post construction) monitoring. The monitoring will determine the success rate of the proposed project by monitoring several key hydrological parameters before and after the proposed works. Any deviation from the baseline hydrological environment recorded during the operational phase will quantify the success of the project. Separately, monitoring will also be implemented during the construction phase for the protection of local surface water quality.

The project site at Derryclare lies to the west of Lough Inagh and Derryclare Lough in Connemara, Co. Galway. A site location map is shown as **Figure A** below.

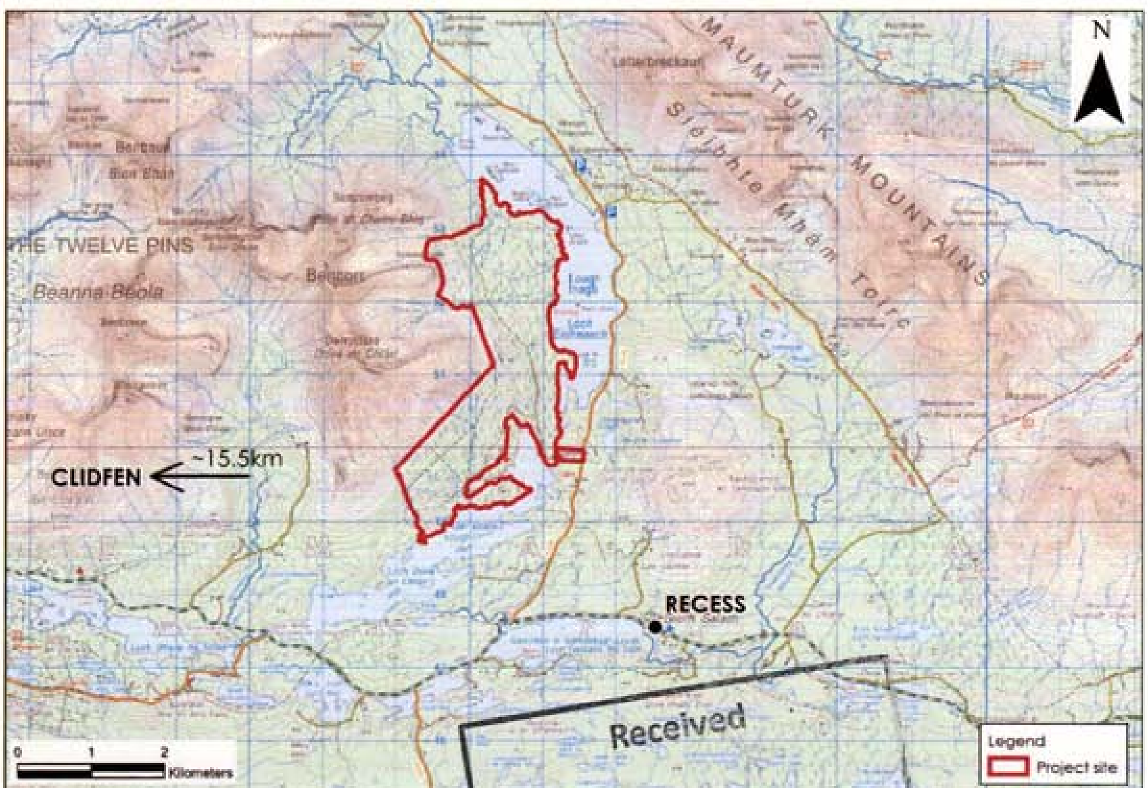

Figure A: Site Location Map

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1.2 STATEMENT OF EXPERIENCE

Hydro-Environmental Services ("HES") are a specialist geological, hydrological, hydrogeological and environmental practice which delivers a range of water and environmental management consultancy services to the private and public sectors across Ireland and Northern Ireland. HES was established in 2005, and our office is located in Dungarvan, County Waterford.

Our core areas of expertise and experience include upland hydrology and forestry and windfarm related drainage design. We routinely complete impact assessments for hydrology and hydrogeology for a large variety of project types. We also specialise in the area of wetland hydrology, ecohydrology, and bog restoration.

This hydrological monitoring plan was prepared by Michael Gill and Conor McGettigan.

Michael Gill (BA, BAI, Dip Geol., MSc, MIEI) is an Environmental Engineer and Hydrogeologist with over 22 years' environmental consultancy experience in Ireland. Michael has completed numerous hydrological and hydrogeological impact assessments of wind farms and other developments in coniferous forestry plantations and bogs in Ireland. Michael has substantial experience in surface water drainage design and SUDs design and surface water/groundwater interactions. For example, Michael has worked on the EIS for Oweninny WF, Cloncreen WF, Derrinlough WF, and Yellow River WF, and over 100 other forestry and wind farm-related projects. Michael also routinely provides hydrological/hydrogeological support and input to bog and wetland restoration projects.

Conor McGettigan (BSc, MSc) is an Environmental Scientist with 3 years' experience in the environmental sector in Ireland. Conor holds an MSc in Applied Environmental Science and a BSc in Geology from University College Dublin. Conor has prepared the hydrology and hydrogeology chapter of EIARs for numerous projects including wind farms, grid connections and quarries. Conor has also been involved in several bog restoration projects including the restoration of Clonaslee Fen and Liffey Head Bog.

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2. SITE SETTING AND BASELINE CONDITIONS

2.1 INTRODUCTION

This section provides summary details on the existing environment and the hydrological/hydrogeological characteristics in the area of the project site.

2.2 PROJECT SITE DESCRIPTION AND TOPOGRAPHY

The Coillte property at Derryclare (the "project site") lies to the west of Lough Inagh and Derryclare Lough in Connemara, Co. Galway. The project site lies to the north of the N59 which joins Galway in the east to Clifden in the west.

The project site is owned by Coillte and was planted with Sitka Spruce and Lodgepole Pine in the 1960s. The overall Coillte landholding at Derryclare is ~567ha with the majority of the project site being dominated by coniferous forests (76%). The forestry plantations at Derryclare are of low to moderate productivity. Approximately 6% of the project site is unplanted, comprising of bog or wet heath habitats or is located along riparian buffer zones. An additional 18% of the forest cover has been felled or burnt and is reverting naturally wet heath or blanket bog.

The project site can be accessed from the R344, which branches off the N59 to the southeast of the project site and extends northwards travelling to the east of Derryclare Lough. A forestry track extends westwards from the R344 into the project site between Lough Inagh and Derryclare Lough. The project site is currently served by approximately 6.8km of forestry roads and tracks.

Topography of the project site is highly variable, ranging from 10-180mOD (meters above Ordnance Datum). The project site lies on the eastern slopes of Derryclare and Bencorr mountains with topography sloping steeply to the east towards Lough Inagh and Derryclare Lough. The western section of the project site contains the steepest gradients. Meanwhile, the eastern section of the project site, adjacent Lough Inagh and Derryclare Lough, is comparatively flatter.

2.3 PROJECT SITE – ENVIRONMENTAL SETTING

2.3.1 Geology

The published soils (www.epa.ie) maps show that the project site is predominantly overlain by blanket peat (BktPt) with some acid shallow, rocky, peaty mineral soil (AminSRPT) located on the higher ground in the west.

The published subsoils map (www.gsi.ie) shows that the north of the project site, along the western shores of Lough Inagh, is underlain by blanket peat (BktPt). Further south, till derived from metamorphic rocks (TMp) is mapped along the western shores of Derryclare Lough. Meanwhile, bedrock outcrop or subcrop (Rck) is mapped on the elevated ground in the west of the project site.

Soils and subsoils have been verified at the project site by intrusive site investigations completed between Summer 2021 and Winter 2022 (RPS, FT). The recorded peat depths range from 0.1 to 4.7m, with peat at the project site being typically shallow – 81% of peat probes recorded peat depths of less than 2m. The peat is underlain by till or solid bedrock.

2.3.2 Hydrology

The project site lies on the eastern slopes of Derryclare and Bencorr mountains and on the western shores of Lough Inagh in the north and Derryclare Lough in the south. The project site

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drains to these 2 no. lake waterbodies via several mountain streams. These streams rise on the mountains to the west of the project site and flow to the east, through the project site, before discharging into the adjacent loughs.

Detailed drainage maps for the project site have been produced by HES using EPA/OSI mapped watercourses, aerial photography, field mapping and Lidar data.

Within the project site there are also numerous manmade drains that are in place predominately to drain the forestry plantations. The current internal forestry drainage pattern is influenced by the topography, peat subsoils, layout of the forest plantation and by the existing road network. The forestry drains are the primary drainage routes towards the natural streams at the project site.

Recent hydrological monitoring completed as part of the EIAR included (refer to **Figure B**):

- Surface water flow monitoring was completed at 12 no. locations within the project site by HES (SW1-SW14, no flow monitoring was completed at SW2 or SW9) on 22nd and 23rd November 2022.
- HES also completed field hydrochemistry analysis was completed by HES at 14 no. locations.
- RPS completed grab sampling at 5 no. locations (P1-P5) on 2 no. occasions (10TH August and 08th October 2022).

The following additional monitoring has also been completed since January 2023 (refer to **Figure B**):

- Coillte have completed monthly grab sampling at 5 no. locations (P1-P5).
- Biological Quality Surveys were completed at 4 no. locations (DB2-DB4, and DB6) by Mayfly Ecology.

Summary of Recent Monitoring Results:

- A large range of flow volumes (2L/s to 2,000L/s) were encountered.
- Field hydrochemistry parameters were as expected for mountainous streams on peatlands: Electrical conductivity (EC) ranged between 64 and 117µS/cm, % dissolved oxygen saturation was between 69 and 93% and the pH values were generally acidic, ranging between 4.2 and 6.9.
- Based on the RPS grab sampling (2022):
    - All suspended solids were below the S.I. 293/1988 threshold limit of 25 mg/L;
    - 9 out of 10 samples were found to be of High status with respect to Ammonia (S.I. 272/2009);
    - Nitrate was below to LoD (Limit of Detection) in all samples ((<0.51mg/l N);
    - All samples were found to be of High status with respect to Orthophosphate (S.I. 272/2009); and,
    - Total phosphorous concentrations were below the LoD in all samples.
- Based on the Biological Quality Surveys:
    - DB-2 achieved "Moderate" status i.e. Q3-4
    - DB-3 and DB-6 achieved "Good" status i.e. Q4
    - DB-4 achieved "High" status i.e. Q4-5.
- The Coillte grab sampling from Jan 2023 – April 2023 found that:
    - The waters have low alkalinity, are very soft, have low nutrient concentrations and are acidic with low pH;
    - All suspended solids concentrations were below the S.I. 293/1988 threshold limit of 25mg/L;
    - Only 1 of 16 no. samples was found to be above the Good status threshold with respect to Ammonia (S.I. 272/2009);
    - The concentration of orthophosphate in the 16 no. samples were ≤0.01mg/L and all samples achieved High status (S.I. 272/2009); and,

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- Zinc was elevated in all sites (P1-P5) with the average concentration ranging from 8.75µg/L at P3 to 19.67µg/L at P5.

The full results of the 2023 biological quality surveys and grab sampling is presented in the attached Biological and Chemical Monitoring of Surface Waters (**Appendix I**).

The locations of the recent surface water monitoring points are shown in **Figure B** below.

2.3.3 Hydrogeology

A shallow perched ground water table exists in the peat and is largely isolated from the underlying regional groundwater system (which occurs in the underlying bedrock).

Due to the extensive coverage of peat at the project site, combined with the low permeability of the bedrock aquifer and the sloping nature of the surface topography, groundwater recharge at the project site is limited and water is rapidly discharged to nearby forestry drains and natural streams.

Recent hydrogeological monitoring completed at Derryclare included:

- Installation of 27 no. piezometers at Derryclare in 2021 by RPS in order to record the elevation of the peat water table (note that 16 no piezometers are located within the proposed restoration areas i.e. study areas – see **Figure C**).
- These piezometers were dipped on 2 no. occasions in autumn 2021 (August and September).

Summary of Monitoring Results:

- The elevation of the peat water table ranged from 0 mbgl (metres below ground level) to 0.67mbgl.

The locations of the existing piezometer network within the proposed restoration areas of the project site are shown in **Figure C**.

2.3.4 Designated Sites

The project site is surrounded on all sides by the Twelve Bens/Garraun Complex SAC and pNHA (Site Code: 002031). While the project site is not located within any designated conservation site, direct hydrological connections exist between the project site and the Twelve Bens/Garraun Complex SAC and pNHA (Site Code: 002031). All watercourses draining the project site flow into Lough Inagh and Derryclare Lough which both form part of the SAC/pNHA.

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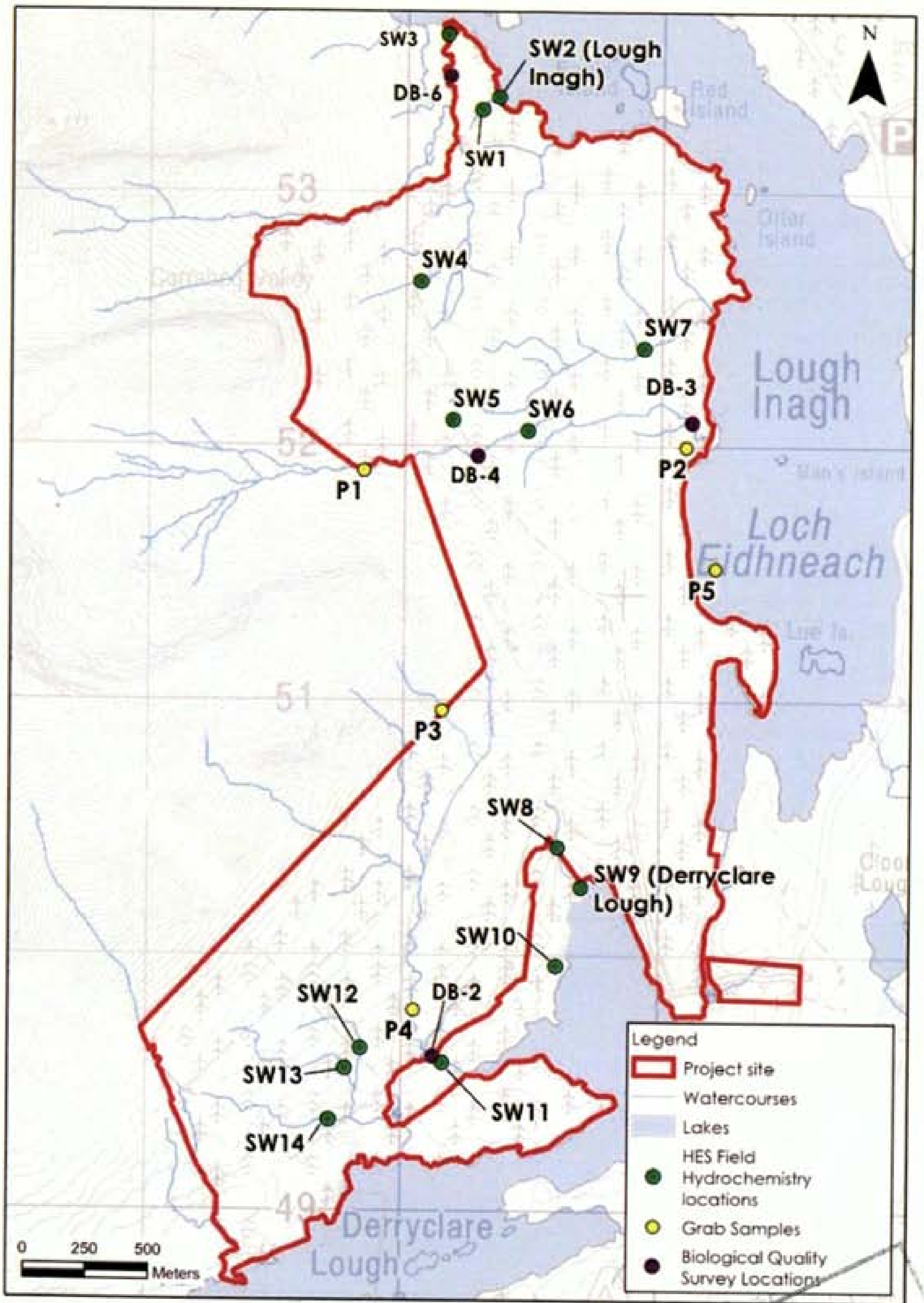

Figure B: Existing Surface Water Monitoring Locations

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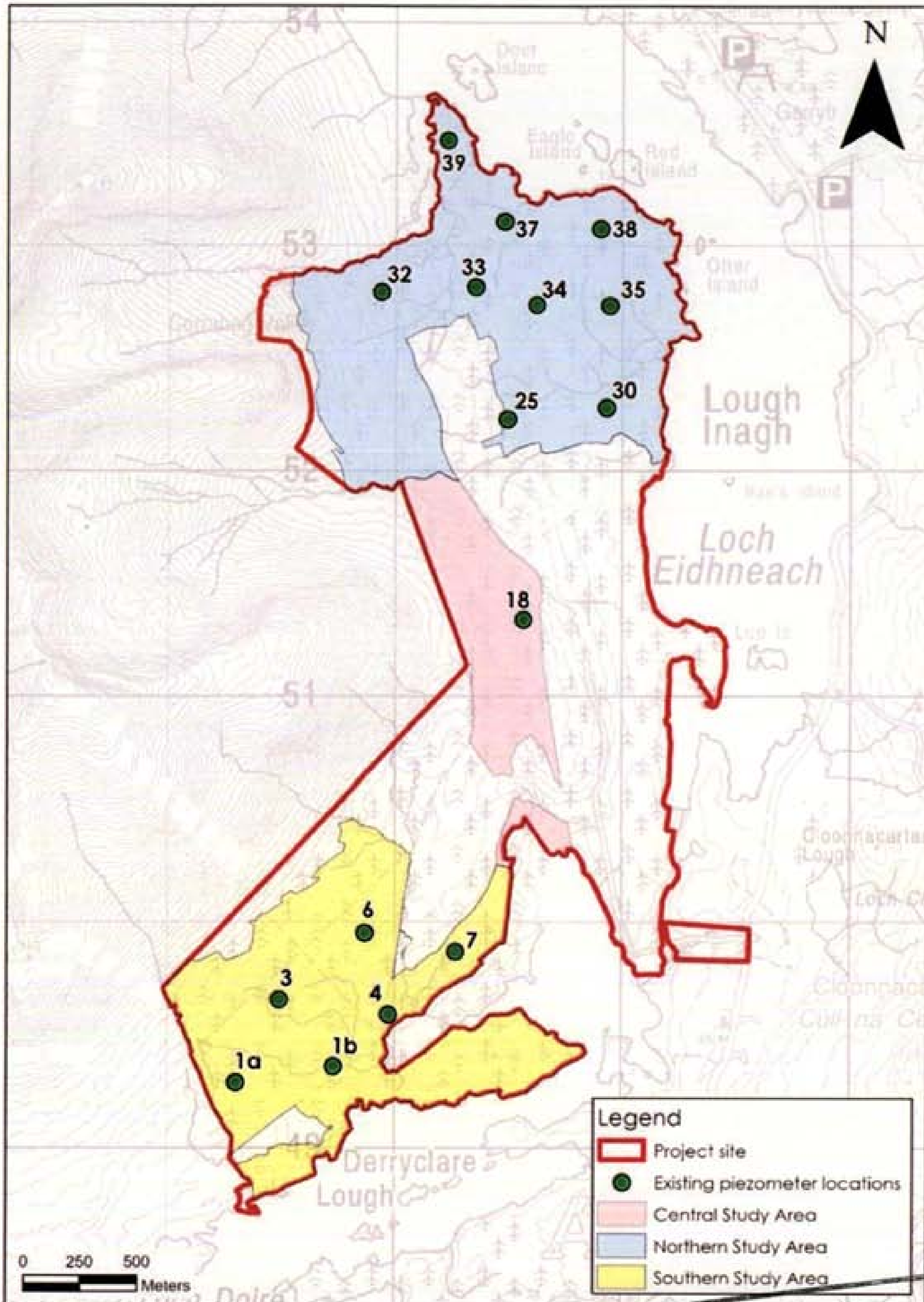

Figure C: Existing Ground Water Level Monitoring Network within study areas (RPS, 2021)

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3. PROPOSED PROJECT AND KEY HYDROLOGICAL ISSUES

3.1 PROPOSED PROJECT

The Derryclare Wild Western Peatlands Project (the "proposed project") aims to restore and rehabilitate ~281 hectares (ha) of Atlantic Bog and heathland that is currently planted with lodgepole pine and Sitka spruce forests and managed for commercial forestry. The Proposed Project will comprise of felling of the existing forestry plantations and a series of restoration works, including drain blocking and ground reprofiling designed to aid the restoration of the peatland at the project site. The Proposed Project also aims to convert ~62 Ha of coniferous forestry to native scrub woodland.

Coillte have subdivided the Derryclare landholding into a total of 22 no. forestry harvest blocks. A total of 2 no. harvest blocks (GY27_HB0025 and GY27_HB0026) are not included in the Proposed Project. GY27_HB0025, located in the south and west of the project site is already natural bogland and does not require restoration. Meanwhile, GY27_HB0026 located towards the center of the project site and along the western shores of Lough Inagh will be retained as commercial forestry. As part of the Proposed Project the other 20 no. harvest blocks will be subject to felling (where felling has not already been completed) and the implementation of restoration measures.

The harvest blocks proposed for restoration are spread out across the Derryclare Site and are located in different local surface water catchments. However, all restoration areas ultimately drain to Lough Inagh and Derryclare Lough.

3.2 REQUIREMENT FOR A HYDROLOGICAL MONITORING PLAN

3.2.1.1 Determining the Overall Success of the Restoration Project

Hydrological monitoring is an essential element of any peatland restoration project. It is of paramount importance in determining whether the restoration measures have been successful and whether the overall objectives of the project are being achieved.

The success of the Derryclare Wild Western Peatlands project will be determined by the comparison of several key hydrological characteristics between the operational phase (i.e. post-construction) and the pre-construction phase.

In terms of peatland restoration the key hydrological characteristics of any hydrological monitoring plan are:

<u>Surface Water Flow Volumes</u>:
Following rainfall events in a drained upland peatland site, such as that which currently exists at Derryclare, water quickly enters the surface water drainage network. Drained peatlands contain a dense network of manmade drains which in turn discharge to local natural watercourses. At Derryclare, the mound and ribbon forestry drains discharge into the numerous natural mountain streams which flow through the site before discharging into Lough Inagh and Derryclare Lough.

This rapid discharge of water into the drainage network can be monitored through continuous water level and flow monitoring. The resulting hydrographs from a drained peatland show a rapid and flashy response to rainfall events with steep rising and falling limbs and a very short lag time between peak rainfall and peak discharge (refer to **Figure D**). In drained peatlands, water flows rapidly downslope following rainfall/storm events.

The aim of the Derryclare Wild Western Peatlands Project is to restore ~281ha of conifer plantation to peatlands. This will be achieved through restoration measures including drain blocking which aims to slow down the rate at which surface water is discharged downstream. Therefore, the hydrographs from a restored peatland will be more subdued in

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comparison to a drained peatland, with more moderately sloping rising and falling limbs and an increased lag time between peak rainfall and peak discharge (refer to **Figure D**). In a restored peatland, more water will be retained by the bog and this water will be released at a slower rate and over a longer period of time in comparison to a drained peatland.

However, the hydrology of the restored peatland is unlikely to ever return to pre-drained characteristics (prior to the 1960s) which would have been characterised by a very subdued hydrograph.

Elevation of the peat water table:
Another hydrological parameter used to determine the success of peatland restoration projects is the elevation of the peat water table with respect to the ground surface.

In a drained peatland the elevation of the peat water table is subdued to the presence of surface water drains. The network of forestry drains at Derryclare have lowered the peat water table and the hydrograph of the peat water table is flashier, with sharp peaks corresponding to rainfall events and steep falling limbs (refer to **Figure D**). The capacity of the site to store water is reduced due to the rapid discharge of water to the forestry drain network.

The elevation of the peat water table in a restored peatland will be located closer to the ground surface in comparison to that of a drained peatland. The peat water table hydrographs will be more subdued in comparison to a drained peatland, with more moderately sloping rising and falling limbs (refer to **Figure D**).

However, the hydrology of the restored peatland is unlikely to ever return to pre-drained characteristics (prior to the 1960s) which would have been characterised by a peat water table close to or at the ground surface.

3.2.1.2 Surface Water Quality Monitoring During Construction Phase

Whilst the overall success of the project will be determined by monitoring during the pre-construction and operational phases and ultimately the comparison the key hydrological parameters between these phases, there is also a requirement for monitoring during the construction phase. During the construction phase the primary hydrological issues relate to water quality downstream of the work areas. The main potential issues include:

- Clear felling of the conifer plantation. Runoff from works areas has the potential to contain elevated concentrations of suspended solids and nutrients.
- Bog restoration measures including drain blocking and ground reprofiling can have a negative short-term effect on surface water quality. Runoff from works areas has the potential to contain elevated concentrations of suspended solids and nutrients.

The main concern raised by the NPWS is the potential effects that the proposed project may have on surface water quality within the project site, Lough Inagh and Derryclare Lough, and consequently, the Twelve Bens/Garraun Complex SAC.

Comprehensive mitigation measures have been proposed within EIAR and CEMP and will ensure that no surface water quality effects result from the proposed project.

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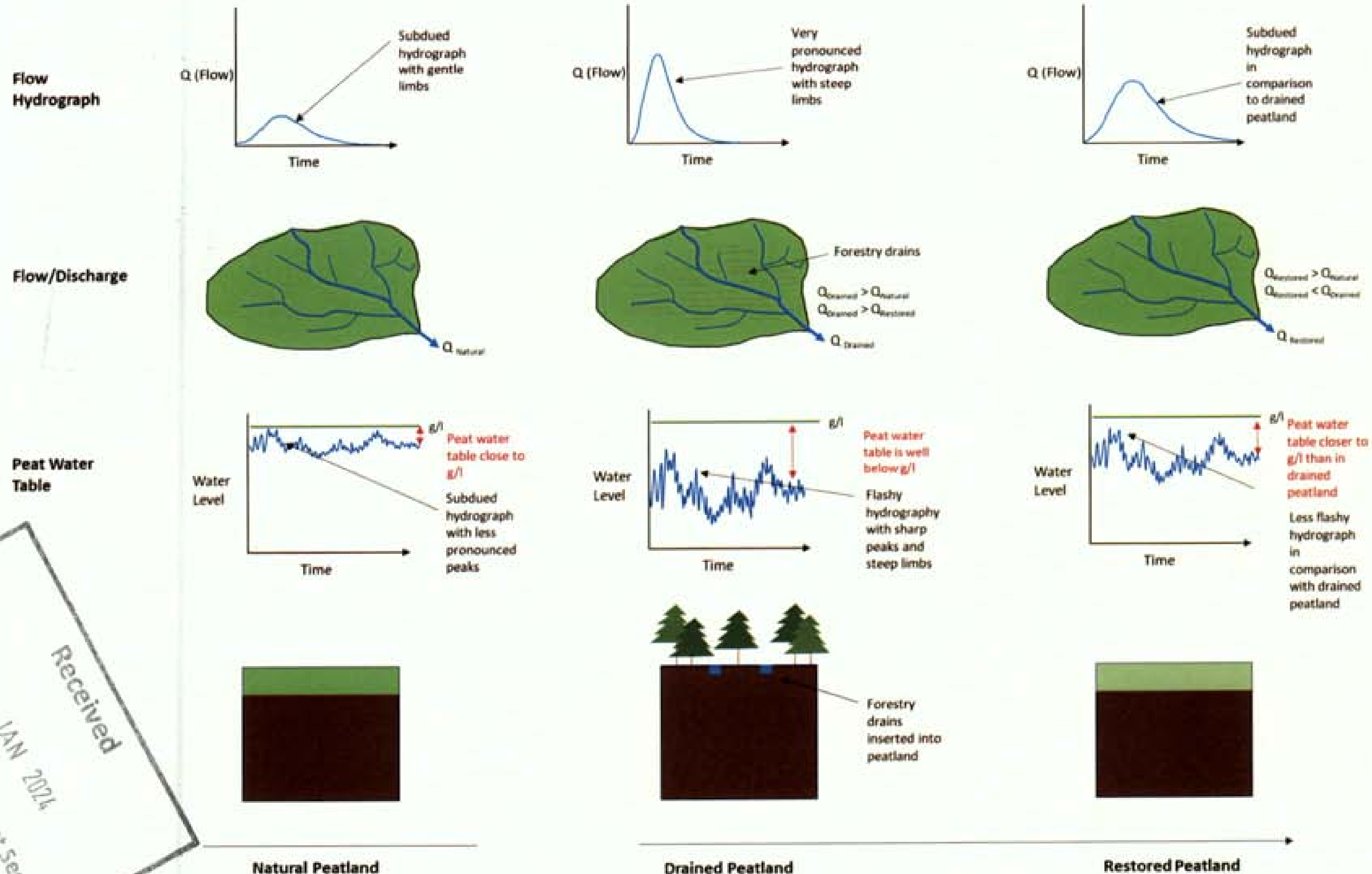

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Figure D: Summary of Hydrological Characteristics of Natural, Drained and Restored Peatlands*

*adapted from McCarter, C.P.R. and Price, J.S. 2015. The hydrology of the Bois-des-Bel peatland restoration: hydrophysical properties limiting connectivity between regenerates Sphagnum and remnant vacuum harvested peat deposits. Ecohydrology. 8, 173-187.)

4. PROPOSED HYDROLOGICAL MONITORING PLAN

4.1 PROPOSED HYDROLOGICAL MONITORING PLAN PHASES

This section sets out the proposed hydrological monitoring plan associated with the Derryclare Wild Western Peatlands Project.

The hydrological monitoring plan can be sub-divided into 3 no. phases as detailed below. These phases and the objectives of the hydrological monitoring plan for each phase are presented in **Figure E**.

4.1.1.1 Pre-Construction Phase

The success of the project will be defined by how the several key hydrological characteristics of the project site respond to the proposed restoration works.

In order to determine the success of the project from a hydrological perspective, the baseline hydrological environment will be monitored and characterised prior to the commencement of any restoration works. Coillte have committed to undertaking hydrological monitoring at the site for a period of **12 months** post-consent. The EIAR already provides sufficient information for the planning application and this monitoring plan is intended to be completed once consent for the project has been attained.

The key parameters to be monitored during this Pre-Construction phase of the monitoring plan include surface water flow volumes/discharge rates from the project site and the elevation of the peat water table with respect to the ground surface.

The data obtained during this phase of monitoring will later be compared with data from the operational phase in order to quantify positive changes in the hydrological regime as a result of the restoration works.

4.1.1.2 Construction Phase

During the construction phase, hydrological monitoring will focus on water quality.

Monitoring of surface water quality during the proposed works will facilitate the measurement of any immediate, short-term or temporary effects associated with the restoration works.

Monitoring can help determine the success of the proposed mitigation measures (as outlined in EIAR/CEMP)and inform whether works should be postponed if high levels of turbidity are recorded.

4.1.1.3 Operation Phase

During the Operation Phase (i.e. Post-Construction) hydrological monitoring will concentrate on the key parameters of flow volumes/discharge rates and the elevation of the peat water table with respect to the ground surface.

Operation Phase monitoring will determine the hydrological success of the overall restoration project by recording any long-term changes in the hydrological/hydrogeological environment and comparing the result with those recorded during the pre-construction phase i.e. the baseline hydrological environment. Post-works hydrological monitoring shall be completed for a period of **5 years**.

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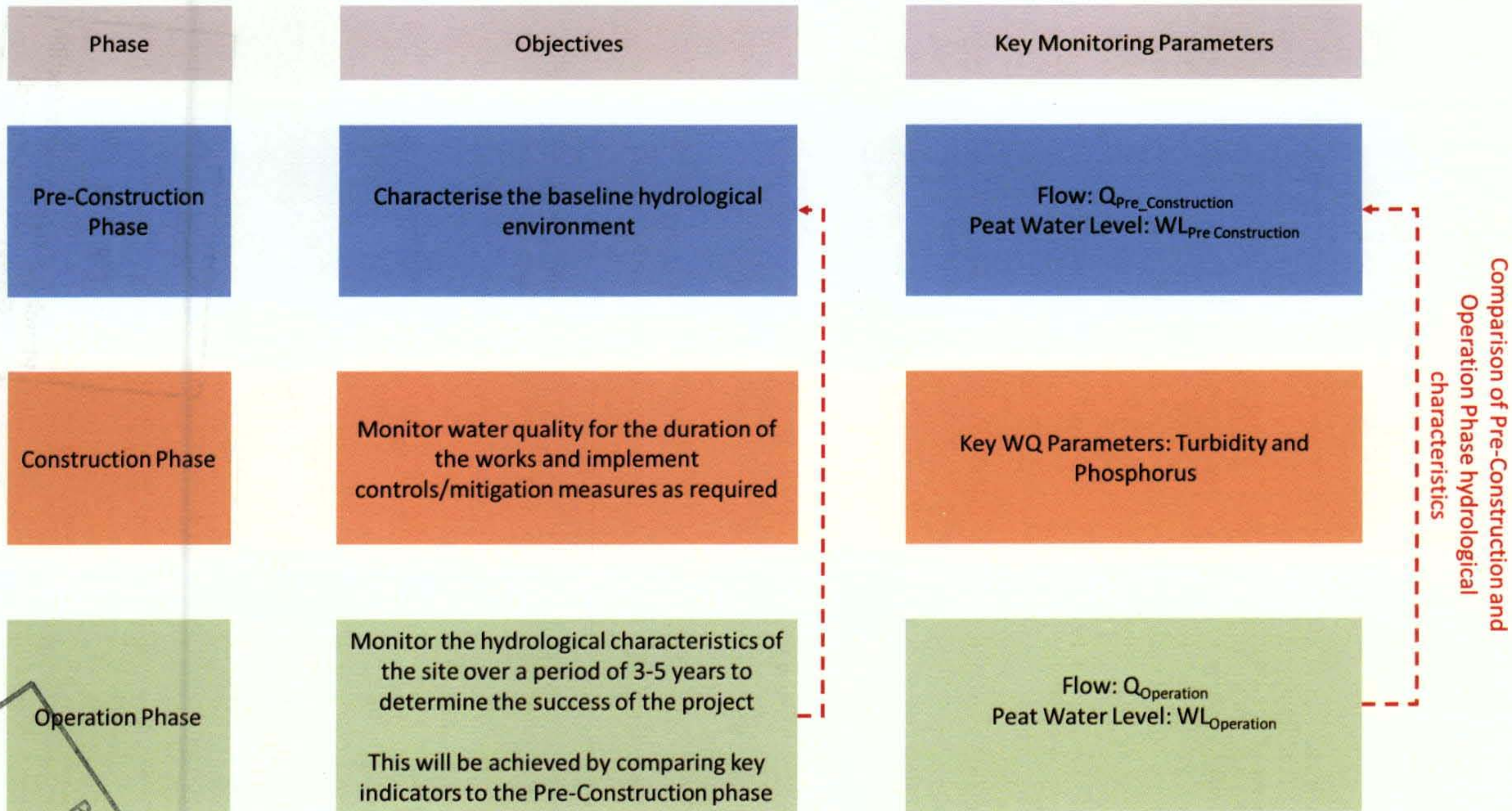

Figure E: Hydrological Monitoring Plan Objectives

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4.2 METHODOLOGIES

4.2.1.1 Water Flow Monitoring

Water flow monitoring will be completed throughout all phases of the monitoring plan (Pre-Construction, Construction and Operation).

It is proposed to monitor surface water flow volumes at 2 no. locations within the project site (SW1 and SW2). These monitoring locations have been chosen due to their location downgradient of much of the proposed work areas. Furthermore these proposed monitoring stations are situated on two of the main natural watercourses which flow through the project site. Therefore, the monitoring of the quantitative (flow) characteristics of these watercourses will help determine any changes in discharge rates which may result from the proposed restoration measures. The locations of these proposed monitoring stations are shown in **Figure H** below.

At these 2 no. locations surface and flow rates will be monitored in-situ through the use of an automated water level probe which will record the water level at regular intervals (typically every 15-minutes). A relationship will be established between water level and flow volumes through several manual flow measurements either recorded with a flow meter and/or through the installation of a flume or weir (refer to **Figure F**).

During all phases of the proposed project, the water level data will be downloaded from the loggers and analysed every 6 months.

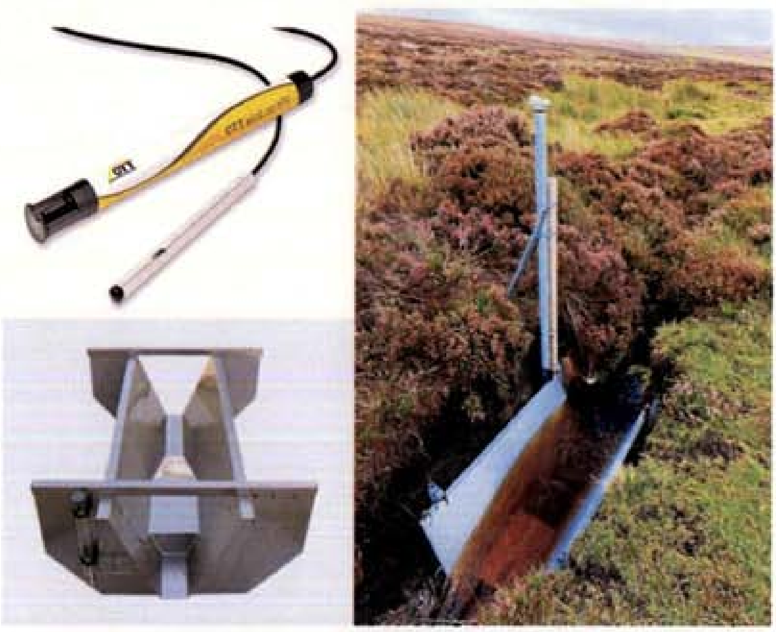

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Figure F: Example of Flow Monitoring

4.2.1.2 Water Quality Monitoring

General Water Quality Monitoring
In addition to the flow monitoring being completed at SW1 and SW2 during all phases of the proposed project, water quality monitoring will also be completed at these locations.

The loggers at SW1 and SW2 will also be fitted with several water quality probes which will record key hydrochemical parameters including temperature, pH, conductivity and turbidity.

The in-situ monitor could be installed with a telemetry which would allow real time data to be accessed remotely, although at a higher cost.

Similar to the flow data, this water quality data will be downloaded and analysed every 6-month during all phases of the proposed project.

In relation to phosphorus no sensor is currently available to provide continuous phosphorus measurements. Therefore, it is recommended to take monthly grab samples at each of these locations.

Monthly grab sampling will continue at the 5 no. monitoring locations (P1-P5) during all phases of the proposed project. 4 of these monitoring locations are situated on local watercourses while P5 is located on Lough Inagh. There is no monitoring being completed by Coillte on Derryclare Lough. Any monitoring here is deemed superfluous given the extensive monitoring being completed by the EPA. We also note that there has been a request for the EPA to increase monitoring frequency at Derryclare Lough.

Annual biological monitoring will also continue at 4 no locations (DB2-DB4 and DB6) during all phases of the proposed project.

<u>Intensive Water Quality Monitoring During Construction Phase</u>
More intensive surface water quality monitoring will be completed during the construction phase. This monitoring will be completed in addition to the general monitoring at SW1, SW2, P1-P5 and DB2-4 and DB-6 detailed above.

This intensive monitoring and associated mitigation measures are outlined in the EIAR/CEMP and include:

Turbidity:
It is proposed to complete continuous turbidity monitoring of surface watercourses downstream of the proposed work areas throughout the construction phase of the Proposed Project. This will be completed with the installation of automated water quality probes which will record turbidity and other hydrochemical parameters at regular intervals (typically every 15 minutes). These probes will be installed in natural watercourses downstream of work areas. The data will be processed and analysed at regular intervals and work will cease if elevated turbidity concentrations are recorded. In this event, all upstream silt traps and drainage routes will be inspected to identify the cause of the elevated turbidity levels. Work will not recommence until any issues have been resolved and the turbidity concentrations have returned to background concentrations.

In combination with the above, grab sampling will be completed before, during and after the felling activity (as is the norm in forestry operations). The 'before' sampling should be conducted within 4 weeks of the felling activity, preferably in medium to high water flow conditions. There is only the requirement for 1 no. "during" sample as most felling activity will occur in a short, concentrated time period. The 'after' sampling will comprise of at least 1 no. sample post felling or as many sampling events as necessary to demonstrate that water quality has returned to pre-activity status (i.e. where an effect has been shown).

Criteria for the selection of water sampling points include the following:

- Avoid man-made ditches and drains, or watercourses that do not have year round flows, i.e. avoid ephemeral ditches, drains or watercourses;
- Select sampling points upstream and downstream of the forestry activities;
- It is advantageous if the upstream location is outside/above the forest in order to evaluate the effect of land-uses other than forestry;
- Where possible, downstream locations should be selected: one immediately below the forestry activity, the second at exit from the forest, and the third some distance from the second (this allows demonstration of no effect through dilution effect or

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contamination by other land-uses where impact increases at third downstream location relative to second downstream location); and,
- The above sampling strategy will be undertaken for all on-site sub-catchments streams where tree felling is proposed.

The final details defining this monitoring will be included in the Construction Stage CEMP which will be finalised in advance of any construction works.

Phosphorus:
Grab sampling before, during and after felling operations as detailed above. The monitoring will be used to ensure that the threshold of 62 mg/l Total P (EPA, 2001) for surface waters is not being exceeded. In addition, during the construction phase of the Proposed Project monthly grab samples will be taken from Lough Inagh (P5) to ensure there is no upward trend in total P occurring, and to demonstrate that the Site Specific Conservation Objectives (SSCOs) for nutrients are maintained (i.e. annual average total phosphorus (TP) ≤10□g/l TP, average annual total ammonia concentration should be ≤0.040mg/l N, and annual 95th percentile for total ammonia should be ≤0.090mg/l N) (NPWS, 2017). As stated above, any additional monitoring at Derryclare Lough is not necessary given the extensive monitoring already being completed by the EPA in this lake waterbody.

4.2.1.3 Proposed Peat Water Level Monitoring

Peat water levels will be monitored throughout all phases of the monitoring plan (Pre-Construction, Construction and Operation).

The proposed monitoring plan will utilise the existing piezometer network at Derryclare which was installed by RPS in 2021. A total of 16 no. piezometers have been installed with the proposed restoration areas of the project site (refer to **Figure C** above).

It is proposed to install automatic water level devices (i.e. Eijkelkamp Diver / Solinst Water Level Logger) for continuous water level monitoring in these 16 no. piezometers. Data logged by the automatic loggers should be downloaded every 6 months. In addition to the continuous water level monitoring, the water level in the piezometers will be manually recorded at 6-month intervals for the duration of the monitoring plan.

All 16 no. piezometers will be instrumented at the beginning of the Pre-Construction Phase and monitoring will continue during the Construction and Operation Phases. During the Operation Phase (i.e. post works) all piezometers will be monitored using automatic loggers for the first year. Upon review of the data at the end of Operation Phase Year 1, the number of piezometers being monitored could be reduced if it is deemed that the data is not of significant importance or value.

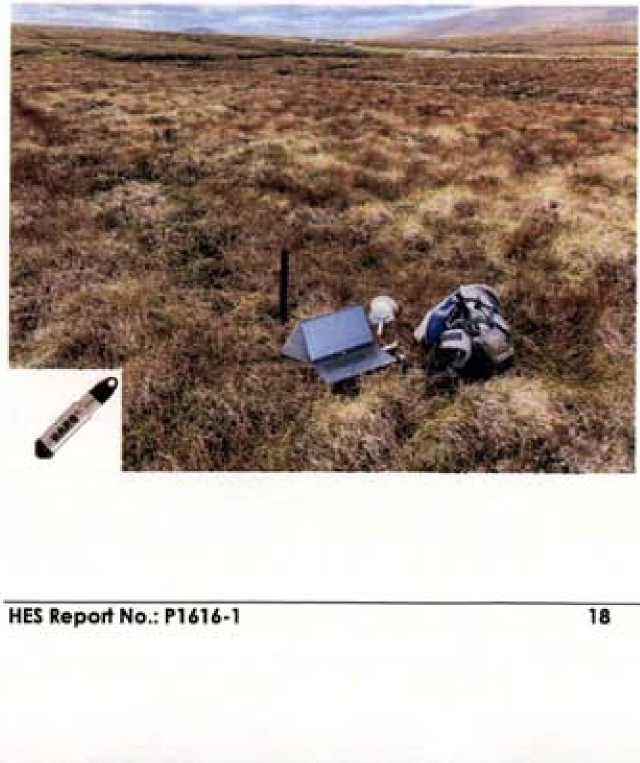

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Figure G: Groundwater Level Monitoring

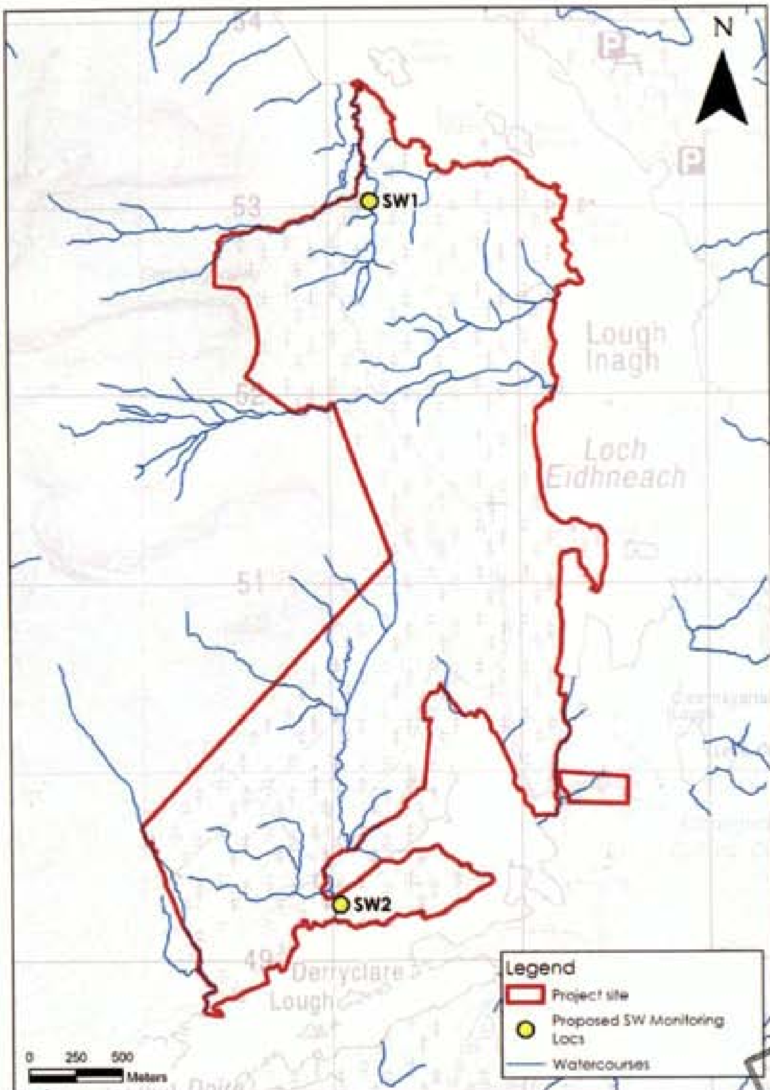

Figure H: Proposed Flow Monitoring Locations

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4.3 MONITORING PLAN SUMMARY

Refer to Error! Reference source not found. below for details.

4.4 REPORTING

Subject to planning approval, Coillte will begin the pre-construction hydrological monitoring which will continue for a period of 12 months prior to the onset of restoration works. Following the establishment of the hydrological monitoring network, monitoring reports and subsequent trend analysis reports will be completed on a biannual basis.

The biannual report will include the presentation of water level hydrographs for the piezometers and the monitored streams and a discussion/analysis of the surface water hydrochemistry data. The trend analysis will determine if there is any significant quarterly variation in water levels or hydrochemistry that requires action/investigation.

The monitoring reports will be shared with all Stakeholders and the NPWS.

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Table A: Proposed Monitoring Plan Summary

Monitoring Location	Easting (ITM)	Northing (ITM)	Parameter	Auto/Manual	Monitoring Frequency	Data Download Frequency
Pre-Works Monitoring (Establishing the Baseline)						
SW1	483201	75304	Temperature	Auto – probe	Continuous (15-minute intervals)	Biannual
			Conductivity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Turbidity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Phosphorus	Auto – sampler/grab samples	Monthly	N/A
			Flow	Auto – flume/logger	Continuous (15-minute intervals)	Biannual
				Manual – flow meter	Biannual	Biannual
SW2	483019	749322	Temperature	Auto – probe	Continuous (15-minute intervals)	Biannual
			Conductivity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Turbidity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Phosphorus	Manual – grab sampling	Monthly	Biannual
			Flow	Auto – flume/logger Manual – flow meter	Continuous (15-minute intervals) Biannual	Biannual
P1 – P5	See **Figure B** above		21 no. parameters	Manual - grab samples	Monthly	N/A
DB2 – DB4 and DB-6	See **Figure B** above		Aquatic invertebrate communities	Manual – kick sampling	Annual	N/A
Existing Piezometers	See **Figure C** above		Water level	Auto – logger Manual – dip piezo	Continuous (2-hour intervals) Biannual dips	Biannual
Construction Phase (During Works)						
SW1	483201	75304	Temperature	Auto – probe	Continuous (15-minute intervals)	Biannual
			Conductivity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Turbidity	Auto – probe	Continuous (15-minute intervals)	Biannual
				Manual – grab sampling[1]	1 pre-works, on a weekly basis during works Turbidity event – daily samples until turbidity returns to baseline	N/A
			Phosphorus	Manual – grab sampling	Monthly	N/A
				Auto – sampler	1-week	Weekly

[1] Construction Phase Only

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				Manual – grab sampling	Monthly	N/A
			Flow	Auto – flume/logger	Continuous (15-minute intervals)	Biannual
				Manual – flow meter	Biannual	Biannual
SW2	483019	749322	Temperature	Auto – probe	Continuous (15-minute intervals)	Biannual
			Conductivity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Turbidity	Auto – probe	Continuous (15-minute intervals)	Biannual
				Manual – grab sampling	1 pre-works, on a weekly basis during works Turbidity event – daily samples until turbidity returns to baseline	N/A
			Phosphorus	Manual – grab sampling	Monthly	N/A
				Auto – sampler	1-week	Weekly
				Manual – grab sampling	Monthly	N/A
			Flow	Auto – flume/logger Manual – flow meter	Continuous (15-minute intervals) Biannual	Biannual
P1 – P5	See Figure B above		21 no. parameters	Manual - grab samples	Monthly	N/A
DB2 – DB4 and DB-6	See Figure B above		Aquatic invertebrate communities	Manual – kick sampling	Annual	N/A
Additional Auto Sampling Locations	Downstream of works area		Turbidity / Temperature / Conductivity	Auto - probe	Continuous (15-minute intervals)	Weekly
Additional Grab Sample Locations	Downstream of works areas		Range of parameters including turbidity and phosphorus	Manual - grab sampling	1 no. sample before felling 1 no. sample during felling 1 no. sample post felling	N/A
Existing Piezometers	See **Figure C** above		Water level	Auto – logger Manual – dip piezo	Continuous (2-hour intervals) Biannual	Biannual
Post-Works (Determining the success of the Project)						
SW1	483201	75304	Temperature	Auto – probe	Continuous (15-minute intervals)	Biannual
			Conductivity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Turbidity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Phosphorus	Manual – grab sampling	Monthly	N/A

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			Flow	Auto –flume/logger	Continuous (15-minute intervals)	Biannual
				Manual – flow meter	Biannual	Biannual
SW2	483019	749322	Temperature	Auto – probe	Continuous (15-minute intervals)	Biannual
			Conductivity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Turbidity	Auto – probe	Continuous (15-minute intervals)	Biannual
			Phosphorus	Manual – grab sampling	Monthly	N/A
			Flow	Auto – flume/logger Manual – flow meter	Continuous (15-minute intervals) Biannual	Biannual
P1 – P5	See Figure B above		21 no. parameters	Manual - grab samples	Monthly	N/A
DB2 – DB4 and DB-6	See Figure B above		Aquatic invertebrate communities	Manual – kick sampling	Annual	N/A
Existing Piezometers	See **Figure C** above		Peat Water level	Auto – datalogger Manual – dip piezo	Continuous (2-hour intervals) Biannual	Biannual

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5. MONITORING PLAN SUMMARY

A hydrological monitoring plan has been proposed for the Derryclare Wild Western Peatlands Project.

The overall aim of the monitoring plan is to determine the hydrological success of the restoration project. This will be achieved by monitoring several key hydrological parameters pre- and post-construction.

- The key hydrological parameters generally used to characterise the success of a peatland restoration project are surface water flow volumes and the elevation of the peat water table relative to ground level.
- The plan includes the monitoring of groundwater levels, surface water hydrochemistry and flow volumes at appropriate and accessible monitoring locations within the project site;
- The groundwater level monitoring plan utilises the existing piezometer network at the project site, with groundwater levels being continuously recorded by dataloggers and downloaded at 6-month intervals.
- Surface water hydrochemistry and flow volumes will be recorded at 2 no. locations downstream of the proposed restoration works. It is proposed to complete the monitoring through the use of surface water quality probes and auto-samplers.
- Coillte have committed to completing the proposed hydrological monitoring for a period of 12 months pre-construction and for a period of 3-5 years post-construction.
- The pre-construction monitoring will help establish the baseline hydrological characteristics of the Derryclare Site.
- The operation phase monitoring data will be compared to this baseline data and any deviation from the baseline will be used to determine the overall success of the restoration project.
- In addition, intensive water quality monitoring will be completed throughout the construction phase. This water quality monitoring will concentrate on key parameters including turbidity and phosphorus and will be carried out in accordance with the CEMP.
- All data will be downloaded every 6-months and annual monitoring reports and trend analysis will be shared with all stakeholders and the NPWS.

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Appendix I:

Biological and Chemical Monitoring of Surface Waters:

Derryclare & Cappaghoosh

(Mayfly Ecology 2023)

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APPENDIX 6

FOREST TO BOG BEST PRACTICE OPERATIONAL GUIDELINES FOR BLANKET BOG RESTORATION IN IRELAND

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Draft

Forest to bog

Best practice operational guidelines for blanket bog restoration in Ireland

This document has reviewed the available best practice guidelines for blanket bog restoration applicable to Irish conditions and collated the results into a technical report that can be used for operational planning for Forest to bog restoration projects in Ireland. This is intended to be a working document that will incorporate all applicable future best working practice and developments.

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Author: D Tiernan

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Timber or composite (mixed materials) dams: Peat Bog Restoration in Scotland - YouTube

Wave dams and Zipping: Peatland Restoration – Wave Damming and Zippering - Technique Guide - YouTube

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Notes on terminology used.

Artificial drainage pattern: This refers to the forestry drainage resulting from the ground cultivation used to afforest the site. Typically, this is double or single mould board ploughing.

EPA streams:

'Forest to bog' restoration: This refers to the practice of converting forested areas on peatlands back to a bogland habitat.

Furrow blocking: This refers to the bog restoration practice of blocking the ploughed furrow, usually with dams, debris or peat.

Ground smoothing: This refers to the bog restoration practice of smoothing out the ploughed ridge furrow profile, which can be achieved by a variety of methods such as cross tracking, smoothing with the excavator bucket and stump flipping.

Relevant watercourses are existing drains and channels that do not appear on the 6-inch ordinance survey map, that may contain flowing water during and immediately after rainfall and flow directly into an EPA stream or lake

Rewetting: A generic term often used to describe the bog restoration practice of raising the water table to favour the restoration of the peatland habitat.

Ridge and furrow pattern: This refers to the ploughed profile that results after ploughing, where a channel (furrow) is scraped onto the bog surface to create an elevated ribbon (ridge).

Silt traps: A standard water protection measure used to capture sediment flows and slow water flows, typically using strategically placed dam(s) using various materials capable of trapping fine sediment.

Stump and root plate mulching

Natural drainage pattern: This refers to the natural drainage pattern that consists of EPA streams (that appear on the 6-inch map) and relevant watercourses (that do not appear on the 6 inch map). This is best defined as the drainage pattern of the bog before afforestation.

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Introduction.

The principal goal of 'Forest to bog' restoration is to remove the conifer forest cover, raise and stabilise water tables as much as possible, and restore the natural topography of the peat surface. Forested sites typically retain a legacy 'ridge and furrow' pattern, with either single or double ploughed furrows varying from 30cm up to 80 cm depth. The type of restoration technique required will depend on site conditions, including site topography, peat type, hydrology, peat depth, peat slide risk, as well as the tree species present, their age, Yield class, rooting depth, alongside the ability to extract timber and harvesting technique used/considered, and the presence or absence of peat forming vegetation. Peat depths and the ground preparation method used for drainage can often inform the type of peatland community that will be restored and help identify the expected target habitat. In addition, assessing the condition of ploughed ridges and furrows is also important as the more prominent these are then the more intervention will be required to flatten and restore the hydrology and topography of the site.

A full literature review on the current understanding of bog restoration for blanket bogs is presented in Appendix 5. This review provides the context of the information presented in these operational guidelines.

In brief, all Forest to bog operations should include the following main steps.

1. Prepare a detailed strategic plan.
2. Correctly time and schedule the restoration work.
3. Develop a site-specific operational plan.
    - Step 1: Remove the conifer trees.
    - Step 2: Prepare a detailed restoration plan for the felled area.
    - Step 3: Segment the site based on slope and peat slide factors.
    - Step 4: Plan effective buffer zones.
    - Step 5: Specify suitable restoration technique(s).
    - Step 6: Control Invasive species.
    - Step 7: Have a grazing management plan.
    - Step 8: Have a site monitoring plan.
    - Step 9: Have a fire plan.

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1.0 Prepare a detailed strategic plan.

Forest to bog restoration is a complex process that requires careful planning to ensure its success. A detailed strategic restoration plan for each site is essential for Forest to bog restoration and this requires careful evaluation, planning, stakeholder engagement, implementation, monitoring, and long-term management. This operational guideline deals with the implementation steps needed for bog restoration, and as a result, only a summary of the detailed required for a restoration plan is briefly outlined here. A detailed strategic restoration plan can cover a period of up to 10 years and it address the following main items.

1. Site Evaluation: The first step is to evaluate the site to assess its suitability for bog restoration. An example of some of the factors to consider include location, proximity to statutory designated areas, soil type, hydrology, suitability for restoration, vegetation, and the presence of invasive species.

2. Situation Analysis: Based on the site evaluation, conduct a situation analysis to identify the problems and opportunities for bog restoration. This process involves gathering information about the site's history, current condition, and potential risks and threats.

3. Goal Setting: Determine the goals and objectives for the bog restoration. These goals could include improving hydrology, enhancing biodiversity and habitat restoration.

4. Restoration Plan: Develop a detailed bog restoration plan that outlines the specific actions needed to achieve the goals identified in step 3. Central to this is understanding the site hydrology.

5. Stakeholder Engagement: Consult with stakeholders such as landowners, community groups, and government agencies to build support for the restoration project and gain insight into local factors that may affect restoration success.

6. Permitting and Approval: Obtain necessary permits and approvals from regulatory agencies to carry out the restoration activities.

7. Implementation: Implement the restoration plan, following best practices to minimize disturbance to the existing plant and animal communities and ensure successful restoration.

8. Monitoring and Adaptation: Monitor the restored bog over (especially water quality) time to evaluate the success of restoration efforts, identify any issues or threats, and make necessary adjustments to the restoration plan.

9. Long-term Management: Develop a long-term management plan to maintain the restored bog, control invasive species, and ensure that the site continues to meet the restoration goals and objectives.

The above approach suits Irish conditions, where large scale projects can be typically phased over several years. In this approach, sites with good restoration potential are initially selected and a detailed hydrogeological assessment is carried out using a combination of LIDAR and field data collection. This allows for an assessment of the drainage system of the

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site to identify where water is entering and leaving the site and this information is used to develop a plan for managing water levels and protecting water quality. Vegetation mapping is used to identify rare species and the dominant plant species and potential for the future target habitats can be assessed. Plans may or may not include water table monitoring.

2.0: Correctly time and schedule the restoration work.

Most restoration work will occur in sensitive areas and consequently the timing of all work is important. While water protection is often the main concern, depending on the site other additional protections maybe required for site-specific bird, mammals, or rare species on site. These protections will be identified at the planning stage.

For a variety of reasons, restoration measure should ideally occur immediately after the conifer trees have been removed. A felled site that has not been re-wetted can continue to emit carbon for up to ten years after re-wetting. The sooner a site can be rewetted, the sooner it can start to recover and move to a system which releases less carbon to the atmosphere and water courses. While restoration techniques can be prepared prior to felling, for optimum results and the selection of the best technique(s) for the site, sites are best surveyed post felling. Post-felling surveys ensure the site can be fully viewed and an accurate assessment made of the drainage patterns, slopes, flushing and the optimum locations of the water protection measures (silt traps, dams, buffer zones etc.). This survey can also occur before the trees are felled, if accessibility through the forest is good. Regeneration of lodgepole pine seedings and invasive species is a known issue with peatland restoration in Ireland. In Scotland, it was observed that carrying out the restoration work immediately post felling and raising the water table as soon as possible, is an effective way to limit conifer and invasive species regeneration by creating unfavorable condition for seeding germination.

A range of restoration techniques can be used on the same site. The guiding principle should be to achieve the restoration aim with the least amount of peat disturbance as possible. In Scotland this is referred to the "Enough and no more". For example, on a well buffered site that is very wet and flat with poorly grown trees on deep peat, restoration might be achieved with tree removal followed by strategic drain blocking of the artificial drains with peat and machine cross tracking to reprofile the site. In contrast, on another site, on a drier flat site where large trees grew on deep peat, restoration might be achieved with tree removal followed by large undisturbed buffer zone creation with strategic drain blocking of the artificial drains achieved using stump flipping.

Another important consideration in the selection of the restoration technique(s) is to ensure that the post felling restoration works do not impact on the adjoining areas that are scheduled for future felling. To do this it is necessary to identify the hydrological units. While this could be approximated at the planning stage, identifying the hydrological units is best done post felling, when you have full visibility of the site. Careful planning will ensure that any restoration work will not compromise the harvesting of adjacent stands. In the

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Coillte estate, forest properties are typically divided into compartments using 3-5m wide unplanted ride lines. Very often these ride lines will use the existing stream network, and this can be used at the planning stage to schedule felling, using the existing stream network as the divide between planned felling coupes.

3.0 Develop a site-specific operational plan.

Once the planning phase is completed, and the correct timing schedules are in place, the following steps are recommended to implement the blanket bog operational plan. The underlying aim is to select the best site-specific restoration technique that can provide the best restoration results with the least amount of disturbance. This is achieved using the following.

Step 1: Map the drainage patterns (natural, artificial, forest road).

Step 2: Develop a tree removal plan.

Step 3: Develop a restoration plan.

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Step 1: Map the drainage patterns (natural, artificial, forest road).

To understand how a forested site is drained it is important to map a) the natural drainage pattern that occurs from the existing streams, b) the artificially installed forest drainage, and c) the drainage installed on the forest road network. It is recommended that the site drainage pattern should be mapped where possible before the trees are felled, or immediately after the trees the felled. Depending on accessibility through the forest crop, the drainage pattern can be mapped before felling, but generally it is easier to map post felling. A detailed walk-over survey is recommended, to assess the site and collect and map key practical information that will inform the restoration technique(s) to employ.

The natural drainage pattern refers to the existing EPA streams and all relevant watercourses. Typically, EPA streams are well mapped and relevant watercourses are usually not mapped in forested areas in Ireland. A relevant watercourse is any other watercourse that has the potential to act as a pathway for the movement of significant amounts of sediment and/or nutrients from the site to an aquatic zone. Relevant watercourses are existing drains and channels that may contain flowing water during and immediately after rainfall. Note, not every watercourse is a 'relevant watercourse'. For example, a well-vegetated drain or ditch draining a small area of moderately sloping ground may not be a relevant watercourse, as there will be little or no potential for it to carry significant amounts of sediment/nutrients. In peatlands, relevant watercourses often have channels that are well eroded and have cut down to the mineral layer. All EPA streams and relevant watercourses will not be blocked during the restoration process as they represent how the bog drains naturally. The most practical and recommended way to locate these relevant watercourses is to walk the length of all the mapped EPA streams and map the relevant watercourse using a field mapping GPS devise.

The artificial drainage pattern refers to the forest drainage pattern installed to establish the forest, which on the Coillte estate is typically plough and furrows bisected with occasional interceptor drains. Most Forest to bog sites on the Coillte estate will be cultivated using ploughing. However, on a minority of older sites tunnel ploughing might have been used, and on the more recent sites, mounding might be used. Typically, approximately 90% of Forest to bog sites on the Coillte estate will be ploughed and how to map these ploughed sites is discussed here. Ploughed site generally were ploughed up and down the slope, with strategic interceptor drains bisecting these drains at right angles. The interceptor drains are small drains, usually only a foot wide, that were installed just below the plough drains and these drains were placed to run along the contour to slow the water down and effectively drained the site. Most sites have only a few interceptor drains that when strategically placed, effectively become the main channels for water exiting the site. It is recommended to map all the flowing interceptor drains and to map the plough drain direction using an arrow to show the plough drain direction pointing downslope. Combining this information with the natural drainage pattern will show how water leaves the site. The effectiveness of the interceptor drains, and the depths of the ploughed furrows need to be considered when selecting the most suitable restoration technique. For example, if an interceptor drain has a low flow of water and the drain is partially revegetated, then reprofiling of the entire drain would be effective. However, if the drain is wide and the flow is strong, then damming might be more effective, if the slope allows.

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The forest road drainage typically includes drains on both sides of the forest road that connect to road culverts and feed into the forestry drainage network. These drains should me mapped with special care given to where they connect to the forestry drainage network. A series of strategically placed silt traps and measures to slow the speed of the water should be considered for these drains. Where available, the hydrological sub-catchments should be overlaid on the planning map. These sub-catchments are the hydrological units specific to the site. (These can be provided at the planning stage using LIDAR and DTM [digital terrain data] data).

The mapping of the natural drainage pattern, the artificial drainage pattern and the forest road drainage pattern provide the necessary information to understand how the site is currently draining and this can then be used to decide the best restoration plan to restore the site. This mapping is most effective when it is done using a field mapping GPS devise.

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Step 2: Develop a tree removal plan.

In general, it is always preferable to remove as much timber and brash (including brash mats) from a site prior to restoration. Water tables are lowered in areas where conifers are planted due to the drainage network present as well as the interception and increased rates of evapotranspiration (Irish Wildlife Manuals No. 99. 2017). Removal of woody material makes subsequent restoration activities easier. If trees cannot be removed, then the next preferable option is to fell to waste and the least favourable option is to mulch the trees and stumps. Typically, a combination of methods will be employed on the same site, owing to the variability of tree growth typically found on these sites. Tree removal on bog restoration sites will occur using 3 main harvesting methods, namely:

1. Conventional harvesting machines/excavator with shears head – extract timber.
2. Conventional harvesting machines/excavator with shears head – fell to waste.
3. Excavator fitted with a mulcher/manual – fell to waste.

All machines used in tree removal will have to have suitable ground pressures (see appendix 1: Understanding ground pressures).

Conventional harvesting machines (harvester and forwarder combination) are expected to be used where there is harvestable material available. This is the preferred option as it ensures that most of the woody vegetation is removed from the site and machines that are purpose built for operating in challenging forestry conditions are used. Conventional harvesting machines typically leave a raised stump, whereas shear heads do not. Where possible, shear heads should be used, as they remove more woody material and make subsequent restoration easier (as there is no raised stump).

The next preferred option for tree removal is felling to waste, either manually or with a conventional harvester. This option leaves the felled trees on site. This will typically occur where there is no harvestable material available, but the trees are still large enough to be harvested either manually with chainsaws or with a conventional harvester (or an excavator mounded with a shears head). This option leaves the woody vegetation on site, which must then be windrowed with an excavator, before anymore restoration works can commence.

Mulching is typically used when the tree size is too small for a conventional harvester to be used. This will occur in areas where there are no harvestable trees, and the tree size is also too small to be felled to waste. (Mulching can also be used for larger tree sizes, but in these cases felling to waste of conventional harvesting is preferred). Typically, a mulcher attachment is fitted to an excavator and the small trees are mulched down to ground level. Mulching leaves the above ground biomass scattered across the surface. Using an excavator with a mounted mulcher is a safer and more cost-effective operation when compared to the alternative of using chainsaws to complete the task manually.

Stump grinding or stump paring with an excavator mounted with a stump grinder is an untested proposed new method. This is proposed as an alternative to stump flipping. The stump grinder pares the stump and part of the root plate away to allow the site to be subsequently reprofiled without flipping the stump. This is expected to be more suitable to sites with large stumps. Field trials will be needed to evaluate if this option is suitable.

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Step 3: Develop a restoration plan.

Understanding the best restoration option to use to restore the site depends on a variety of site conditions that must be considered collectively. As each site is variable, a detailed consideration is needed to ensure the best restoration option is used. No one factor will determine the best restoration method to adopt. Only when all factors are considered collectively should the restoration option be decided. It is recommended, in a Forest to bog restoration, that the sub-compartment be used as the planning unit when prescribing which restoration option to use. As part of standard forestry practice, forested sites are segmented into sub-compartments, which are homogeneous forest areas, typically containing an even aged crop of the same species. For practical purpose, using the sub-compartment is a useful way to assess all the parameters included in the operational specifications, when deciding on which restoration option to use. A summary of all the restoration options and their corresponding operation specifications are given in Table 8 below.

The planner must always aim to choose the restoration option that will yield the greatest results with the least amount of peat disturbance. The main site conditions recommended to segment a site for restoration works include the following.

a) Buffer zones.
b) Peat slide risk factor.
c) Slope.
d) Peat depth (soil type).
e) Tree species (expected stump size).
f) Cultivation type (furrow depth).
g) Water catchment.
h) Elevation (low or high-level blanket bog).
i) Peat piping and peat cracking

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a) Buffer zones

Buffer zones are essential, and they are a central part of the restoration plan. Once the site drainage pattern is mapped, buffers can be put in place along all EPA streams, relevant watercourses and lakes. The width of the buffer zones will depend on the watercourse and the slope. Recommended buffer widths are given the Table 4 below. Wider buffer zones can be specified where deemed appropriate.

Table 4: Recommended buffer widths for blanket bog restoration.

Watercourse	Gentle slope (< 6⁰)	Intermediate slope (6-11⁰)	Steep slope (> 11⁰)
EPA streams	20	30	40
Relevant watercourses	10	20	20

Having effective buffer zones installed is the first restoration operation to carry out as it is a key requirement for water quality protection. The function of the buffer zones is to provide protection to the watercourses from subsequent restoration operations. This is provided when the buffer zones are effective. When planning the buffer zones, the goal is to ensure that the buffers are made effective before the mechanical restoration activities begin. After tree felling and the removal of brash from the buffer zones, the only operations permitted in the buffer zones are the installation of silt traps, dams and silt curtains on the plough drains, relevant watercourses, interceptor drains and roadside drains. Effective buffer zones will contain a mixture of strategically placed series of silt traps and dams. Ideally, silt traps should be installed before tree removal begins to afford protection from the harvesting operations. Post felling, a greater number of additional silt traps and dams can be installed (as the site will be more assessable). Generally, dams are not effective over slopes of 6 degrees, and it is recommended that larger buffer zones are used on the steeper sites (Table 4).

Once the width of the buffer zones is decided, the next step is to walk all the buffer zones and identify which drains within the buffer zone are carrying water. The number of these drains will depend on the original ploughing method. In some cases, the plough drains will not be continued right into the water courses and in these cases, an effective buffer is effectively already in place. However, in the cases where plough drains were continued right into the watercourse, it will be necessary to map all these effective drains that are visibly carrying water. A detailed combined damming and silt trap plan will be required for all these drains, to ensure that the buffer is fully effective. If the slope is too steep for effective damming, consider the use of a series of silt traps in combination with methods to slow down the flow rate of the water. Alternatively, install dams further back the drain upstream from the buffer zone, if more suitable locations can be found to install the dams and silt traps.

A detailed description of best practice for all damming techniques is detailed in Appendix 1.

b) Peat slide risk factor

Peat slide risk assessments are detailed and complicated. However, their output is presented in an easy-to-understand numeric value. This value is called a "Factor of safety" (FOS) and it describes the calculated risk of a peat slide occurring. Depending on the calculation and the assumptions made in the peat slide risk assessment, typically, values under 1.3 are deemed to be higher risk, whereas values greater than 1.3 are deemed to be lower risk. This FOS value can be used to ensure that the higher risk restoration activities do not occur in the areas with the higher risk FOS values.

c) Slope

Slope is one of the main determining factors when deciding the best restoration technique(s) to adopt. Slope can be very variable across a site, especially in undulating terrain. Therefore, it is recommended where possible to map the average slope on a sub-compartment basis and use this to inform the decision of which restoration technique(s) to adopt. For example, the installation of dams is preferable when the slope is under 6 degrees, surface smoothing can be effective on both gentle and intermediate slopes and windrowing with an excavator can occur on steep slopes up to the manufacturers specified safe working limit.

Table 5: Typical slope categories.

Slope*	In Degrees	In %
Gentle	0 to 5^0	0 - 10
Intermediate	6 to 11^0	11 - 20
Steep	12 to 17^0	21 - 33
Very steep	18^0 and over	33 and over

*Slope categories based on the Coillte inventory standard.

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d) Peat depths

Peat depth is variable for blanket bogs, but it is a useful parameter to use when prescribing the restoration option to use. For example, shallower peat depths would be more vulnerable to more intensive restoration techniques than deeper peats, which would be expected to be more resilient. Afforestation has occurred on both blanket bogs and heaths (wet and dry) and using peat depths can also help distinguish between these on site. The depth of peat can also be used to indicate opportunities for establishing pioneer woodland, where suitable potential areas expected to correspond to peat depths of <0.25m. Table 5 below provides a general guide on how to use peat depths to inform the restoration technique decision. For practical reasons, it is recommended that an average peat depth be calculated for each sub-compartment, to facilitate interpretation.

e) Tree species (expected stump size).

The sub-compartment information is useful existing information to use as it can allow for the extrapolation of the expected stump size. Using this information, the stump size can be estimated using the table below and segregated into 3 categories, namely small, medium, or large stump sizes.

Table 6: Examples of stump size categories.

Stump size	Diameter of stump
Small	< 15 cm
Medium	15 – 30 cm
Large	> 45 cm

f) Cultivation type (furrow depth).

The forestry cultivation type will determine the furrow depths. In terms of restoration, deep furrow depths lead to uneven water table depths across the site, leading to the situation where the upper plough ribbon is considerably drier that the lower plough drain, often leading to one plant community in the wetter plough furrow and one in the drier plough ribbon. Understanding the cultivation type can help inform whether damming or surface smoothing should be considered. Most Forest to bog restoration sites on the Coillte estate are double mould ploughing.

Table 7: Expected furrow depths based on cultivation type.

Cultivation type	Expected furrow depths
Single mould board ploughing	0.2 m
Double mould board ploughing	0.3 m
Tunnel ploughing*	0 m
Mounding	0.5m
2nd rotation flat planting on 1st rotation ploughed sites	0m to 0.3m

**The tunnel drain (or mole drain) is 0.45m underground, with minimal ground disturbance above ground.*

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g) Water catchment

The water framework directive has provided national catchment and sub-catchments layers. All planned sites should include the sub-catchment to inform the restoration options selected, to ensure the site is planned in line with the hydrology.

h) Elevation (low or high-level blanket bog)

In Ireland, a distinction is made between low and high-level blanket bog using the 150m contour line as the divide. This information is useful (especially when combined with peat depths) to help inform the level of restoration effort to adopt.

i) Peat piping and peat cracking

Water quality in a peatland is complex and it depends upon the way the water moves and how it interacts with the peat itself. Peat piping occurs naturally, but it can also occur because of peat drying out post drainage. Desiccation cracking is also a major initiator of pipe formation in peat soils (Jones, 2004). Since peat is typically 90% water, desiccation can lead to peat piping and lead to increased flow in the macropores. This shrinkage and peat cracks increase water colour (dissolved organic carbon) and triggers erosion. Jones (2004) found that natural soil piping affects water quality in blanket bogs and suggested that it can be an important source of "dirty water", with very marked brown colour especially during the first rains of autumn following a dry summer. It can also lead to increased acidity (low pH) of surface water streams. He also noted that by draining and aerating peaty horizons, piping may encourage release of sulphates and organic acids from the peat. Jones noted that 30% of the UK is covered by soils susceptible to natural piping (including peat), so this important flow path should not be ignored.

Peatland restoration needs to consider the impact of peat piping and peat cracking. By its nature, peat piping, and to a lesser extent peat cracking, is difficult to quantify and often the best way to assess a site is to couple visual inspections with monitoring of DOC levels. Successful Forest to bog restoration will inhibit site drainage, close off the surface peat cracks, and this should be reflected in the monitored DOC levels. Soil piping and cracks can make it hard for dams to form good seals, and as a result, using peat dams as the sole restoration measure contains an inherent risk. In these cases, it is preferable to adopt additional restoration measures such as reprofiling, to lessen the risk and use long term monitoring of DOC levels, to monitor their effectiveness.

In Derryclare, the peat piping and peat cracking concerns will be addressed by a combination of establishing effective buffer zones, peat dams, using appropriate reprofiling techniques and long-term monitoring of DOC levels and a detailed monthly chemical analysis. The site will be monitored for surface cracking post felling and if required, remedial action will be taken at this stage. A site walk over survey has not indicated any obvious surface cracking and the DOC monitoring to date would suggest that peat piping is currently not an issue in Derryclare. The development of a restoration plan must consider all the above factors. It is recommended that the buffer zone be put in place first before the adjacent restoration works are carried out. A detailed description of best practice for all damming techniques and reprofiling techniques is detailed in Appendices 1 and 2 respectively. When deciding which restoration option to adopt, please refer to tables 8 and 9 below. Table 8 is the planners guide to selecting the restoration option to use and table is the operators field guide for use once the restoration plan is decided.

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Table 8: Operational specification for each restoration options based on site conditions.

Recommended operation specifications for each restoration option						
Option number	**21 Restoration options (20 bog restoration, 1 replanting)**	**Slope**	**Peat depth**	**Peat slide risk (FOS)**	**Tree species (stump size)**	**Soil type**
1	Fell to waste manually & block interceptor drains	< 6 degrees	All depths	>=1.0	All species (small stump)	BB/heath
2	Fell to waste manually & fill in interceptor drains	None	All depths	>=1.0	All species (small stump)	BB/heath
3	Fell to waste manually, block interceptor drains, remove brash from the buffers, windrow	< 6 degrees	All depths	>=1.0	All species (small stump)	BB/heath
4	Fell to waste manually, fill in interceptor drains, remove brash from the buffers, windrow	SWL	All depths	>=1.0	All species (small stump)	BB/heath
5	Fell to waste mechanically & block interceptor drains	< 6 degrees	All depths	>=1.3	All species (small stump)	BB/heath
6	Fell to waste mechanically & fill in interceptor drains	SWL	All depths	>=1.3	All species (small stump)	BB/heath
7	Fell to waste mechanically, block interceptor drains, remove brash from the buffers, windrow	< 6 degrees	All depths	>=1.3	All species (small stump)	BB/heath
8	Fell to waste mechanically, fill in interceptor drains, remove brash from the buffers, windrow	SWL	All depths	>=1.3	All species (small stump)	BB/heath
9	Fell to waste mechanically, block interceptor drains, remove brash from the buffers, windrow, surface smooth with excavator bucket	< 6 degrees	>0.5m	>=1.3	All species (small stump)	BB
10	Fell to waste mechanically, fill in interceptor drains, remove brash from the buffers, windrow, surface smooth with excavator bucket	SWL	>0.5m	>=1.3	All species (small stump)	BB
11	Harvest trees & block interceptor drains	< 6 degrees	All depths	>=1.3	All species (small stump)	BB/heath
12	Harvest trees & fill in interceptor drains	SWL	All depths	>=1.3	All species (small stump)	BB/heath
13	Harvest trees, block interceptor drains, remove brash from the buffers, windrow	< 6 degrees	>50cm	>=1.3	All species (small stump)	BB/heath
14	Harvest trees, fill in interceptor drains, remove brash from the buffers, windrow	SWL	All depths	>=1.3	All species (small stump)	BB/heath
15	Harvest trees, block interceptor drains, remove brash from the buffers, windrow, surface smooth with excavator & bucket	< 6 degrees	>0.5m	>=1.3	All species (small stump)	BB
16	Harvest trees, fill in interceptor drains, remove brash from the buffers, windrow, surface smooth with excavator & bucket	SWL	>0.5m	>=1.3	All species (small stump)	BB

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Table 8 (cont.): Operational specification for each restoration options based on site conditions.

Recommended operation specifications for each restoration option						
Option number	**21 Restoration options (20 bog restoration, 1 replanting)**	**Slope**	**Peat depth**	**Peat slide risk (FOS)**	**Tree species (stump size)**	**Soil type**
17	**Harvest trees, remove brash from buffers, windrow & scrap mound (replanting option)**	SWL	**<0.25m**	>=1.3	All species (small stump)	Heath
18	Harvest trees, block interceptor drains, remove brash from the buffers, windrow, surface smooth with excavator & grind stumps	< 6 degrees	>1.0m	>=1.3	All species (small stump)	BB
19	Harvest trees, fill in interceptor drains, remove brash from the buffers, windrow, surface smooth with excavator & grind stumps	SWL	>1.0m	>=1.3	All species (small stump)	BB
20	Harvest trees, block interceptor drains, remove brash from the buffers, windrow, surface smooth with excavator & stump flipping	< 6 degrees	>1.0m	>=1.3	All species except large LPS (large stump)	BB
21	Harvest trees, fill in interceptor drains, remove brash from the buffers, windrow, surface smooth with excavator & stump flipping	SWL	>1.0m	>=1.3	All species except large LPS (large stump)	BB

SWL – safe working limit of a machine to operate on a slope. Manufacturers specifications.

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Table 9: Operators field guide to the various bog restoration techniques*.

Individual task	Suitability site conditions
Fell trees	All sites where it is safe for a machine to operate. Fell conventionally, fell to water or mulch.
Windrow felled trees	Steep slopes over 6 degrees where dams are not recommended, sloping sites where it is safe to operate a machine but where other restoration methods are deemed ineffective. On fell to waste sites where brash is likely to impede further restoration works.
Dam interceptor drains	Sites with slopes 6 degrees or less. Use peat if the base of the drain is incised to the mineral. Use peat dams or equivalent if base of the drain is peat. Not effective on slopes over 6 degrees. Observe correct spacing between dams.
Dam plough drain	Sites with slopes 6 degrees or less. Use peat if the base of the drain is incised to the mineral. Use peat dams or equivalent if base of the drain is peat. Not effective on slopes over 6 degrees. Observe correct spacing between dams.
Fill in interceptor drains with peat	All sites where an excavator can work safely.
Fill in plough drains with peat	All sites where an excavator can work safely.
Reprofile the plough drains with an excavator bucket	Best where stumps are small (<15 cm diameter) and the site is wet and the peat more malleable. Considered a better option to damming on sites with slopes between 3 and 6 degrees where the peat is shallow.
Cross track with a wide tracked excavator	Used in conjunction with reprofiling, stump flipping. Will depend on the tracked machine used. Limit where possible to one pass, to minimise compaction.
Stump flipping	Best on Sitka spruce stumps (>15 cm diameter) and smaller lodgepole pine stumps, where the inverted stump is large enough to fill the furrow. Best where the peat depth is deep. Can be applied over a range of slopes but most effective on flat sites.
Scrap mounding	All sites identified as suitable for pioneer native woodland where there is sufficient peat depth available to create a scrap mound. Confine to sites where it is safe for a machine to operate.

** The assumption is made that all necessary water protection measures are in place and effective.*

Brief descriptive notes

1. Fell trees: Conventional clearfelling, felling to waste or whole tree mulching.
2. Windrow felled trees: Conventional windrowing using an excavator.
3. Dam interceptor drains: Construction of dams on the interceptor drains (peat, plastic, other) using recommended standards.
4. Dam plough drain: Construction of dams on the plough drains (peat, plastic, other) using recommended standards.
5. Fill in interceptor drains with peat: Infilling of all of the main interceptor drains with peat using an excavator.
6. Fill in plough furrows with peat: Infilling of all of the main interceptor drains with peat.
7. Reprofile the plough drains: Plough rides are slide into the furrows using the excavator bucket.
8. Cross track: Using the machine weight to cross back and over to level off the site.
9. Flip stumps: Filling the furrow with a flipped stump and driving over it to level it out.
10. Scrap mound: Conventional practice of inverting a mound to create a planning medium (for pioneer woodland only).

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Appendix 1: Best practice techniques for drain blocking.

The aim of drain blocking is to block the artificial drainage created to establish the forest and re-instate a more natural hydrology that will retain more water on the peatland. (The natural drainage pattern [aquatic watercourses and relevant watercourses] are not blocked). Typical forest drainage on peatlands in Ireland involved creating a plough ribbon (furrow and ridge) with regular inceptor drains running at 90 degrees to the plough ribbon, with these inceptor drains feeding the collector drains before reaching the drain outlet point.

Blocking drains is a well-established practice in bog restoration and many different materials have been used in the past. More recently, the favoured material is the peat itself as it works well, is cost effective, and is easy to install. While most artificial drainage patterns can often be easily identified from aerial images, the best time to identify these drains is when the crop is felled. A good rule of thumb for all contractors is the instruction to only begin work once effective buffer zones are in place and then block all artificial drains they come across when working on the site. It is also good practice to block drains first at the top of the site and then working downslope. Optimum results are achieved when drain blocking is done in conjunction with reprofiling.

For all dam types, the most important factor is the spacing between the dams. Recommended spacings are given in Table 1. Dam spacing depends on the slope and flow rates. The steeper the slope the closer dams should be spaced. **The water should back up to the toe of the previous dam**. Dams work best on average slopes of 6^0 or less, but with careful planning they can work on steeper slopes. The water pressure behind the dam needs to be also considered, and therefore more and shallower dams are preferable to fewer tall dams, because the failure of one dam may lead to overwhelming the next dam downstream. The more dams are installed the less the overall risk of failure across the site. Dams work best when there is peat in the base of a drain, so a good seal can be created. Dams that are not keyed in are more likely to fail. If your drain has eroded down to the mineral layer, consider stone dams or reprofiling or blocking the drain at another point where there is peat at the base of the drain.

Table 1: General guide to dam spacing in relation to slope.

Slope (degrees)	*Dam spacing (m)*
1	15
2	7.5
3	5
4	4
5	3

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The main drain blocking techniques to block drains are:

1. Peat dams.
2. Plastic dams.
3. Timber or composite (mixed materials) dams.
4. Wooden, metal or stone dams.
5. Leaky dams.
6. Drain reprofiling.
7. Wave dams (new).
8. Zipping (new).

1. Peat dams

NPWS peat dams on raised bogs - see page 55

NatureScot Peatland ACTION - Video 1 Ditch Blocking - YouTube

Peat dams are best suited to standard forestry drains on deep peats (at least 50cm), which have not incised down to the mineral layer and on slopes less than 6 degrees. It is good practice to install peat dams where drains are at their narrowest. The spacing between these dams is slope dependent (see Table 1). A good rule of thumb to assist contractors with the spacing is to ensure that the water from the upper dam always reaches the toe of the lower dam. The dams themselves must be wide enough to ensure water cannot flow around the edge of the dam. The correct width must consider the effect of the drain on the surrounding peat. Immediately beside the drain the peat will be drained and slightly lower on either side of the drain. To assist contractors in building the dam to the correct width, instruct them to build the dam three times as wide as the drain width. Always engineer the dams assuming peak water flows. Where possible, construct dams with a bit of a longer spur on the downhill side to encourage spreading out flow laterally. The height of the dam should also be slightly higher than the fall line of the drain so that water cannot flow or seep across the top of the dam. Take good care to tamp down the dam with the excavator bucket to make sure it is well consolidated and a good seal forms. To finish off the dam it is recommended to take a vegetated scraw from the adjoining bog surface (not the drain) and place it on top of the dam. The construction if peaty dams is better done mechanically as better seals can be achieved, as opposed to a manually constructed peat dam.

The location and quantity of peats dams is best assessed when the crop is felled, when the site is fully visible. When planning the installation of peat dams, it is also important to know when not to use a peat dam. Do not use a peat dam when the drains are over 1m wide, and the flow rates are high. Do not use peat dams when the peat is shallow (< 50cm), and the bottom of the drain is exposing the mineral layer. Peat dams are not suitable on steep slopes and in areas where there are flashy peak flows. Proceed with caution if the drains are close together and running across the slope (as water may be shed from an upper drain into a lower drain because of the dams).

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Another consideration when constructing peat dams is the tendency of deer/sheep/goats or cattle using the dams as crossing points and damaging them. Wherever possible, reprofile the drain sides to prevent dams being the only crossing points. Alternatively, construct a large number of dams so animals aren't using a few dams as the crossing points, and build the dams high enough so they are more robust.

2. Plastic dams

NPWS plastic dams on raised bogs - see page 58

NatureScot Peatland ACTION - Video 1 Ditch Blocking - YouTube

Plastic dams are best used in areas where peat dams are unsuitable and typically these would be in areas where the slope is over 6 degrees, the drain width is too wide and where the pressure of the water is likely to exceed the shear strength of peat dams. Plastic dams create a good seal when driven into at least 25 centimeters of solid peat or clay. On more porous mineral soils, plastic piling dams may not create a good seal. Similar to peat dams, the width of the dam must extend well into the banks either side of the drain. The same rule of thumb used for the width of peat dams can be used for plastic dams i.e., build the dam three times as wide as the drain width. Heavy rain can undercut the dams, especially if there is poor seal. Logs and brash can be placed in the drain to help relive this pressure. Plastic dams can also be used in conjunction with peat dams to relieve water pressures on the peat dams, by strategically interspersing them with the peat dams. Most plastic dams are installed manually but an excavator can also be used. Larger plastic piling structures have a visual impact and they also degrade over time and so carry a long-term pollution risk. Using plastic piling is also much more expensive than using peat dams, and the cost and time to transport materials on and off site has to be considered.

When planning the installation of plastic dams, it is also important to know when not to install them. Plastic dams are not suitable in drains with high flow rates, in areas where the peat is very shallow or there is no peat in the base and on previously afforested sites where the roots make it very difficult to sink the plastic piling and get a good seal.

When planning the installation of plastic dams, it is also important to know what additional work is needed to ensure they are effective. Wide plastic dams need to reinforced, otherwise they will belly out in the middle under water pressure and collapse. Typically, plastic dams wider than 1.5m need to be reinforced. If the sides and the base are not keyed in properly an inefficient seal results, and the peat shrinks around the same resulting in dam failure.

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3. Timber or composite (mixed materials) dams

Peat Bog Restoration in Scotland - YouTube

Composite dams are made with a combination of different materials such as plastic piling, wood, or other materials and are combined with peat. In special situations, composite dams can also be made using wood and mineral soils. Composite dams are generally installed on drains greater than 1.5 m wide where other methods may sag, burst or form a poor seal. Composite dams can be very effective and are capable of holding back a lot of water.

Further details on composite dams are not provided here as it is not expected that any composite dams will be required in Derryclare.

4. Wooden, stone or metal dams

Wooden, stone and metal dams can be used where peat or plastic dams are unlikely to survive, i.e., drains with high water flows, drains with slopes over 6 degrees, in peat drains with a mineral bottom and in wide drains. Stone dams are used where there is not enough peat depth in the base of the gully to secure wooden dams. Metal dams (iron or steel shuttering) have been used to hold back significant amounts of water in very wide drains. It is expected that only wooden or stone dams will be used in a Forest to bog project.

The drawback of wooden dams is that they have a limited shelf life. The type of wood used dictates how long the structure will last. The shelf life is restricted further when only the recommended untreated wood is used. As with all dams, the width of the dam must be three times the width of the drain. Where these are located if often hampered by the terrain.

Stone dams offer flexibility in damming areas where peat dams are not possible. This would include areas on steep slopes and in drains where undercutting is expected i.e., drains where there is no peat at the bottom of the drain. Typically, stone dams are under 1m in height (to avoid collapse). The stone used in the dam should be about 20 cm in diameter, as smaller rocks are more likely to be washed away by strong water flows. The advantage of stone dams is that they do not need to be keyed in the sides of the drain. The disadvantage of stone dams is that they can be washed away by very high-water flows.

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5. Leaky dams

NPWS how to construct a plastic leaky dam - see page 63

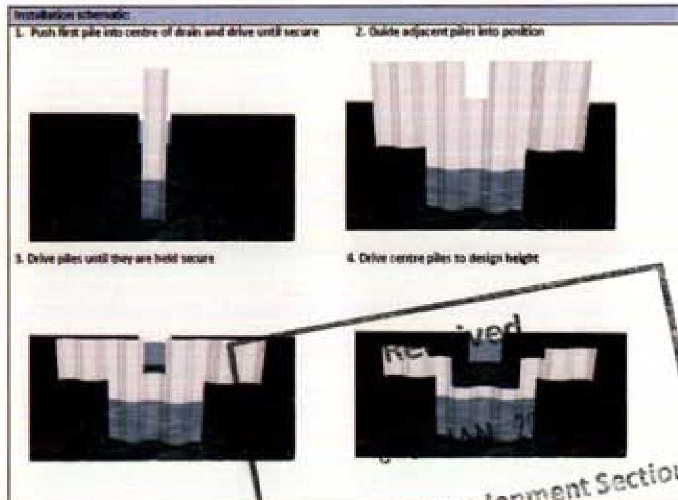
'Leaky dams' refer to partially blocking a drain to keep water levels as high as possible and where the flow is too significant for the channel to be completely blocked. Partially blocking drains is typically undertaken though the use of plastic or wooden dams. Leaky dams are best employed in gullies that are eroded with a lot of bare mineral at the base of the drain. Leaky timber dams are very effective at trapping large amounts of suspended peat, and so are very useful sedimentation control measure.

How to construct a wooden leaky dam

The wooden dams are made from several boards that are allowed to leak so that suspended peat builds up behind the dam and that over time this will be stabilised by vegetation over time. A well-constructed wooden dam will have the lower boards placed close together (to retain water), and the higher boards will have more gaps between them (to allow water to pass through). It is good practice to cut a v-notch in the central splash plate of the dam. Backfilling the downslope face of a timber dam with peat and turf can also be carried out to improve the dams' structural integrity and reduce visual impact.

How to construct a plastic leaky dam

Push the first plastic pile into the centre of the drain, ensuring it remains vertical. Drive the pile into the peat further until it is held firm using a large rubber mallet (if necessary, protect the top of the plastic using a timber batten). Once the centre pile is in a secure position guide adjacent piles into position, pushing into the peat and using the rubber mallet to drive into a firm position. The dam should extend beyond the width of the drain into the bog, typically by a minimum of 50cm to ensure the dam is held firmly. Once all piles have been positioned and are secure they should be driven to a final position, starting from the centre and driving all the piles in the drain down until they reach the design height. Piles towards the outer edge should be driven into the peat until they are secure (remaining approximately 10-20cm above the surface). The plastic piles within the drain should extend at least 50cm below the base of the drain if the peat is very firm. If the peat is weak the plastic should be driven in further until the plastic is held secure.



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6. Reprofiling of interceptor drains

NPWS complete infilling of drains - see page 61

In combination with damming, drain reprofiling is used to further reduce water loss down artificial drains, to remove incised drain features and to reduce erosion of exposed peat on the sides of a drain. It is important to note that the natural drainage pattern of the bog (EPA streams and relevant watercourses) will be left untouched. Therefore, drain reprofiling will only occur on the artificial forestry drainage pattern. This section refers to the reprofiling of the interceptor drains, which were typically installed at 90 degrees to the plough drain as a means of slowing the water and directing it along a preferred drainage pathway. These drains are not part of the natural drainage pattern, and it is recommended that these should be blocked or reprofiled. Drain reprofiling of these interceptor drains should be carried out in conjunction with damming and the use of effective buffer zones at the outlet points.

There are three general techniques:

1. Pushing the edges of the drain into the drain line using the back of the excavator bucket.

2. Re-turving the drain line, which is more like hag reprofiling, when turves are stretched from the drain side into the drain channel, with borrowed turves used from either side of the drain if required.

3. Use of a rollerball.

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7. Wave dams (new)

Watch video on wave dams and zipping (Source Nature Scot)

Peatland Restoration – Wave Damming and Zippering - Technique Guide - YouTube

Wave dams are a new technique that are used for drain sizes less than 1m in width and depth. This was first used in 2014 in Scotland. Wave dams are essentially peat dams constructed at regular intervals constructed from the peat around the drain. This is a quick process, typically 2 minutes per dam, making this cost-effective. They are called wave dams because the regular peat dams along the drain have a wave like pattern in the landscape. This technique applies to long continuous drains that are generally not found in Irish conditions on drained blanket peats.

Wave dams works best on sites that have plenty of bog vegetation and peat available to create the peat dams. The dam width is 3 times the width of the drain. The machine positions itself so that it lines up with the drain and it creates a depression by pulling the bucket towards the machine to create a mound. By reversing the bucket, the mound is squeezed together to compact the mound so that the central mass forms a good seal. The vegetation must not be kept intact on the mound. Tamp down the vegetation on top of the dam and smooth out the sides of the dam using the bucket. Ensure the finished height of the dam is higher than the nearest adjacent ground. Initial form up height should be approximately 30cm above ground level. The whole dam and associated pool will be 1.5 m. It is recommended that wave dams should occur every 4m, or every 8m if done in association with zipping. This job is suited to a 7 – 14 t excavator, on low pressure tracks with a toothed wide bucket

Wave dams work best on deep peat sites, with gently sloping ground and good bog vegetation. Wave dams are not suitable on steep ground (> 12 degrees), when drains are too large, when the peat is too dry and fibrous and when drains have incised down to mineral or bedrock and on ground with poor vegetation cover.

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8. Zipping (new)

Watch video on wave dams and zipping (Source Nature Scot)

Peatland Restoration – Wave Damming and Zippering - Technique Guide - YouTube

Zipping is best used for wide drains (<1.5 m wide). Zipping is a form of re-profiling where the peat dams are constructed at regular intervals (usually every 8m) and the drain completely closed in or "zipped". This form of re-profiling completely in-fills the drain. The combined technique can be used on any site or slope angle that is safe to work with a machine.

To zip a drain, start 1m below the wave dam. Blocks are pivoted across the drain channel from either side of the drain edge in a staggered pattern, inserting the bucket vertically to the full depth, and ensuring the blocks of peat key in behind each other. The voids created by moving these blocks are filled by bulking up peat from behind the first blocks to ensure no voids remain. For this step, only insert the bucket to half its depth. Fill behind the half-depth void behind this infill, move further behind the second blocks and insert just the teeth into the vegetation and roots, and gently stretch the vegetation over the void left by the second blocks. To ensure the blocks of peat are well integrated, tamp down across entire surface of peat that has been moved. If there is a ridge of drain spoil from the original drainage, especially on the downstream facing side of the drain, use the teeth of the bucket to tease the drain spoil ridge apart and then gently tamp down the surface can help to avoid obstacles to water movement. This process is repeated until the next wave dam position is reached. The end result is a zip-like appearance down the drain line. There should be very little sign of the treatment pattern or original drain in the landscape.

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9. Slow water flows (bunds)

Slowing the flow of water is a good strategy to employ where possible. This technique can be used mostly in gullies, and it is also suitable to use artificial drains which have eroded down to mineral layer. There are many different techniques that can be matched to the site, and these include:

Surface bunds can be made out of peat, logs, wood, geo-textile sacks, heather bales, mineral gravel. These bunds slow and break up the flow of water through a gully system and they can catch a lot of sediment. Bunds help alleviate micro-erosion and they reduce the pressure on other downstream restoration measures. (The use of sheep wool may not be suitable as there is a risk of potential contamination of water courses with sheep dip chemicals and straw bales are not very effective as bunds). Bunds work best if placed in a chain formation and the steeper the gradient, the less the distance between the bunds. Generally place bunds 10 m apart, but as well as slope, if the gully is deep (>50 cm deep) then narrow the spacing between the bunds to 7m. Quite often in Forest to bog areas the gully is eroded down to the mineral layer. In this case, using the exposed mineral deposits, build a small mineral bunds across the gully to 30 cm high, place peat on top of mineral bund, then turf over. When installing bunds, start at the top of the system and work down, slowing the flow as you go and remember the bund size is likely to increase as you move down the system.

Surface bunds are not suitable when there is a lot of water moving through the system and when there is very soft sloping ground. Bunds should not be too bog and hold back too much water. Also, be careful with mineral bunds as these will probably eventually wash out. Bunds can very quickly silt up and be over-topped so they will need to be monitored and maintenance will be needed to maintain them in good working order.

10. Stone Dams

Stone dams are very expensive and usually need a helicopter drop. Stone dams are suitable for gullies that are eroded down to the mineral layer, or in areas where the peat is so shallow that timber or peat dams cannot be constructed properly. Stone dams can be a very effective technique that are quick to construct, and they are not prone to erosion or damage, but because of their cost, they are often discounted. Source stone appropriate to the local geology, 15-40 cm in diameter. Use larger cobbles where a leaky dam is required, or smaller stones where the dam is meant to be watertight. Dam spacing is slope dependant ranging from 7-8 m on average and closer for larger slopes. Dams should be no higher than 1 m, the downhill slope of the dam should be 60°and the uphill slope 45°. The dam should be higher at the sides than in the middle (approx. 60 cm). The average dam is 1 unit of 750 kg stone across a gully less than1 m wide. If machine access is possible then re-profile and turf the gully sides and key into the dam. Stone dams can backfill with sediment very quickly, so consider if lots of small, leaky stone dams would be better.

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Appendix 2: Best practice for site reprofiling.

Reprofiling (also known as ground smoothing or surface smoothing) produces an instant surface topography that results in the quickest recovery of peat forming vegetation. Reprofiling removes the ridges and furrows on previously afforested sites to reinstate the topography to what it was before the site was drained. Only the artificial drainage pattern is reprofiled and the existing natural drainage network is left untouched (i.e., relevant watercourses and EPA streams). It is recommended that this technique be used in conjunction with effective buffer zones and peat dams, to protect water quality and ensure that water preferential pathways do not develop along the base and sides of the drains in the future. Vegetation recovery on the resultant smooth surface can be rapid, with good cover of species seen within a matter of 1-5 years. The aim here is to restore the site to as near its original condition before the site was afforested. The walk over site survey post felling will inform the reprofiling decision and match the best reprofiling technique to the site. While this can be approximated at the planning state, it is best done once the site is felled, allowing a trained assessor to make a site-specific informed decision. There is no right or wrong way to reprofile a site. Site reprofiling can involve using a range of reprofiling techniques on the same site. Each site should be treated as unique so that the reprofiling techniques can be matched to the site. Brash mats can be problematic. Ideally you should reprofile under the brash mat, but if the mat is compacted into the ground, then reprofiling under the brash mat should be avoided as it likely to cause too much peat disturbance.

The main reprofiling techniques now employed are as follows.

1. Stump flipping.
2. Reprofiling without stump flipping.
3. Cross-tracking.
4. Reprofiling with stump grinding.

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1. **Stump flipping**

Stump flipping is a reprofiling technique, which peels off the shallow root systems from the underlying peat, flipping them over, followed by compressing them upside down into the furrows with the back of the bucket. The technique used by the machine operator is important and it involves using a toothed bucket to peel the stump off the peat (to minimizing peat disturbance) and then flip the stump over into the furrow and then by driving over it, the stump is compressed into the furrow. Before stump flipping it is important to set out effective buffers along all watercourses, as a water protection measure. Stump flipping is best used on peats deeper than 1m. Stump flipping is suitable for Sitka spruce crops as they have a shallow root plate, which is least likely to disturb the peat in the catotelm. Conversely, the larger lodgepole pine trees have a deeper root ball, that may bring catotelmic peat to the surface, and for these areas an alternative restoration technique would be more appropriate. Stump flipping can also be done on intermediate slopes. Flipping every stump is not always the best approach, do not flip the large stumps if the expected disturbance is too great, flip all the medium sized stumps and push all the small stumps down into the peat. Aim to retain as much of the surface vegetation as possible, by finding a balance between disturbance from reprofiling and minimal disturbance. All stump flipping should minimize the level of peat disturbance and for the larger stumps and root plates it is advisable to leave these in situ. The machine needed for stump flipping can be either a 14 or 20 t machine, with the larger stumps needing the larger 20 t machine. Underpowered machines will not be unable to flip the stumps (you will observe that the machine will be pulled into the peatland and the stump will not move).

Videos

Peatland ACTION delivery partners are at COP26 (spotlight restoration technique "shears harvesting). - YouTube

Stump flipping

Surface smoothing and stump flipping

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2. **Reprofiling without stump flipping – reprofiling with the excavator bucket.**

Reprofiling without stump flipping can occur on poorly drained sites where tree growth is very poor, bog vegetation abundant and furrow depths shallow. In these areas, the excavator bucket can be used to level up the site by filling in the plough furrows by either scraping or nudging the ridges into the furrows. Typically, this is followed up by and complimented by cross tracking with the machine to ensure a level surface is achieved and a good deal is formed. This option is limited by the presence of tree stumps and roots, and it is therefore only suitable for the very smaller stumps, but it can also be used in felled areas that are left fallow for a long enough period of time that has allowed the stumps and roots to rot and decay. If reprofiling without stump flipping reprofiling is not possible, then more intense drain blocking of the main and peripheral drains will be required.

If the peat depth is deep, then the felled timber and brash can be used to block the furrows. For this to be effective, peat dams must be installed first. The timber and brash are useful to slow down the speed of the water but they do not form a good seal in the peat. Therefore, this technique will also require peat dams. It is recommended to block all outflows from existing furrows and install silt traps along collector drains and install dams at 10-20 m intervals along furrows and drains (flat ground or shallow slopes <1 degree) and increase frequency on steeper gradients. Dams should be built to plough ridge height (or approximately 20 cm about the round surface if ridges are absent) and staggered between adjacent furrows to encourage rewetting over a wider area. Plastic piling should only be considered if there is no other option as it is more difficult to get a good seal with plastic piling when there are roots in the peat adjacent to the furrow.

Video

NPWS complete infilling of drains - see page 61

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3. Cross-tracking.

Cross-tracking involves an excavator driving back and forth over the ground so that the whole surface gets flattened, any mulch or brash is distributed, and any stumps or woody debris do not spring back up. This method tends to only be used as a secondary technique on sites where previous efforts have failed to completely remove the ridges and furrows. Newer harvesting techniques with machines with wide tracks render it unnecessary. The recommended cross-tracking technique is to initially pass up and down the slope followed by a second pass across the slope. Cross tracking with conventional tracks is not recommended, as it leads to peat compaction. Instead, wide tracked machines (1.5 m to 1.9 m wide) are the preferred option.

4. Reprofiling with stump grinding (new).

Reprofiling with stump grinding is a new approach that involves grinding the stump first to make subsequent reprofiling with the excavator bucket easier. This approach is the same reprofiling without stump flipping as described above, with the addition of first using a stump grinder to grind all the larger stumps. This approach requires two passes with excavators. The first pass is with an excavator mounted with a stump grinder attached to grind the larger stumps. The second pass (it can be same machine with the stump grinder attachment replaced with a bucket) is with the excavator with a bucket attached.

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Appendix 3: A brief note on ploughing

Ploughing was the main cultivation technique used to establish the majority of existing first rotation forestry on peatlands in Ireland and it is these sites that the majority of blanket bog restoration is expected to occur on the Coillte estate. Large scale forestry developments in Ireland started in the late 1950s with ploughing as the cultivation method. It fell out of favour because it presented problems for access for thinning and led to instability as roots were often confined to the plough ribbons. The dominant type was mould board ploughing (single and double mould board). Tunnel ploughing (or mole ploughing) was also used but it was found to be unsatisfactory on peats (where the tunnels collapsed and did not aid in draining the land) and was eventually phased out. Figure 1 below shows the typical method used to plough a site.

- Ploughs were mounted on bull dozers and straight plough lines were typically ploughed up and down the slope.
- The ploughs produced a ridge (or ribbon) and furrow (or plough drain) network.
- Inceptor (or collector) drains were often placed along the contour at 90 degrees to the plough direction (to slow the water down) and these were often channelled along a preferential flow path to the exit point at the watercourse.
- Very often the plough ridge (or ribbon) led directly into the watercourse or stopped just short, leaving a buffer zone or overland flow area.
- The plough ridge (or plough ribbon) was planted with trees usually at 1.7m to 2.0m spacing.
- Most plough furrows do not carry continuous flowing water with the majority of furrows only carrying overland flow. Their effectiveness was to dry out the immediately surrounding peat to allow enough aerobic conditions for the tree to survive.
- Overtime the plough furrow becomes overgrown and often the only furrows with flowing water are the ones where the preferential flow path exists.
- Typical furrow for ploughing depths were 0.2 and 0.3m for single and double mould board ploughing respectively.
- Tunnel ploughing (or mole ploughing) were typically to a depth of 0.45m and for the mole drains to be effective it was necessary to install collector drains that were deeper than the mole drain. Mole drains worked best on flat sites and were not suitable for peat sites, as the mole drains were prone to collapsing.

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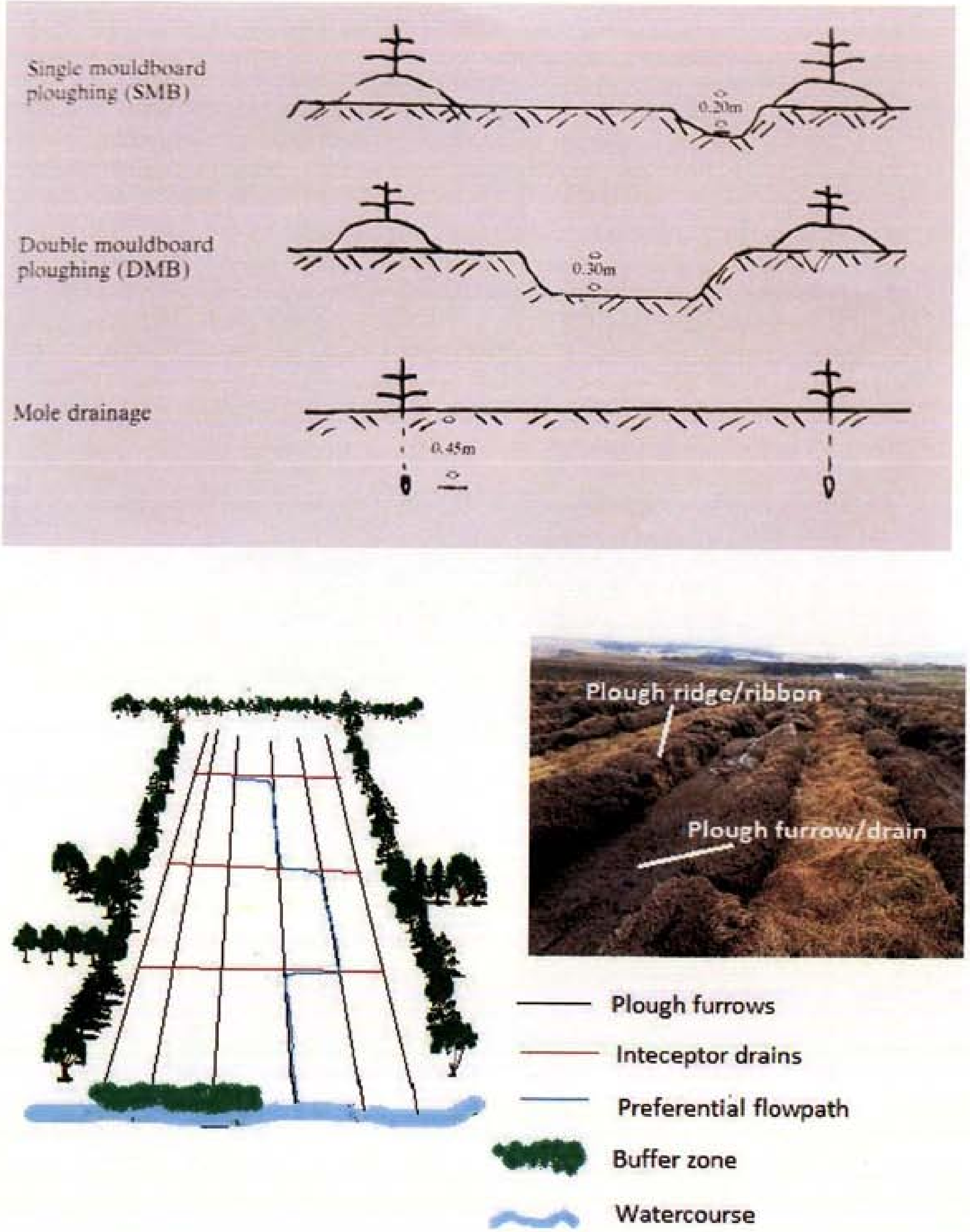

Appendix 3 figure 1: Schematic overview of main ploughing techniques used historically for forestry on peatlands in Ireland.

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Pictures gallery of forestry ploughing

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Appendix 4: Understanding machine ground pressures.

The context

Forest to bog restoration requires the use of low ground pressure machines. Typically, 14-ton and 20-ton excavators are used and to work these sites safely, these machines need to be modified by fitting wide tracks. The determining factor is the nominal ground pressure of the modified machine. This note provides the relevant details necessary to understand this approach. Increasing the size of the contact area on the ground (the footprint) in relation to the weight decreases the ground pressure. Ground pressure of 14 k/Pa (2 psi) or less is recommended for traversing very soft terrain like bogs.

Definition

Ground Pressure (or nominal ground pressure, NGP) for machines is basically their weight divided by the ground contact area.

How to calculate it

Nominal Ground Pressure (NGP) = Weight (in Kg) / Contact area (meters),

SI units (Metres, and Kilograms) so that the NGP is in kilopascals (k/Pa)

Example 1

14-ton excavator with standard tracks (0.7m x 2.3m) with a contact area of 3.2 m^2

14,000 kg / 3.2 m^2 = 4375 kg/m^2

Convert to kPa by multiplying by 0.00980665 = 42.9 kPa

Example 2

14-ton excavator with 1.9m wide tracks (1.9m x 3.5m) with a contact area of 13.3 m^2

14,000 kg / 13.3 m^2 = 1052.6 kg/m^2

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Main points to note…

1. The machine weight in the manufacturer's specification sheets are not always correct. Machine manufacturers often promote their machine as 'forest friendly' without reference to how these were calculated. Therefore, manufacturer figures related to a machines Ground Pressures should be used with caution.
2. Where possible, verify the ground pressures on site.
3. When measuring remember that:
    a) Effective comparisons must assume .
        - Equal weight distribution on both tracks.
        - All calculations are based on the horizontal surface.
    b) Ground pressure can change in the following circumstances.
        - When operating on a slope (weight transfers).
        - When tracking (tractive effort).
        - If track 'wings' are fitted.
    c) In Coillte, our NGP is typically measured on actual contact areas (sinkage is ignored).
4. There are practical implications to consider when fitting wider tracks to a machine and these are:
    - Modifying an undercarriage to have a low ground pressure is costly.
    - Fitting 1.9m wide tracks cannot be done on existing undercarriage without significant costly machine modifications.
    - General industry practice is to have specially engineered undercarriages with the wide tracks and the excavator is then mounted on top.
    - Certain excavators can be moved onto different undercarriages with 'minimal engineering' effort. Undercarriages can be interchanged to most excavator brands:
        - Generally, the hydraulics are interchangeable.
        - Slew ring bearings may differ but this can be corrected using a custom-made adapter.
        - Custom grease plates maybe needed but these are generally inexpensive.
    - Provisional rough cost (over the phone) from Ryan Engineering is 100k and 130k per for 1.9m and 2.2m wide fitted undercarriages with pads.

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Appendix 5: Literature Review.

Best practice blanket bog restoration

Literature review

Author: D Tiernan

Date: June 2023

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1.0 Introduction

This paper reviews the best current understanding for the main parameters affecting peatland management with particular emphasis on understanding the dynamic associated with peatland restoration on blanket bogs and in particular the restoration of afforested peatlands, more commonly known as 'Forest to bog'. Many countries are now developing national peatland strategies to promote their restoration and ensure their continued existence and functionality into the future. In general, the consensus today is that peatland restoration should be attempted where it is feasible. This review looks at some of the main questions that need to be considered when attempting Forest to bog peatland habitat restoration projects.

According to the IPPC (2021), the peatland cover in the Republic of Ireland is in position 3 in the world, with peatland covering 17.2% of our land area. Coillte is the largest single owner of peatland in the Republic of Ireland. The total peatland area under its management is 232,509 ha. The Conservation Status of Irelands peatland habitats is described by the NPWS as largely "Bad and Deteriorating". Wise use of peatlands is essential in order to ensure that sufficient areas of peatlands remain on this planet to carry out their vital natural resource functions while satisfying the essential requirements of present and future human generations. According to Joosten et. Al (2002) the European experience shows clearly that an abundance of mires (bogs) is no guarantee of their long-term survival. For example, Finland has lost 60% of its formerly extensive mire area, largely by drainage for forestry since the 1950s. The mires of Polesia in Belarus and Ukraine, one of the largest continuous mire areas of the former Soviet Union have largely been drained in the 1970s and 1980s. Ireland, where bogs originally covered 17% of the country, has lost 93% of its raised bog and 82% of its blanket bog resource (Foss, 1998). With such a large area of bogs lost, availing of restoration opportunities where possible becomes even more important.

Coillte as the largest single owner of peatland in Ireland and is ideally placed to play key role in bog restoration (IPCC, 2021). Table 1 below shows that forested peatland accounts for the largest land use type and restoration in this area will potentially have the greatest impact. To date Coillte have engaged in various bog restoration projects on both raised and blanket bogs. The Western Peatland Project aims to abide by Principle P24 of the National Peatland Strategy which states that "Coillte as the managers of significant tracts of peatlands on behalf of the Irish people will continue to show leadership in responsible management, rehabilitation and restoration of peatlands".

Table 1: Land use of Ireland's peatlands

Land use on national peatlands	National peatlands (%)
Forested	28%
Turbary/private turf cutting	27%
Reclaimed for agriculture	6%
Peat energy	6%
Overgrazed	5%
Milled for horticultural moss peat	2%
Relatively intact but under pressure	*25%*

Source: Irish Peatland Conservation Council, 2021.

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Coillte Nature (https://www.coillte.ie/coillte-nature/coilltenature) is the not-for-profit branch of Coillte that is dedicated to the restoration, regeneration and rehabilitation of nature across Ireland. Our mission is to deliver real impact on the climate and biodiversity crises through large-scale projects based on the best ecological evidence. We are building on 30 years' experience in forestry, land management and habitat restoration to deliver real impact on the climate and biodiversity crises through innovative projects-of-scale across including planting new native woodlands on un-forested land, restoring important biodiversity areas by investing in major habitat improvements, regenerating urban forests for the benefit of people and nature and rehabilitating ecosystem services by bringing sensitive or degraded lands into better health. Our approach is underpinned by principles of partnership, integrity and accountability, informed by the best ecological evidence, and supported through collaboration and engagement with public, private, non-governmental and community partners. The Wild Western Peatlands (WWP) project is a Coillte Nature project that looks to rehabilitate blanket bog ecosystems. It is a 2,100ha project that is publicly funded by DAFM to serve as a template for future large-scale Forest to bog projects. Coillte's new strategic vision for forestry has identified 30,000 hectares of peatland forests that could be redesigned by 2050 through a programme of rewetting or rewilding. Coillte Nature is working closely with NatureScot in Scotland, who are leading the way in Forest to bog restoration projects at scale.

This report is prepared to inform readers of the main factors associated with blanket bog restoration and serves to inform and educate. Where possible references are made to scientific papers and on-line tutorial videos. The author's concluding remarks are given at the end.

The main factors discussed are as follows.

1. Blanket bogs – the basics.
2. A brief history of afforested peatlands in Ireland.
3. A review of EU LIFE bog restoration projects to date.
4. Effects of forestry on peatlands in Ireland
5. Understanding Peatland hydrology.
6. Why is it urgent to restore afforested peatlands now?
7. Forest to bog restoration in Great Britain, Scotland and Ireland.
8. Author's concluding remarks.

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1.0 Blanket bogs - the basics

Blanket bog formation

Blanket Bog formed when the climate changed 10,000 years ago to wetter conditions and/or the action of man felling forests resulting in watertight iron pans in their upper horizons and consequently waterlogged soils triggering the process for blanket peat formation to begin (Lindsay, 2010). Active peat forming bog refers to a peatland habitat that supports a significant area of peat-forming vegetation where the right conditions prevail for active peat accumulation to occur. Peat in its natural state is composed of 90% water and 10% solid material. It consists of Sphagnum moss along with the roots, leaves, flowers and seeds of heathers, grasses and sedges. Occasionally the trunks and roots of trees such as Scots pine, oak, birch and yew are also present in the peat. Active peat forming blanket bog is defined as peatland supporting significant areas of vegetation that are normally peat forming (e.g. Schoenus nigricans, Molinia caerulea, Eriophorum species and Sphagnum species). Plant communities and microtopography of "active" or peat-forming blanket bog can be very variable. Due to centuries of use and continued degradation, only 20-30% of blanket bogs are regarded as active (Regan 2020), with the remained described by the NPWS as "Bad and Deteriorating" (IPCC, 2021).

Blanket bogs and carbon

Carbon is taken in by peatland plants through the process of photosynthesis from CO2, largely from the atmosphere. Actively growing peatlands accumulate organic mass, and thereby sequester C as the accumulation of organic mass is greater than the extent of vegetation decay. Peatlands has some vegetation decay and this releases C, but the accumulation process is greater, resulting in the peatland becoming a C sink (Joosten et al.,2002). Most of the vegetation decay takes place aerobically in the surface horizons (the acrotelm). However, anaerobic decay also continues, albeit at a much slower rate, at depth in cold, anaerobic horizons (the catotelm), releasing methane. When peat is wet the carbon stocks are safe and carbon sequestration may be occurring. When peat is drying, the carbon stock is being lost as well as the capacity of the peatland to sequester carbon.

Forest to bog

Forest to bog is term used to describe the removing of a forest on a peatland to restore it to its original bogland habitat. According to Campbell et all (2019) the challenge of restoring blanket bog from forestry requires different approaches to those generally used for open peatland restoration. Restoration projects must reverse the impact of the ridge-furrow cultivation process which continues to persist post-felling, as well as raising the bog water table within the underlying peat mass, which have been damaged by the afforestation process. Methods comprising various surface smoothing techniques, and furrow/drain blocking or a combination of both have shown good potential in restoring the blanket bog habitat. Mitigation measures to manage surface runoff (particularly water quality) are required. The timescale for specialist bog plants to fully recolonise following treatment - and for bare peat to be re-colonised is likely to be 3-10 years. Conifer regeneration can be dealt with by surface smoothing methods, but otherwise must be removed by additional treatment depending on size and density (Campbell et al., 2019).

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2.0 A brief history of afforested peatlands in Ireland

The bulk of afforestation of western peatlands in Ireland occurred between the early 1960's to the late 1980's, with a single objective of timber production (Farrell, 1997). At the time, the suitability of certain peatland areas for sustainable forestry was secondary to the more urgent short-term requirement to provide employment in disadvantaged rural areas (Tiernan, 2004). Today, public support for afforestation on western peats has declined (Renou and Farrell, 2005). As a result, afforestation on peatlands is no longer grant aided by the Forest Service, and this effectively has curtailed further afforestation on western peatlands for well over a decade. In 2012 the Forest Service moved away from grant aiding forestry on blanket peatlands, based mainly on environmental and economic concerns. The Forest Schemes manual requires that "The land must be capable of producing yield class 4 for oak or beech or at least yield class 14 for Sitka spruce using normal forestry practices". (Forestry Schemes Manual, Section 6.2.). This economic threshold for forestry on peatland is often not met and in 2012 the Forest Service no longer grant aided new forestry developed on 'unenclosed land', which is typically almost exclusively associated with blanket peat soils. However, the main driver behind this decision was the environmental sensitivities associated with forestry on peatlands in general. In terms of peatland restoration, the forest industry has responded appropriately by preventing future afforestation on peatlands, but the legacy of afforested sites remains, and the challenge ahead is how best to manage these going forward.

3.0 A review of EU LIFE bog restoration projects to date

The importance of bog restoration was recognised by the EU and resulted in significant LIFE funding for bog restoration projects across the EU. A detailed review of all LIFE funded projects between 1993 and 2015 was conducted by Anderson et al., (no date) and this review provided valuable insights for future restoration projects. The EU-LIFE nature programme alone invested €167.6M in 80 peatland restoration projects and these included 1) 319 projects on Raised bogs, mires and fens", 2) 80 projects on improving peatland habitats, 3) Restoration of extracted peatlands, 4) restoration of damaged raised and blanket bogs, 5) Restoration of isolated and remnant peatlands (Belgium, Switzerland, Spain), 6) Restoration of mountain peatlands, 7) Restoration of afforested peatlands, 8) Restoration of eroded peatlands. Anderson advocated that while peatland restoration should be attempted wherever it is feasible, not every site is suitable for restoration and that the level of peatland derogation will determine its ability to recover. Post restoration recovery can be slow and can take up to 10 years on some sites (Carroll et al. 2009). Anderson also observed that monitoring of LIFE sites was limited to the sites under restoration (i.e., no reference sites) and not comprehensive enough for statistical analyses, making a general conclusion about the "success" of the programme's investment impossible to reach. Published evidence of restoration progress for LIFE sites is limited and generally lacks both baseline measurements and robust standardised monitoring schemes. The prohibitive cost of monitoring was cited as the main (and acceptable) reason for not doing the comprehensive monitoring. Consequently, Anderson concluded that in the absence of comprehensive monitoring, selecting the best sites for restoration becomes critical and an evidence-based priority setting with clear guidelines needs to be in place. Anderson

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observed that across the EU, many forestry plantations on peatlands are now coming to the end of their first rotation and the issue of re-stocking these sites must be addressed. To assist this, it is recommended that an evidence-based approach be taken to enable a rigorous assessment of which sites are best suited for re-stocking and which ones for restoration.

This review highlights that it is difficult to measure the success of bog restoration projects and that the level of monitoring needed for statistical comparisons can be prohibitive. Consequently, the most important decision is to select the best sites for restoration and ensure that a robust assessment is made to determine its suitability for restoration. Adopting an evidence-based approach will ensure that only suitable sites are selected for restoration.

4.0 Effects of forestry on peatlands in Ireland

Most afforested peatlands in Ireland were drained using single and double mould board ploughing and to a lesser extent tunnel ploughing. Tunnel ploughing involved creating a small tunnel under the surface to facilitate drainage. This method was deemed unsuitable as the tunnels were prone to collapsing and this method was discontinued. Most afforested peatlands were drained using mould board ploughing, which scraped the surface of the bog to create a plough furrow drainage pattern. Forest drainage typically facilitated drainage and drying out of upper layers of the acrotelm and left the catotelm relatively unaffected (except maybe at drain edges). It was generally observed that these forestry drains were only effective adjacent to the drain and that the sites remained wet (Labadz et al., 2010). The successfully establishment of forestry on these sites also required a tree species that can tolerate wet conditions (lodgepole pine) and additional fertiliser inputs.

According to Lindsay (2010) drainage impacts on peats in 3 ways. 1) Primary consolidation occurs. Shrinkage of the peat adjacent to the drain occurs, especially where the plough furrows are deep. 2) Secondary compression of the peat occurs. This is the phenonium when drained peats drain the 'free' (or interstitial) water from the peat and this removes the floating effect. The catotelm peat adjacent to the drains becomes a heavy load on the peat and this load compresses the peat beneath it and squeezes more water from the peat into the drain, causing the bog surface to subside. 3) Oxidative wastage occurs. Deep drainage allows oxygen to penetrate the catotelm. Once oxygen penetrates the catotelm peat store, relatively rapid decomposition can take place. As the trees grow, their roots suck water from the peat and the canopy will prevent rainfall reaching the bog surface, while the weight of the trees further compresses the peat (Armstrong, et al., 2010); (Wallage, et al., 2006). Drainage can increase DOC production. Drainage modifies the peat structure and hydrological flow pathways, and, depending on topography, runoff can become increasingly flashy, even though lower water tables restrict overland flow (Holden, et al., 2006). The loss of peat forming species may cause leaching of acidity, metals and nitrates into watercourses with subsequent impacts on water quality aquatic ecosystem condition. Typically, afforested western peatlands in Ireland are a damaged haplotelmic bog (a single-layered bog). It may still have vegetation cover, but this vegetation is not adding fresh peat because it is not a

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wetland vegetation and is more likely to be causing further degradation of the peat through the aerating and drying action of its root systems.

There are three other pressures typically associated with afforested peatlands in Ireland and these will also apply to any restoration effort and these are pressures from grazing, invasive species and fires. Grazing pressures from mainly sheep and deer can lead to dominance by Molinia caerulea and Eriophorum vaginatum (Shaw & Wheeler, 1994) with a decline in Sphagnum species (Lindsay, 2010). There are many papers on rhododendron control (Higgins, (2008) Cross, (1973) Rotherham, (1983). Edwards, (2006)) and it is well understood. Their control is essential and often problematic and success removal requires continual vigilance and many costly interventions. Fires tend to burn only the surface vegetation and drier features such as hummocks but leave much of the wet surface relatively intact. For infrequent fires there is generally sufficient time for the bog surface vegetation to recover, but for more frequent and severe fires, (where the fire burns under the surface) it can take more than 50 years for Sphagnum plants to return when burning has produced a bare peat surface (Maltby, et al., 1990); (Evans & Warburton, 2007).

Habitat loss of peatlands is having a dramatic effect on peatland birds. Many peatland birds are on the amber or red lists as a result of habitat loss. These include Merlin, Meadow Pipit, Red Grouse, Curlew, Snipe, Golden Plover, Skylark, Kestrel, Hen Harrier, Marsh Harrier, Peregrine and Lapwing (Irish Peatland Conservation Council 2021).

5.0 Understanding Peatland hydrology.

Understanding peatland hydrology is key to successful bog restation. Peatland hydrology can be very complicated and site specific. The aim of all bogland restoration is to reinstate the acrotelm with the expectation that it will actively deposit plant material annually to the catotelm. At its core, a sites hydrology essentially depends upon the way the water moves and how it interacts with the peat itself. Raised peat contain many different peat types and often the hydrology in these bogs is more complex than in blanket bogs where there is not the same peat type variation. Water quality in a peatland is influenced by the underlying geology, the number and nature of water sources and the chemical deposition from the atmosphere as well as the characteristics of the vegetation and the peat itself (permeability, presence of 'pipes' etc. (Labadz et al., 2010). Blanket bogs are rain-fed peatlands where most of the water flows either over the surface or close to the surface. The hydraulic conductivity of peatlands is generally very low and can vary between the mm or cm range per day and this range is largely determined by the physical properties of the peat (Labadz et al., 2010). In blanket bogs the physical properties of peat can vary, but typically this variation is not as great as it is for raised bogs. The soil profile in a blanket bog is broadly categorised into two types, namely the "acrotelm" (the upper active layer where the water table fluctuates) and the "catotelm" (the lower layer which remains saturated). This profile is described as "diplotelmic", meaning that it has two layers of soil, an upper active layer of roots and recently decomposing plant called the "acrotelm" and a lower layer of denser and more decomposed (humified) peat called the "catotelm" (Ivanov, 1981). In an active blanket bog, material is added annually to the catotelm by decomposition of plant material from the acrotelm, so that the catotelm becomes deeper and denser over time. As the catotelm gets denser it also reduces the size of the pores which also reduces the hydraulic

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conductivity of the catotelm peat. The low hydraulic conductivities within the catotelm are key to maintaining a high-water table close to the ground surface, a condition which is essential to the continuing functioning of surface bog vegetation (Labadz et al., 2010). Forest drainage and tree growth disturbs this hydrological balance by lowering of the water table, aerating the acrotelm layer and allowing tree growth to occur. In terms of restoration potential, drained peatlands are viewed as disturbed and degraded and are no longer considered as "active" because material from the acrotelm is no longer added annually to the catotelm. Restoration looks to reinstate the acrotelm with the expectation that it will actively deposit plant material annually to the catotelm.

Little of the water received in an intact peatland as rainfall is retained by the bog. Peat has an extremely high-water content and in an intact peatland, most of the water storage capacity is already full. Therefore, contrary popular understanding bogs do not act to delay peak flows into streams. The often-quoted idea of a peatland as a "sponge" that soaks up rainfall and then releases it slowly into rivers is erroneous. The response of an out-flowing stream to rainfall received over a peatland depends upon the path taken by the water and the velocity of the flow it achieves. In a pristine peatland, the water table is likely to be close to the surface almost all the year and rainfall will quickly lead to saturation of the peat, which in turn leads to overland flow. Holden and Burt (2002) performed rainfall simulation experiments on blanket peat and showed that 30-40% of rainfall could appear as surface runoff and another 20-35% would runoff rapidly at a depth of only 5cm, but under vegetation the flow at 10cm depth was much less than 10% of rainfall. Rainfall input produces a rapid stream runoff response in peatlands, especially where the catchment has a dense gully network.

The majority of blanket peatland afforestation in Ireland is on a relatively impermeable underlying geology. In peatland areas where the underlying geology is more freely draining, flushed peats have developed (typically served by a consistent water supply from springs). Darcy's law says water flows through a unit area of wet peat is determined by the combination of hydraulic conductivity of the material and the hydraulic gradient (fall in height over horizontal distance travelled). Bogs remain wet because peat generally has low hydraulic conductivities, retaining water even when there is a relatively high hydraulic gradient. Velocity of flow of water though peat therefore is determined by its hydraulic conductivity. The acrotelm peat is more porous than the catotelm peaty and as a result the acrotelm has a higher hydraulic conductivity than the catotelm. The low hydraulic conductivities within the catotelm help to maintain a water table close to the ground surface, and any disturbance of the catotelm (or acrotelm) hydrology has an impact on surface vegetation.

The water table is critical for peatland development because it controls species composition through anoxia (lack of oxygen) at depth, which retards decomposers and so enables peat accumulation. Studies have found that the water table stayed within 5cm of the ground surface for 83% of the time, with the fall in summer being explained by evaporation losses. The water table is the level at which water pressure in the soil is equal to atmospheric pressure, at which water will stand in a well that is hydraulically connected with the groundwater body (Gilman, 1994). In peats these water tables fluctuate naturally. In general, studies have found that most variation in water table levels occur during the

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summer when the levels fall, possibly due evaporation losses. Evans et al (1999) found that blanket bog water tables remained within 5cm of the ground surface (i.e., within the acrotelm) for over 90% of the time. This is consistent with another study which has shown that for 83% of the time the water table remained within 5cm of the ground surface and fluctuated for 17% of the time (Labadz et al., 2010). This seasonal variation is problematic when monitoring water table levels. Allott et al (2009) have suggested that 15 dipwells is the minimum required for adequate representation of water table fluctuations at a site. However, studies by Labadz et al., (2007) quantified the level of water table fluctuations (Figure 1) and this demonstrated that extent of natural water fluctuations in the water table. In terms of monitoring, this presents a huge challenge to distinguish between natural fluctuations and fluctuations caused by the bog restoration measures. Evans et al (1999) found that blanket bog water tables remained within 5cm of the ground surface (i.e., within the acrotelm) for over 90% of the time, and that high stream flows always occurred at times of high-water table. They concluded that there are 2 important mechanisms for generating rapid flow from blanket peat catchments: 1)saturation-excess overland flow (in areas such as hollows or close to the stream channel, where already saturated peat cannot accept any further input of water from the surface) and 2) rapid acrotelm flow over a saturated catotelm (a lateral flow, often within 5cm of the ground surface, generated by the lower hydraulic conductivity of the deeper peat).

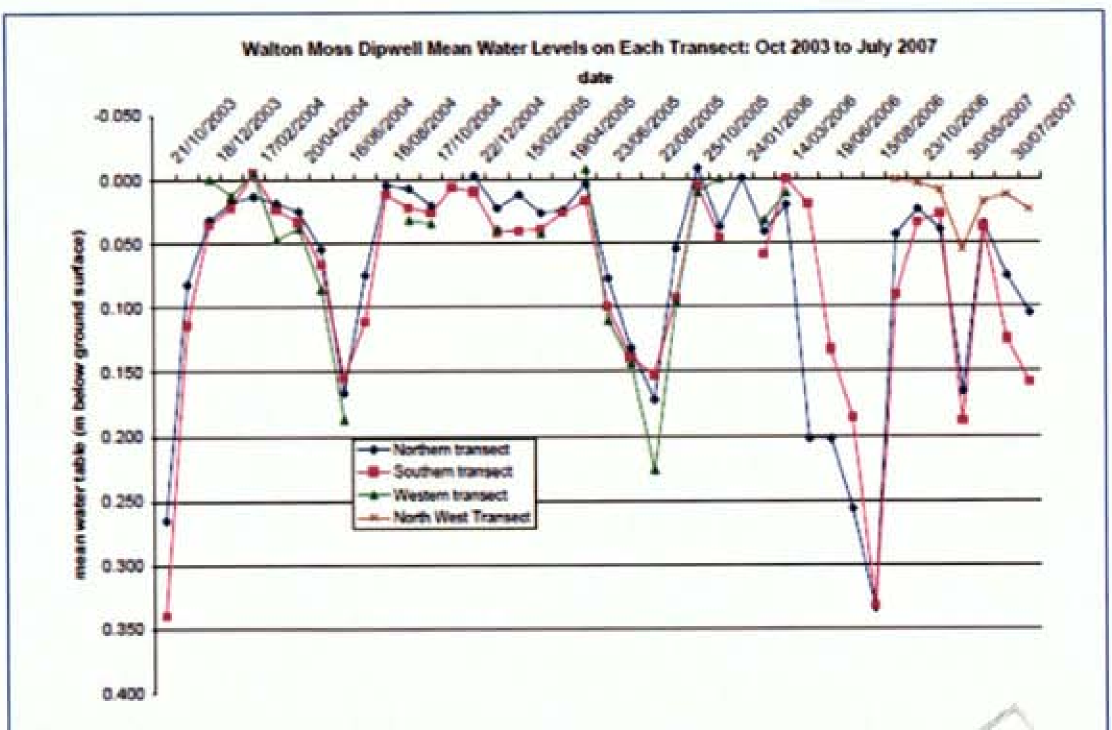

Figure 1: Average water levels at Walton Moss, Cumbria, 2003-7 (Labadz et al, 2007)

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Water quality in a peatland is complex and it depends upon the way the water moves and how it interacts with the peat itself. Influencing factors include the underlying geology, the number and nature of water sources and of chemical deposition from the atmosphere as well as the characteristics of the vegetation and the peat itself (permeability, presence of pipes etc.). Discharge of dissolved organic carbon (DOC) occurs naturally in peat soils, and it is associated with blanket peat catchments and manifests itself as brown discoloration. As expected, DOC concentrations are positively correlated with stream discharge. High levels of DOC in water from peaty catchments come primarily from humic substances, which although not directly harmful are removed from drinking water for aesthetic purpose. Clark et al (2008) stated that peatlands are the greatest source of DOC to natural waters and that most of it is transported during storm (rainfall) events. Adamson et al (2001) found that dissolved organic carbon (DOC) at 10cm depth peaked each summer and was related to temperature. Jones (2004) found that natural soil piping affects water quality in blanket bogs and suggested that it can be an important source of "dirty water", with very marked brown colour especially during the first rains of autumn following a dry summer. It can lead to increased acidity (low pH) of surface water streams. He also noted that by draining and aerating peaty horizons, piping may encourage release of sulphates and organic acids from the peat. The lowering of the water table in dry conditions allows oxygenation of sulphides to sulphate, which is acid and so reduces the solubility and mobility of the carbon, thus DOC concentrations will be lower during droughts and rise again afterwards. Therefore, when water levels are high, bogs can act as substantial sinks for sulphate and reduce DOC mobilisation. Stream DOC is positively related to temperature and is the main factor affecting DOC levels. Gibson et al (2009) concluded that the blocking of drains can decrease the export of DOC, but this decrease was mostly associated with decreasing water yield (flow) rather than reduced concentrations.

Land management influences the vegetation on site which in turn influences the hydrology and water quality. Drainage of blanket bogs has been shown to influence both the properties of the peat and the runoff characteristics of outflowing streams. Ramchunder et al (2009) noted impacts on peat shrinkage and consolidation, microbial activity and decomposition, all influencing hydraulic conductivity and water storage capacity as well as flow rates and processes and susceptibility of the peat to erosion. Historically, the purpose of forestry drainage (using plough ditches) on peats in Ireland was to lower the water table so that the top layer of peat would become aerated enough to facilitate tree growth. Price et al (2003) said the efficacy of drainage depends on the depth of the ditch, the distance between ditches and the hydraulic conductivity of the peat. Water tables might be drawn down up to 50m from the ditch in fibrous peat. Robinson et al (1998) showed in upland peat soils that drainage for forestry initially increased the runoff response of peat areas under wet conditions but can also induce increased storage between storms leading to larger antecedent soil moisture deficits. Some drained blanket peatland catchments have been found to exhibit an increase in low flows and this may be associated with the de-watering of the catchment through the slow drainage and drying out of the normally saturated catotelm (Holden and Burt 2003). Although it is accepted that the lowering of the water table may cause an increase in available storage of water during rainfall events, making the stream runoff response less sensitive in the short-term and as a result water will continue to leave the catchment (Holden et al 2004, Holden, 2006). In the long-term, continuous dewatering of peat potentially creates desiccation and soil instability resulting in an increase in

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subsidence and decomposition, a widening of surface drainage and subsequently an increase in runoff and the return of a flashy response to rainfall events and flood-risk once more (Holden et al 2004, Holden et al 2006). Holden et al (2006) studied five locations in two blanket peat catchments that had been drained with open ditches in the 1950s and found that on the drained catchments the overland flow response was short and sharp, as the ditches efficiently removed runoff and produced an even narrower, more peaked hydrograph than on the intact catchments.

The loss of water from the drained catchments may also increase macropore flow through the soils in the form of soil pipes developing in deep peat (Holden et al 2006). He found that macropore flow and the number of soil pipes in drained catchments were significantly higher than those on the intact catchments. The study indicated both the number and the size of the pipes increased. This suggests that peat properties can alter over time, changing the structural properties of the peat caused by enhanced desiccation which may not always be reversible simply by a process of ditch blocking (Holden et al 2006). Ramchunder et al (2009) reviewed the impacts of peat drainage on water chemistry and noted multiple and sometimes contradictory findings on carbon, pH, nutrients and metals. In summary, however, he found that the main effects were on the mobilization of metals and pollutants and reduction of instream light penetration (linked to higher turbidity and water colour)

Forest drainage on peats will increase the runoff response of peat areas under wet conditions, but it can also induce increased storage between storms, leading to larger antecedent soil moisture deficits which would tend to reduce stream runoff (Robinson et al (1998)). Holden (2006) suggests that ageing system of drains on steeper slopes should be targeted for ditch blocking because these drains are subject to a greater discharge of sediments and carbon, because these drains expose the deeper layers of peat. He suggests that artificial drainage of peatlands encourages the development of pipes and macropores and this opens the way for water, sediment and nutrients to be transferred from deep within and below the peat rather than just simply transferred rapidly through the aerobic acrotelm (upper peat layer). It seems likely that ditches running up and down slope will produce more rapid flow velocities and so are likely to lead to increased peat erosion compared to ditches excavated along the contours, but little direct evidence for this has been found in the literature. New forest peat drains can increase stream flows initially but as the drains vegetate over time there will be a progressive decrease in the frequency of flow pulses and an increase in pulse duration, so that after 12 years the runoff response had become much less flashy Archer (2003). New forest drains on peatlands affects flows but these affects vary over time. Robinson et al (2003) suggested these effects could last 10 years or longer. In small upland catchments they also suggested that drainage for forestry could double the originally low base flows, but as the tree crop grows again this will decline, depending on the nature of weed growth and accumulation of leaf litter to block the drains. Also, mature forest has a drying effect, lowering the soil water table to beneath the artificial drains, so that the long-term drying is "biological" rather than engineered. They concluded that peak flows from a mature forest cover on peaty soil in north-west Europe may be little different from on unforested land.

Impacts of heavy construction on peatland hydrology include the effects of roads, railways, grouse moor tracks and more recently access tracks for wind farm developments. Gunn et al

(2001) noted that the hydrological impacts of the turbines themselves are likely to be very limited, the management and engineering of excavated access roads is where the problems are. On these roads the volume of the acrotelm is reduced possibly by more than half, which would in turn reduce permeability, increase saturation and could potentially pond water on the upslope side. Stunnel (2010) noted that the risks associated with construction on deep peat are much greater than those on shallow peat, and that much can be done in the design and construction to reduce impact.

Changes in water quality following drain blocking

O'Brien et al (2008) found that the water table rose after drain blocking and significant rise and fall in water table was observed in the monthly average of daily mean stream flow, suggesting that the catchment was successfully rewetting, but they did not find any statistically significant changes in water colour over the 3 years of the trial. In this trial they found that drains on slopes gentler than 2° rarely eroded and natural infilling of drains often occurred on slopes less than 4° Holden et al (2007). The study observed that drain blocking is an effective treatment for reducing sediment movement, with better-than-expected revegetation response. Sediment transport was found to occur most during winter, even though this was not the time of greatest rainfall. Active drains were a major source of sediment, giving sediment yields around 30-50 t.km-2 during the 12-month study, and accounting for 18.3% of the sediment from only 7.3% of the catchment area. However, drains that had been dammed along their length using peat blocks had very low sediment yields, and even poorly functioning dams were very effective at reducing suspended sediment.

Wallage et al (2006) study at a single blanket peat site, found that DOC and water colour values were significantly greater at the drained site than the intact site, whilst those at the site with blocked drains were significantly lower. There was a contrast in the quality of the carbon from the different areas, with the drained and blocked sites having more of the large molecules of highly coloured humic acids and the intact sites more of the fulvic acids that characterise newly decomposing plant litter. They also looked at the ratio between water colour and DOC and suggested that an elevated ratio at the blocked site indicated continued disturbance to DOC production and transportation, possibly by enhanced microbial activity, despite the lower concentrations found. It should be noted that the drainage and blockage had occurred prior to the start of this study so no direct "calibration period" was available for comparison, and the conclusions do depend upon finding situations which were truly comparable before the intervention took place.

There is not a consensus in the literature with regard the effectiveness of drain blocking on water quality. *According to* Schumann and Joosten (2008, p 22) restoring peat hydraulic conditions is virtually impossible. They suggested that compacted peat prevents the water from entering the peat body and the decreased storage coefficient of the peat leads to larger water level fluctuations, which increases peat decomposition. This means that peatlands where the hydraulic peat properties have been changed often cannot be restored to their former hydrological functioning, but that alternative restoration aims have to be formulated. Worrall et al (2007) said that drain blocking was ineffective for reducing water

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discolouration and DOC, at least in the short term. Their work at Whitendale (blanket peat) showed that mean water colour and DOC were higher in the blocked drains than in unblocked drains or streams. Relative water colour was approximately twice as high in the blocked drains compared to unblocked ones. Streams tended to have higher specific absorbance (ratio of colour to DOC) than the drains and showed a greater increase in water colour after the blockages were installed. However, seasonality effects still seemed to be more important than the effect of the blockage in explaining observed variations. Worrall et al (2008) noted that, the increase in DOC concentration observed in many rivers with extensive peat cover may be indicative of changes in terrestrial carbon reserves as a result of climate change.

6.0 Forest to bog restoration in Great Britain, Scotland and Ireland

Forest to bog restoration refers to the practice of removing an established forest and restoring the original bog habitat. This requires a change of land use from forestry to a blanket bog habitat (NatureScot, 2023). Forest to bog restoration in the EU was funded under Previous LIFE projects, where the main methods involved tree removal with drain blocking. More recent Forest to bog restoration methods now also include ground reprofiling, which is associated with quicker site recover. Forest to bog is almost unique to the Great Britain, Scotland and Ireland and not comparable to other EU countries such as Scandinavia, where the climate is different, peatlands are often naturally forested, land preparation and drainage are less severe, and nutrient status is often higher (Campbell et al., 2019). It is important to note that this tight geographical spread means that generic restoration techniques that maybe applicable across the EU may not be effective in Great Britain, Scotland and Ireland and that separate techniques more applicable to these areas are more appropriate. In the last decade both Great Britain and Scotland have been engaged in Forest to bog restoration and they have developed techniques that suit their peatland types. Their experience can help guide us in Ireland and inform our work practices. What follows is a summary of the Forest to bog experience in both Great Britain and Scotland,

A review of peatlands and forestry in the Great Britain by Campbell et al (2019) established that the main effect of forestry on peatlands include: a) drainage and tree growth reducing the water table, b) fertilisation facilitating peat decomposition, c) shading and needle drop removing the bog vegetation, d) drainage creating a new ridge/furrow micro-topography, e) post felling the site contains stumps, roots, a litter layer and brash mats, all of which is problematic for a functioning blanket bog habitat, and f) Conifer trees regenerating from dormant seed on the deforested surface can be a significant problem for forest-to-bog restoration projects. To counteract these impacts, Campbell et al (2019) made the following recommendations for 'Forest to bog' Restoration in the UK.

1. Restoration projects must reverse the impact of the ridge-furrow cultivation process which continues to persist post-felling, as well as raising the bog water table within the underlying peat mass which have been damaged by the afforestation process.

2. Surface smoothing techniques and furrow/drain blocking or a combination of both have shown good potential in restoring active blanket bog habitat. Mitigation measures to manage surface runoff (particularly water quality) from restored sites may be required, in the short-term, depending on the method used, site conditions and sensitivity of receptors.
3. The timescale for specialist bog plants to fully recolonise following treatment - and for bare peat to be re-colonised - is likely to be 3-10 years.
4. Conifer regeneration can be dealt with by surface smoothing methods, but otherwise must be removed by additional treatment depending on size and density.

In Scotland, the Forestry Commission (Scotland) have been involved in Forest to bog restoration at scale for over a decade. According to the Forestry Commission Scotland (2015) site selection is based on a "presumption to restore" (Table 2), which sets out high level criteria in the site selection process on a large-scale landscape level. If these criteria were used in Ireland, most of forested sites on the western seaboard would be identified as having potential for restoration. Their research indicates that a negative net greenhouse gas balance may occur from restocking on deep peats where tree growth is poor, even if there is no significant soil disturbance from cultivation. As you would expect, they have observed that the greatest potential for successful and early restoration of peatland into a net carbon sink is generally on the wettest sites which have yielded very poor tree growth. For sites with poor restoration potential, the Forestry Commission Scotland are planting a low-density 'peatland edge woodland' type that is deemed to be more appropriate.

Table 2: The presumption to restore criteria used in Scotland to select sites

For Commission criteria for bog restoration = Presumption to restore	
1	Deep peat (>50 cm) (Can include shallower peats as well)
2	Habitats designated as qualifying features in the UK Biodiversity Action Plan, or on Natura sites, Ramsar sites, Sites of Special Scientific Interest (SSSIs) or National Nature Reserves (NNRs);
3	Sites or parts of sites where restocking is likely to adversely affect the functional connectivity (hydrology) of an adjacent Annex 1 peatland habitat (as defined in the EU Habitats Directive), or a habitat associated with one;
4	Sites where deforestation would prevent the significant net release of greenhouse gases.

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Authors concluding remarks.

The initial afforestation of Irelands blanket bogs occurred in line with the governmental policy of the day and most of these afforested peatlands are now maturing. Concerns about how best to manage them in the future need to be addressed urgently. Unless action is taken now, it might be too late. In the last decade harvesting has begun on these afforested peatlands and is continuing at a pace annually. It was previously assumed that the low productive nature of these sites would mean extra-long rotations and very expensive harvesting. However, this is not the case. Most afforested peatlands were planted with lodgepole pine, which has a short rotation length of between 30 to 40 years. The economic challenges are also offset by the fact that Coillte manages state owned land, which allows them to adopt a net present value approach to forestry. This approach means that past costs are considered 'sunk' making it easier economically to financially justify felling. In addition, as Coillte has now also moved into adding value through its ownership of 2 board mills, it can add value to the raw material (timber) also making it financially more attractive to harvest. The net result is that afforested peatlands are being felled annually at pace. All felling is subject to the Forestry Act which grants felling licenses with a condition to replant with equivalent species. Unless we act now, we will witness a change from afforested western peatlands to reafforested western peatlands. The western peatlands project acknowledges this urgency and is ideally placed to schedule restoration in tandem with harvesting, to ensure that this restoration opportunity is not lost.

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APPENDIX 7

INVASIVE SPECIES MANAGEMENT PLAN OBSERVATIONS

Appendix 1: Observations

Observations on mapping rhododendron using the 10m transect method.

Manually mapping invasives is not easy and it is expensive. Knowing the exact locations of individual plants using point features on a map is useful when the infestation is low, but when the infestation level is high, using a polygon feature on a map is more practical. The use of remote sensing and drones should be explored as a reasonable alternative. The heat map approach using the DAFOR method produces good results but cannot provide granular detail. The bespoke 10m sampling transect method described above produces very accurate maps and establishes a detailed baseline, but it is labour intensive. This method took 3 people 10 days to complete, and it covered an area of 350, equating to covering approximately 35 ha per day. While 90% of the area was assessable, certain areas were not assessable for two main reasons. Firstly, in some areas the levels of infestation were too high to physically allow access. In these areas, the perimeter was mapped, and a polygon created to identify these areas as polygons, as opposed a point features. Secondly, in other areas the area was inaccessible due to dense forestry vegetation (such as thicket stage crops or blown areas). In these areas, the perimeter was mapped, and a polygon created to identify that these areas were not part of the survey. The 10m sampling transect method is a very costly and demanding physically. The purpose for which the data will be subsequently used should be ascertained before deciding on using this method. Ultimately, any survey will be used to inform the operational plan to manage the invasives. In the case of Derryclare, the operational plan is to have an annual management intervention across the entire site for 7 to 10 years, as a means of dealing with invasives. In this instance, it is questionable why a detailed survey is needed, other than to provide a detailed baseline. In addition, subsequent site inoculation post ground disturbance from the felling and restoration activities will not be captured in the baseline and these will require supplementary surveys.

Observations on recent advances on mapping rhododendron.

Some initial trials were conducted using LIDAR, RGB and multispectral imagery and different platforms (aircraft and drones) to detect and map the extent of rhododendron cover. Dense canopy cover can prevent detection, and in some instances the differentiation of rhododendron from other young vegetation (particularly Sitka spruce regeneration) is less distinct resulting in false positives. These techniques particularly in areas with forest cover and mixed vegetation are still proving to be challenging and further work is needed to refine the process.

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