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RESEARCH ARTICLE

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Impacts of a mature forestry plantation on blanket peatland runoff regime and water quality

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Abstract

A lack of information concerning the hydrology and hydrogeology of intact blanket bogs limits current understanding of how their alteration to mature forestry plantations impacts stream flow and associated water quality. An integrated hydrological/hydrogeological monitoring programme compared processes operating in a relatively intact blanket peat-covered catchment with conditions encountered in an adjacent area under closed canopy plantation forestry. Groundwater monitoring revealed contrasting water level regimes and deeper summer water tables in the afforested area, with forest groundwater also having more elevated specific electrical conductance (SEC) and containing higher concentrations of dissolved organic carbon (DOC). Near-simultaneous pairwise runoff sampling at the relatively intact catchment and afforested catchment outlets demonstrated no significant difference in DOC concentration. Conversely, water samples from the afforested catchment outlet displayed significantly greater SEC; this arose in part because of higher concentrations of dissolved calcium and magnesium, discharging via artificial drainage. Comparison of base flow runoff SEC with peat groundwater samples reflected in significant contrasts in ionic signature and greater levels of mineralisation in surface water, pointing to contributions of deeper water, derived from inorganic substrate materials. Study findings indicate that disturbance to the ground in that part of the catchment under plantation forestry has led to greater variations in stream flow and water quality for aquatic ecosystems. Comparable conditions have been observed instreams flowing through plantation forestry in similar physical settings elsewhere. Study findings suggest that plantations on deep peat can adversely affect stream ecosystems and this may impact on a water body's legal status.

KEYWORDS
blanket bog, groundwater, plantation forestry, runoff, water quality

1 | INTRODUCTION

Although blanket bog is a globally rare habitat, it can be encountered in high latitude areas experiencing an oceanic climate in Europe, Asia, the Americas and Oceania (Gallego-Sala & Prentice, 2013). Across Great Britain and Ireland, it forms the most common wetland type, covering extensive areas while making up approximately 20% of the world's total blanket bog resource (Wildlife Trusts, 2021). Blanket bog covers 897 556 ha (approximately 13%) of Ireland (Republic of Ireland and Northern Ireland) (Hammond, 1981), with its occurrence corresponding to areas of high (>1250 mm/year) and frequent rainfall (>200 rain days/year) (Mitchell & Ryan, 1997).

Water logged conditions and low fertility result in blanket bog having a limited capacity for generating conventional economic products in its natural state. This in turn has led to its widespread drainage and conversion to other land uses. Although forest cover in Ireland remains among the lowest in Europe, at 11% in 2020, rates of afforestation have accelerated in recent years, particularly with the growth of private sector forestry (Department of Agriculture, Food and the Marine, 2020). By 2015 this had led to afforestation rates reaching more than 1%/year. Across Ireland, blanket bog has been disproportionately targeted. Planting has favoured fast-growing evergreen conifer species, such as Sitka Spruce (*Picea sitchensis*) and Lodgepole Pine (*Pinus contorta*), in both public and private forestry (Department of Agriculture, Food and the Marine, 2020). These exotic evergreen species prove particularly fast-growing in the Irish climate and can form a closed canopy cover in commercial plantations in less than 30 years (Joyce & O'Carroll, 2002).

Water logged conditions, which are encountered in naturally treeless blanket bog, are unsuited to plantation forestry and require artificial drainage measures to lower water tables. This typically requires installation of drainage networks, often through ploughing at 2–3 m spacings (Francis & Taylor, 1989). The furrows generated by this process can act as foci for localized drainage, and usually discharge excess water to larger drains, leading onto natural water courses (Anderson et al., 2000; Farrell & Boyle, 1990). This process can alter natural hydrological regimes, which become further altered with tree growth through increased transpiration and interception rates (Johnson, 1998).

Plantation forestry on peat can have a particularly detrimental impact on aquatic ecosystems and the associated legal) status of receiving water bodies (Kelly-Quinn et al., 2016). In Ireland the legal status of water bodies is determined through both biotic and abiotic ecological elements of the Water Framework Directive (WFD) (European Union, 2000). The past 30 years have witnessed a consistent decline in the status of a large number of near-pristine High WFD Status water bodies, with an increasing number of catchments containing maturing forestry (Flynn, McConigley, et al., 2021). In accordance with WFD legislation, degradation of water body status triggers implementation of programmes of measures to restore aquatic ecosystems (Giakoumis & Voulvoulis, 2019). However, effective implementation of these measures requires an appreciation of the drivers generating degradation and establishment of appropriate performance metrics to gauge the capacity of interventions to meet restoration targets. For wetlands, this requires an integrated understanding of surface and subsurface hydrological processes (Krause et al., 2007). In the absence of hydrological, hydrogeological and water quality data from unimpacted areas, this can prove challenging.

A considerable body of research has been carried out on the impact of forestry on peatland on water quality and aquatic ecosystems (e.g., Harrison et al., 2020; Kelly-Quinn et al., 2016; Marttila & Kløve, 2010). Much of this work has placed particular emphasis placed on the effects of suspended sediment, especially following ground disturbance linked with initial and final phases of a plantation's life cycle (i.e., planting and felling). Less attention has been paid to the impacts of uncut stands of closed canopy forestry on water quality and hydrology (Drinan et al., 2013). Moreover, those that have investigated the issue have focused on surface water, while the role of groundwater has remained neglected, thus preventing an integrated overview of the hydrological/hydrogeological processes giving rise to differences in water quality and stream flow.

The research presented in this article examines differences in the hydrology and water quality along the course of a stream draining an area of relatively intact blanket bog, and compares these to conditions encountered downstream, where the stream drains more degraded areas, including an area of closed canopy forestry. The integrated use of physical hydrological and hydrogeological data with water quality aimed to provide a basis for better understanding the impact of mature forestry, planted on deep blanket bog peat, on stream flow and quality, and how this may impact aquatic ecology. Ground conditions encountered at the degraded part of the study area compared favourably with those at other forests on blanket peat. Findings revealed that the disturbance to the hydrogeological regime of the area under forest was accompanied by a change in stream water quality due to the discharge of more mineralised water, particularly during prolonged dry periods, when aquatic ecosystems are often at their most vulnerable (Reynolds & Kelly-Quinn, 2020). A more limited body of evidence base suggests that forestry also promotes more variable streamflow regimes.

2 | MATERIALS AND METHODS

2.1 | Site description

The Letterunshin Blanket Bog Hydrological Research Catchment (54°11′10.3"N 8°55′19.6"W, Letterunshin) is located in western Co. Sligo in the northwest of the Republic of Ireland. It forms one of three catchments with a relatively large coverage (>1 km^2) of blanket bog not displaying evidence of artificial drainage (Conaghan et al., 2000; NPWS, 2016). It has been studied under a wider investigation to characterize hydrological processes on catchments containing near-intact blanket bog, across the range of climatic conditions encountered across Ireland (Figure 1, Flynn, Mackin, & Renou-Wilson, 2021). Letterunshin is drained by a second order stream, the Fiddanduff River (Fiddanduff), which flows northwards to discharge as a tributary into the High WFD Status River Easky. Although relatively intact blanket bog occupies the Fiddanduff's headwaters, the area immediately downstream of the relatively intact catchment (Intact Catchment) outlet, consists of an open area of more degraded peatland (Open Degraded Catchment). That has been impacted by burning, along with peat cutting (and associated drainage,) for fuel. Further downstream the Fiddanduff passes into an area of closed

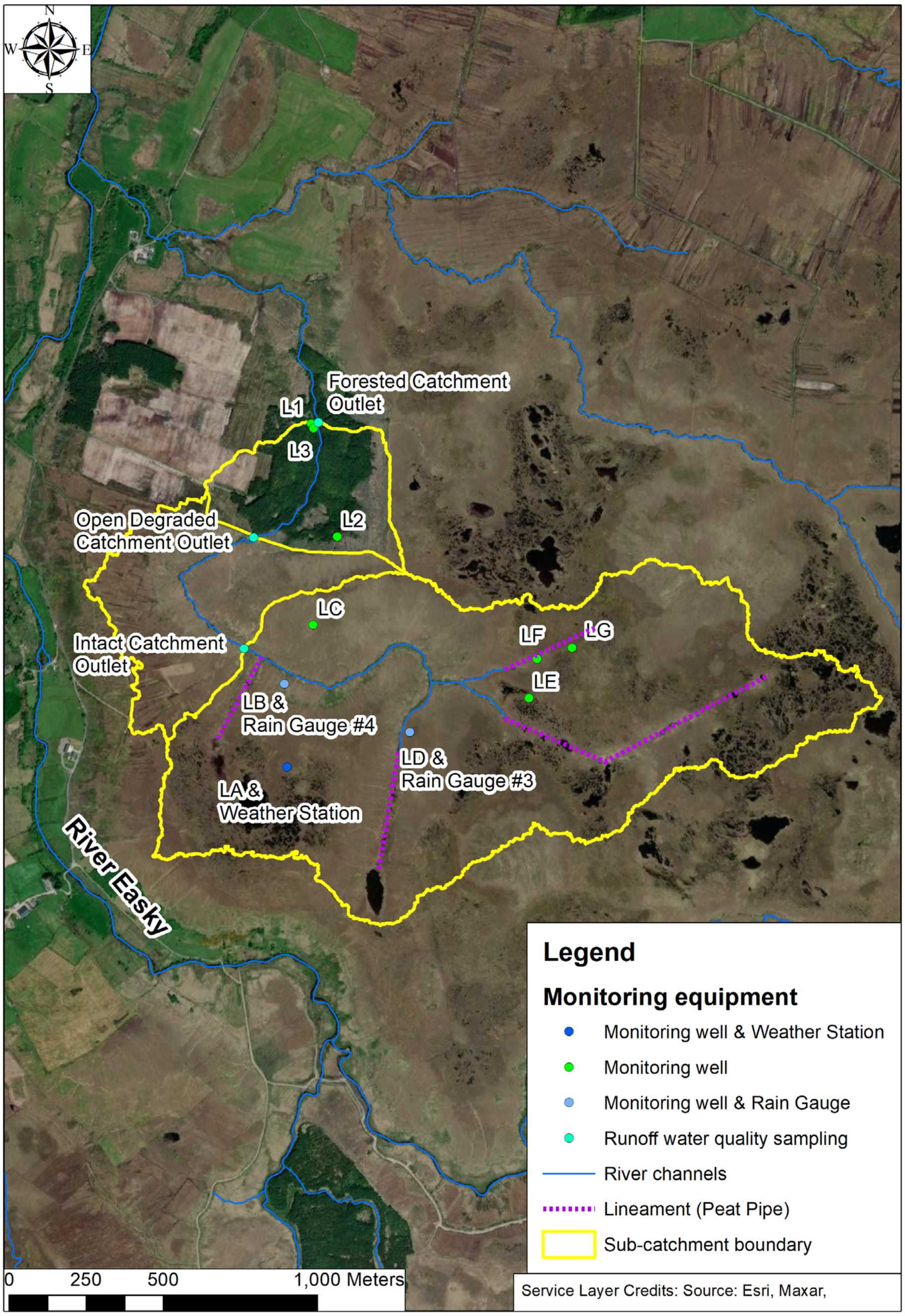

FIGURE 1 Aerial image of intact and degraded areas of Letterunshin test site showing hydrometric monitoring locations. The northerly flowing Fiddanduff River drains both sites. The intact catchment lies to the south and east of the degraded catchment. To facilitate distinction, monitoring wells installed in the intact catchment have been labelled with double letters, for example, LA, LB, and so forth. those wells installed in the Forest catchment have alphanumeric labelling, for example, L1, L2. The dark green area, hosting L2 an L3 corresponds to closed canopy forestry (catchment boundaries defined from Lidar survey data). Pink dashed lines (lineaments) trace the course of subsurface peat piping

canopy coniferous plantation forestry on peat (forested catchment), having an age between 30 and 50 years old.

A review of historical aerial imagery of the area, accessible through Google Earth ©, showed that the pattern of surface water features across the Intact Catchment had not changed over the previous 10 years prior to the investigation, suggesting background hydrological processes remained consistent. Similarly, site observations made in 2016 revealed the canopy in the afforested area to be closed, and remained so over the duration of this study. To better assess how Letterunshin has been affected by land use alteration, an investigation programme aimed to collect data on the area's hydrology, peat hydrogeology and water quality in a series of focused investigations, carried out over a four-year period. Compilation of these data facilitated comparison of the impact of closed canopy plantation forestry on stream flow and water quality, while considering variations in groundwater regime in peat.

Table 1 summarizes physical conditions for both the Intact Catchment and degraded catchments, and their immediate surroundings. Briefly, bedrock geological and hydrogeological data, provide through the Geological Survey of Ireland groundwater viewer (GSI, 2021) revealed the blanket peat cover across the study area to be underlain by a Lr. Carboniferous (Mississippian) limestone bedrock, with no evidence of faulting or karst features within 2 km of the catchment boundary. An airborne Lidar survey, carried out prior to ground investigation, revealed the Intact Catchment to be dominated by an area of relatively flat ground at between 135 metres above mean sea level (mAMSL) and 140 mAMSL, incised by the Fiddanduff River headwaters. Some flatter areas host extensive blanket bog pool complexes.

TABLE 1 Summary of physical conditions encountered at Letterunshin intact and Letterunshin degraded catchments

	Intact	Degraded
Topography		
Area (ha)	160.3	214.5 (incl. 160.3, of which 12.5 ha is closed canopy forestry)
Maximum elevation (mAMSL)	150 < x < 140	150 < x < 140
Min elevation (mAMSL)	<110 < x < 120	<100 < x < 110
Causes of degradation	Grazing, piping	Grazing or forestry, burning
Geology/hydrogeology		
Bedrock	Dinantian upper Ballina limestone formation	
Bedrock aquifer classification	Regionally Important Karst (Rk)	
Peat substrate subsoil	Till derived from Metamorphic rocks (TMp). Not mapped.	
Reported recharge (mm/year)	44	
Hydrology/meteorology		
Effective rainfall (mm/year)	1105	
WFD surface water status	Good	
Nearest Met Eireann Weather Station	Cloonacoo, Co. Sligo (No. 3135)	
Weather station elevation (mAMSL)	204	
30 year average precipitation (mm/year)	1598	
30 year average evapotranspiration (mm/year) - from Belmullet Synoptic Station, Co. Mayo	493	
30 year average rain days (>0.2 mm/day)	259	
30 year average wet days (>1 mm/day)	218	

Note: Hydrogeological data derived from Geological Survey of Ireland Mapviewer.

By contrast ground conditions across the degraded catchment display a more uniform sloping ground, lacking pools (See Figure A1 for topographic summary plots for both areas).

Although remotely sensed topographic data provided a detailed picture of ground conditions, site surveys were completed to better assess drainage. Ground truthing focused on the closed canopy area of the forest to evaluate spacing between plantation furrows feeding associated deeper drainage ditches. However, activities extended to non-afforested areas, notably to anomalous low lying linear features/enclosed hollows, to investigate the possible occurrence of subsurface channelized drainage (piping). In addition, a handheld 10 mm diameter gouge auger (Eijkelkamp, Giesbeek, NL) continuously sampled peat by coring at each groundwater monitoring (monitoring well nest) locations, until encountering inorganic substrate materials (See Figure 1 for locations).

2.2 | Hydrological monitoring

2.2.1 | Precipitation

A review of long term precipitation data, collected at nearby Irish Meteorological Service (Met Eireann) Weather Stations and Cloonnacool, Co. Sligo and Attymass, Co. Mayo, aimed to assess how conditions observed on-site during the investigation period (2017–2021) corresponded to the longer-term climatic conditions across the area. This was achieved through comparison of annual precipitation during the monitoring period with conditions observed over the preceding 30 years. Comparison of data from these stations with on-site precipitation gauges permitted further comparison of study catchment rainfall with wider regional conditions.

Detailed hydrological investigations focused on 2019, during which time two Hobo automatic tipping bucket rain gauges and associated data loggers (Onset Instruments MA), situated within the Intact Catchment, aimed to permit assessment of total precipitation and the spatial variability of site-specific precipitation across the study area. One gauge was located at a lower elevation in the Fiddanduff Valley (Letterunshin Rain Gauge #1, 123 mAMSL), while a second (Letterunshin Rain Gauge #2, 146 mAMSL) was located on slightly more elevated ground to the southeast. An additional gauge, contained within a Davis instruments Vantage Pro-plus Weather Station, (Davis Instruments, CA), permitted continuous precipitation measurement along with determination of potential evapotranspiration rates throughout the monitoring period, while a manual rain gauge facilitated verification of automated rainfall measurement and collection of precipitation samples for chemical analysis.

2.2.2 | Peat hydrogeology

Initial investigations at Letterunshin focused on the Intact Catchment, where monitoring wells and water level loggers were installed in mid-2017, while subsequent instrumentation of the Forested Catchment was carried out in late 2018 (Figure 1). In both areas the location of groundwater monitoring points aimed to provide a representative reflection of hydrological conditions. Given the assumed proximity of the water table to the ground surface across comparable Irish blanket bogs (Flynn, Mackin, & Renou-Wilson, 2021), topography was considered to provide an approximation of shallow groundwater head and thus hydraulic gradient. Application of the Mackin et al. (2017) model to account for localized topographic conditions using a modified version of the Topographic Index, allowed for representative monitoring point identification. Table 2 provides a model parameter value and associated description for each point selected. Across both the Intact Catchment and the Forested Catchment three 32 mmID water table monitoring wells, with 1.0 m long screened intervals, were installed in equilateral triangular arrays, approximately 10 m apart from each other at each monitoring point (See Figure 1 for locations). These permitted water table monitoring, sampling of groundwater quality and estimation of spatial variability in peat hydraulic conductivity. Where peat thickness exceeded 2 m, a fourth deeper monitoring well was installed in the centre of the array, with its 50 cm screened interval extending upwards from the base of the peat. Challenging ground conditions and site access restrictions limited monitoring well installation in the closed-canopy forested catchment to sloping ground close to the course of the Fiddanduff (L1 and L3). A further three monitoring wells were installed in a formerly afforested area of open peatland (L2), which contained comparable vestiges of forest drainage.

Solinst water level loggers (Solinst, ON-5 m range), installed in one monitoring well at each groundwater monitoring location, recorded water table levels at hourly intervals. Manual measurements, completed in all monitoring wells permitted assessment of the representativeness of monitoring wells containing water level loggers with conditions encountered elsewhere at each monitoring point, while also permitting measurement of groundwater levels at the base of the peat.

Combined manual and data logger measurements in all monitoring wells permitted in situ estimation of peat hydraulic conductivity, using the Hvorslev (1951) approach. Briefly, piezometer (slug) testing to estimate hydraulic conductivity was completed during the winter period when peat saturated thicknesses reach their maximum over prolonged periods (determined from water level monitoring records). This allowed investigation of those parts of the top of the peat profile that were both permanently and intermittently saturated. Tests at each location were completed by inserting a solid 15 mm diameter cylindrical HDPE slug, generating a 2.5 cm increase in groundwater head. This change in head aimed to generate responses, measurable by data loggers, while minimizing changes in pore water pressure that may possibly lead to deformation of the peat pore structure (Regan et al., 2019). Following restoration of static groundwater levels, removal of the slug produced a corresponding decline in water level. All changes in water level were recorded by data loggers over logarithmic time intervals, starting at 1 s and extending up to 5 min. During data analysis, the length of the screened interval contributing water to the response was approximated as the saturated thickness of the screened interval immediately prior to testing. The hydraulic conductivity was calculated using the average of both values.

2.2.3 | Runoff

A Solinst Levelogger (1 m range, Solinst Inc., ON), placed in a stilling well adjacent to a bespoke 2.5 m long × 1.5 m wide × 1.0 m deep flume at the outlet of the Intact Catchment, measured stream stage at hourly intervals. Similarly, a Levelogger, installed into a stand pipe adjacent to a stream section of fixed cross sectional area, allowed stage measurement at the outlet of the Forest Catchment. Turbulent flow conditions immediately upstream of each outlet proved ideal for generating rating curves using dilution gauging with dilute NaCl solution (~1 g/L) following the slug injection method, as described by Day and Day (1977).

TABLE 2 Summary of peat properties at sampling points, Letterunshin Test Catchment, Co. Sligo

Location	Peat thickness (m)	Mackin et al. (2017) Model parameter	Shallow peat K_{max} (m/day)	Shallow peat K_{min} (m/day)	Ground conditions
LA	3.02	0.56	2.83×10^{-01}	1.41×10^{-01}	Flat - no pools
LB	2.88	1.73	5.65×10^{-01}	2.83×10^{-01}	Flood plain-adjacent to swallow hole
LC	1.15	0.4	$1.13 \times 10^{+00}$	1.70×10^{-02}	Slope
LD	6.65	2.84	2.36×10^{-02}	3.21×10^{-03}	Flat - no pools
LE	3.62	41.24	8.48×10^{-01}	4.46×10^{-02}	Flat - pool complex
LF	4.02	1.47	7.07×10^{-02}	3.53×10^{-03}	Near piping
LG	3.23	1.92	1.84×10^{-02}	1.41×10^{-03}	Near piping
Closed canopy	1.25	0.4	4.61×10^{-03}	9.22×10^{-04}	Slope
Cut forest	1.1	0.2	1.66×10^{-03}	9.32×10^{-04}	Flat - disturbed peat
Deep peat	See above	n/a	3.52×10^{-03}	1.30×10^{-03}	All intact locations except LC

2.2.4 | Water quality sampling

Monitoring wells permitted the collection of shallow peat groundwater samples for water quality analysis, following monitoring well and sample apparatus purging, using a hand held suction pump. Sampling occurred at quarterly intervals over 2020 and early 2021. A handheld YSI Proplus multimeter (Yellow Springs, OH) measured in-situ (downhole) groundwater temperature and specific electrical conductance (SEC) during sampling to ensure stable water quality before sample collection. Samples, placed in Nalgene© sample bottles before storage in a cool dark location, and were typically analysed for DOC content within 24 h; major ion content analyses were completed within 1 week of collection.

Runoff water quality collection from catchment outlets initially employed ISCO automatic samplers, which complemented semi continuous measurement of runoff, temperature and electrical conductivity using Hobo U24-001 low range EC loggers, (Onset Instruments, MA). Spot measurements of specific electrical conductance, using a calibrated YSI Proplus hand held water quality meter permitted conversion of Hobo logger EC readings to generate a record of specific electrical conductance (SEC) with flow. Limited equipment availability hindered simultaneous sampling from the Intact Catchment and degraded catchment outlets.

Manual collection of grab samples from the outlet of the Intact Catchment, the Forested Catchment outlet, and at Open Degraded Catchment outlet (Figure 1), within a 2-h period, aimed to provide snapshots of runoff water quality at each location along the Fiddanduff River's course.

All samples submitted for laboratory analyses were collected in two separate HDPE sample bottles, with one bottle containing a (0.3 micron) filtered sample, acidified with 1 N nitric acid used for cation analysis. Samples were immediately chilled and stored in a dark space and analysed within 1 week of collection in the field. A Dionex Aquion ion chromatography system permitted analysis of major cations (Na, K, Ca, Mg –Method TM152, 2022), chloride and sulphate (Method TM184, 2022). Where sample pH exceeded 6.5, alkalinity was deterined by titration with 1N HCl (Method TM043, 2022). DOC and TOC analysis were carried out in accordance with Method TM090, 2022.

2.2.5 | Statistical analysis of water quality data

Statistical analysis of water quality data generated from pairs of near-simultaneously sampled runoff samples from the outlets of the Intact, and more degraded (open and forested) catchments aimed to assess which parameters proved significantly different between sampling points. Paired *t*-testing, following the approach described in Cook and Wheater (2005), compared concentrations of major ions, ammonium, silica total organic carbon and dissolved organic carbon to calculate *t*-test scores. Pairs where one or more samples had concentrations below detection limits were not analysed. Paired *T* score values of greater than 0.00 ($p = .05$) were considered to reflect no significant difference in concentration between sampling points.

Plotting concentrations of samples, collected from the outlet of both of the more degraded catchments, against corresponding samples collected from the Intact Catchment Outlet facilitated visual evaluation of concentration relationships, with a 45° straight lines superimposed on plots to permit comparison of concentrations, should no significant difference exist. Consequently, slopes with points lying below the line, with values less than unity, indicated that degraded catchment outlet concentrations were less than those of the Intact Catchment Outlet, while those lying above the line, with slopes greater than 1, reflected greater concentrations. Slopes of the results plots were calculated using linear regression to generate best-fit lines, while calculation of Pearson r values allowed quantification of the error in these relationships.

3 | RESULTS

3.1 | Ground truthing

Beyond the banks of the Fiddanduff, no peat inorganic substrate materials were observed in outcrop in the Intact Catchment, while exposures were only occasionally apparent in localized excavations on steeper slopes in the Degraded Catchment. Coring at all hydrological monitoring locations, across both the Intact Catchment and the Degraded Catchment, revealed peat to reach in excess of 0.75 m, with thicknesses on flatter areas, for example, at LD, reaching up to 6.6 m.

Drainage survey findings across the Intact Catchment revealed enclosed pipes, up to 75 cm in diameter, occurring within the peat. These cross the elevated ground above the Fiddanduff's floodplain and displayed partially-full conduit flow at depths up to 3.5 m below ground surface (mBGS) during the (dry) survey period. Examination of aerial imagery revealed that the pipes corresponded to roughly N-S and NE–SW trending linear features, apparent through contrasts in vegetation (Figure 1); their occurrence has been confirmed by measurements through localized naturally occurring vertical shafts, or swallow holes, of collapsed peat along these features (Figure A6). Moore and Walsh (2021) note that NNW-NW is the principal permeability orientation for joints in Irish Carboniferous limestone sequences, while the NE–SW trend corresponds to the dominant regional structural fabric (Beck, 2010). These findings suggest that the orientation of the pipe network may be influenced by systematic bedrock structural features. Tracing the pathway of the pipes from topographic maps revealed direct discharge of surface water, where they form the source of the Fiddanduff River and its tributaries.

Combining field measurements with aerial imagery suggests that the conduits extended for over 6.3 km in the intact catchment. Despite their depth, water table monitoring wells located within 10 m of these features displayed groundwater levels within 30 cm of the ground surface throughout the year, for example, at Monitoring well Cluster LF. At the same time the ground in the surrounding area slopes toward these enclosed hollows, which acted as localized areas of focused surface water flow during periods of intense rainfall.

Findings from the Intact Catchment contrast with those in the degraded catchments, where drainage survey findings reveal the non-afforested area displayed no evidence of piping. Similarly, investigations in the afforested area revealed no piping. By contrast the degraded catchments displayed widespread evidence of impacts from artificial drainage. This included non-systematic artificial drainage, constructed to allow peat cutting for domestic fuel in the vicinity of the western catchment divide, south of the forest plantation in the Open Degraded Catchment. These conditions compared with those in the Forested Catchment, where a systematic series of shallow (∼0.3 m deep) 1 m wide deep brash-filled furrows at ∼3.0 m spacings fed into larger drains, up to 1.5 m deep. Many of these deeper drains occurred within 100 m of the Fiddanduff River, and contained water laden with Iron oxyhydroxides throughout the monitoring period. A subset of artificial drains also hosted tufa mounds containing the conifer needles in their matrix; none of the tufa investigated was needle-free. During periods of intense rainfall, the forest drains were noted to wet-up with coloured water, which discharged to the larger drains and the Fiddanduff.

3.2 | Meteorology

Examination of rainfall records, collected at the nearby Met Eireann meteorological stations, reflects the variation in average annual rainfall from both Cloonacool or Attymass, with Attymass, at lower elevation, receiving less rainfall (Figure A2). Comparison of site specific measurements with those recorded at the Met Eireann stations reveals precipitation rates lying between those of Attymass and Cloonacool, while comparison of trends between gauges all locations at the site also prove similar (Figure A3). Overall, annual rainfall data collected over the study period, revealed little difference with conditions over the preceding 30 years. Comparison of seasonal potential evapotranspiration records, calculated using a modified Penman Monteith method (Allen et al., 1998) and on-site weather station data, indicates rates during the winter period (1 October to 31 March) to be approximately one fifth of those in summer, while precipitation proves considerably less variable over the same period (Figure 2).

3.3 | Runoff

Runoff monitoring at the outlets of both the intact catchment and the forested catchment revealed that the Fiddanduff River flowed continuously over the whole monitoring period, with stream stage and discharge displaying strong sensitivity to precipitation; Figure A4 presents rating curves for the outlets of Intact Catchment and Degraded Catchment. Figure 2 presents rainfall runoff responses for both catchment outlets, spanning the summer/winter period of late 2019. Comparison of runoff (discharge/catchment area) reveals significant increases in flow following rainfall during both summer and winter periods, with increases in flow occurring within 1–2 h of precipitation at both intact catchment and forest catchment outlets. By contrast, the data suggest that runoff at the forested catchment outlet proves more variable, with storm peaks in being higher. However, exact differences in runoff have proven difficult to quantify due to difficulty at rating high flows at the outlet of the forested catchment (stage data indicate that the Fiddanduff at the forested catchment outlet breaches its banks during higher flows, consequently discharge from the extrapolated rating curve provides an underestimate of true discharge.) By contrast, base flow runoff rates proved more similar for the both catchments outlets until late August, as reflected in the runoff duration curves for each monitoring location (see Supplement A4). During periods of drier weather in the latter part of the summer, the differences in base flow rates between the intact outlet and degraded (forest) outlet become progressively larger, before rising to comparable levels following intense rainfall.

3.4 | Water table levels

Manual measurements of depths to groundwater revealed broad consistency between water levels at each monitoring location. Figure 3 summarizes the ranges of water level fluctuation for each location. Overall, water tables in flatter areas (LA, LE) remained close to the surface (<30 cm) in winter, with variation proving greater on sloping ground (LC). By contrast, depths to water table and ranges of fluctuation proved greater at all groundwater monitoring locations during the summer. Results of monitoring from areas impacted by forestry (L1, L2, L3) indicate that depths to water and ranges of fluctuation proved significantly greater than for the Intact Catchment, despite comparable Mackin et al. (2017) model indices to monitoring well cluster LC. Comparison of water levels between deep monitoring wells and those at the water table revealed heads in the deeper monitoring wells to be consistently lower than those at the water table throughout the monitoring period, albeit with low vertical gradients ranging between 0.001 and 0.05.

The data presented in Figure 3, although summarizing the water table regime belie more complex differences observed in water table responses between monitoring points in the intact catchment and forested catchment. Data presented in Figure 2e reveal the water table for both sloping and flatter parts of the Intact Catchment display a high level of sensitivity to the frequent rainfall experienced across the area, with water levels typically fluctuating by no more than 10 cm on flatter areas in summer, and 20 cm on sloping ground (Figure 3). However, more significant declines in water level occur during prolonged dry periods, when deviations become more significant, for example, from late June to early July 2019.

Responses to rainfall in areas affected by forestry contrast with those observed in the Intact Catchment, despite occurring in comparable topographic settings. The response presented for points under closed canopy (Figure 2d) revealed significantly lower sensitivity to rainfall during the summer period, with many intense rainfall events failing to generate a rise in the water table. Indeed, it is only after a prolonged period of heavy rainfall in early June 2019 that a significant rise in the summer water table is observed. This is followed by a

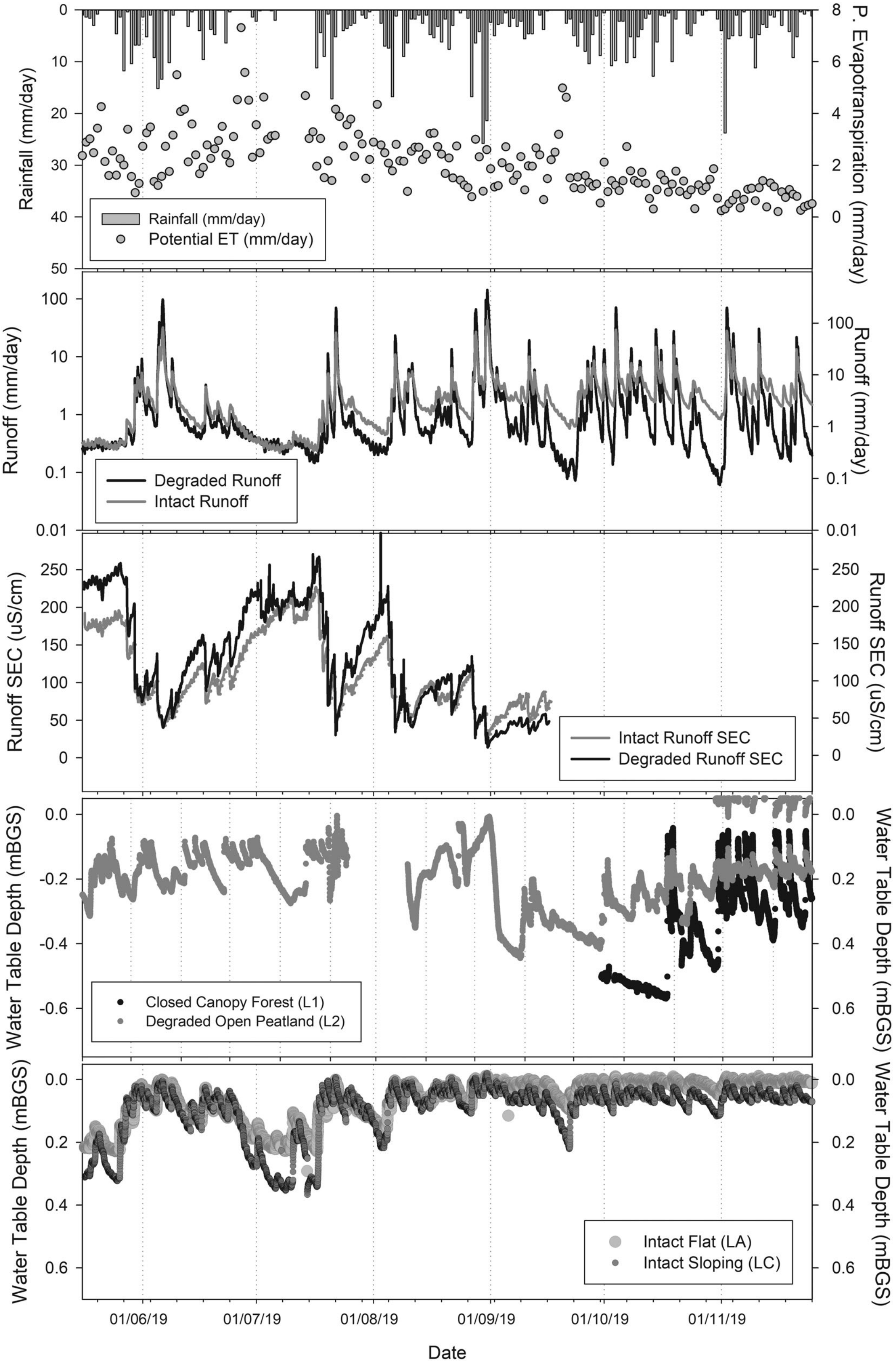

FIGURE 2 Example of hydrological conditions at Letterunshin Test Catchment, Co. Sligo from May 2019 to December 2019. (a) Rainfall and evapotranspiration; (b) Runoff rate and specific electrical conductance-intact outlet; (c) Runoff rate and specific electrical conductance-forested outlet; (d) Groundwater hydrographs for closed canopy and open (cleared) forested areas, degraded catchment; (e) Groundwater hydrographs for flat (LA) and sloping (LC) sites, intact catchment. Note how the peaky response to winter rainfall under closed canopy conditions, after October 2019, contrasts with more subdued responses in the intact catchment for the same period

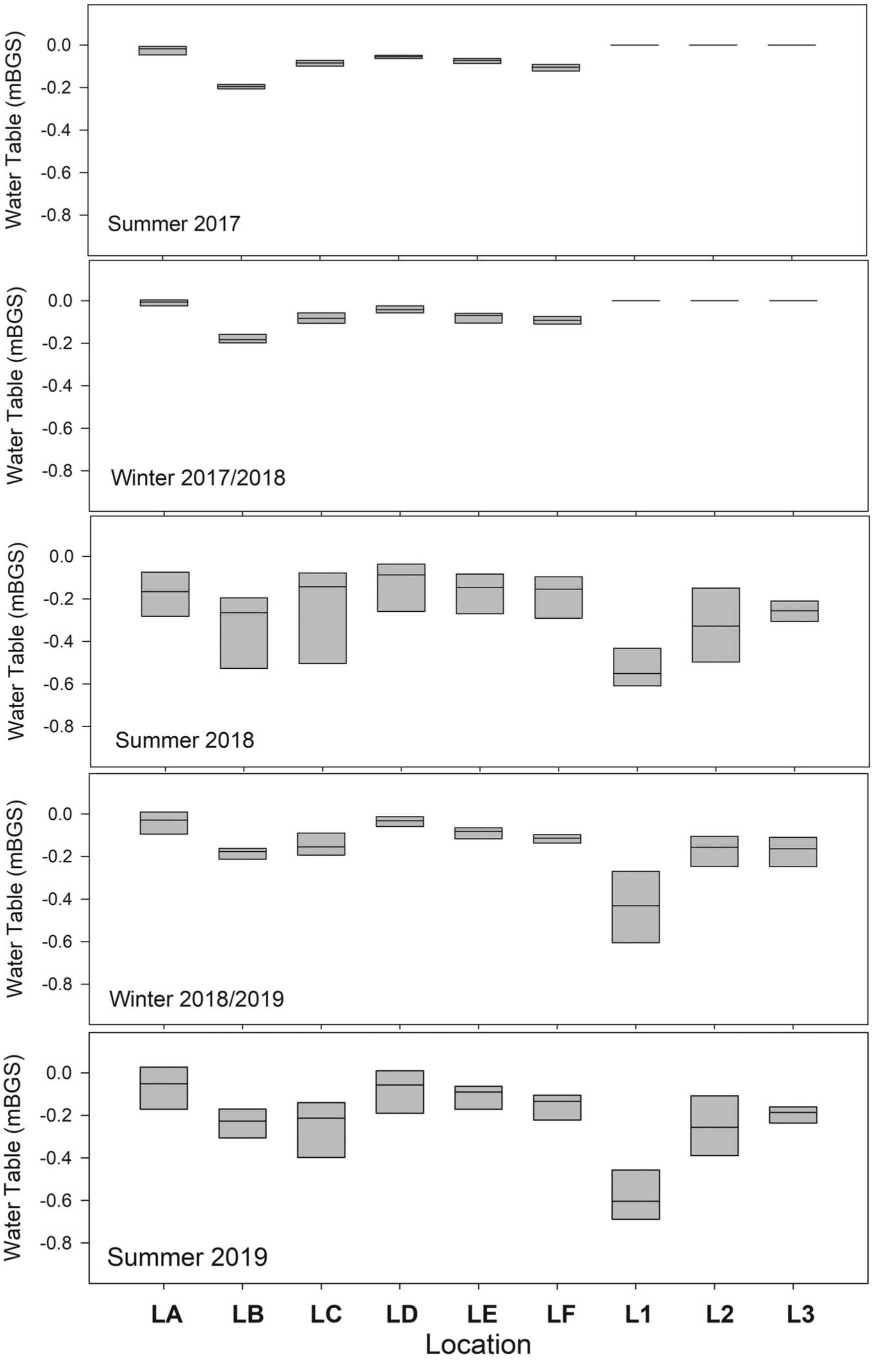

FIGURE 3 Box plots summarizing the range water table fluctuations recorded in groundwater monitoring points in the intact catchment (LA-LF) and forested catchment (L1-L3), Summer 2017 to Summer 2019. Table A2 contains the numerical data underpinning this plot

sustained decline in water table until later August, despite rainfall occurring in the intervening period. Sensitivity to rainfall in the afforested area increases after August, becoming even more marked from later September onwards. Nonetheless, even during the winter period the water table regime differs from that observed at points in the Intact Catchment; water tables in areas affected by closed canopy forestry rise rapidly in response to rainfall, occasionally reaching the ground surface, then rapidly dropping before declining more gradually, starting at approximately 30 cm below ground. Although the regime observed on the formerly afforested area displays greater sensitivity to rainfall, the overall pattern more closely resembles that observed under closed canopy, albeit with more peaks (in response to rainfall) and rising over a smaller interval.

3.5 | Hydraulic conductivity testing

Table 2 summarizes the results of hydraulic conductivity testing completed at monitoring wells installed into the peat across the study area. Findings suggest the values determined for individual monitoring well clusters can vary by over an order of magnitude, although variations in deeper monitoring wells in the Intact Catchment and the wells in settings affected by forestry prove less variable. Comparison of results from tests in shallow and deep monitoring wells point to declines in hydraulic conductivity with depth and anisotropy ratios greater than unity, estimated using arithmetic and harmonic means to determine equivalent (bulk) values for the peat mass; this suggests it is easier for groundwater to flow laterally rather than vertically under a hydraulic gradient of the equivalent magnitude (Freeze & Cherry, 1979). Overall median hydraulic conductivities measured in monitoring wells located away from peat pipes prove higher than those closer to piping. Peat hydraulic conductivities in degraded settings compared with those on deep peat, being lower than shallow peat in the Intact Catchment by up to three orders of magnitude.

3.6 | Water quality

Continuous water quality records, monitored at the outlet of the Intact Catchment, reveal a strong inverse relationship between runoff rates and SEC, with levels rising to over 200 μS/cm during a prolonged dry period in early July 2019 (Figure 2). This contrasts with low values of between 25 and 40 μS/cm observed at peak flow during storm events. Similarly, samples collected from the outlet of Forested Catchment reveal comparable values in runoff for these same events. These values prove slightly higher than SEC levels in rainfall (20–60 μS/cm, *n* = 7). However, analysis of rainfall failed to detect dissolved organic carbon.

The SEC levels observed in runoff samples collected during drier periods at the outlets of both catchments contrast with those observed in peat groundwater samples. These revealed that peat groundwater sample SEC remained consistently less than 160 μS/cm, with levels in the majority of samples remaining below 100 μS/cm (Figure A5). SEC levels in samples collected from the forested catchment generally lie above those of observed at the more intact locations.

Figure 4 summarizes the variation in dissolved organic carbon (DOC) concentration in groundwater between sampling points, while

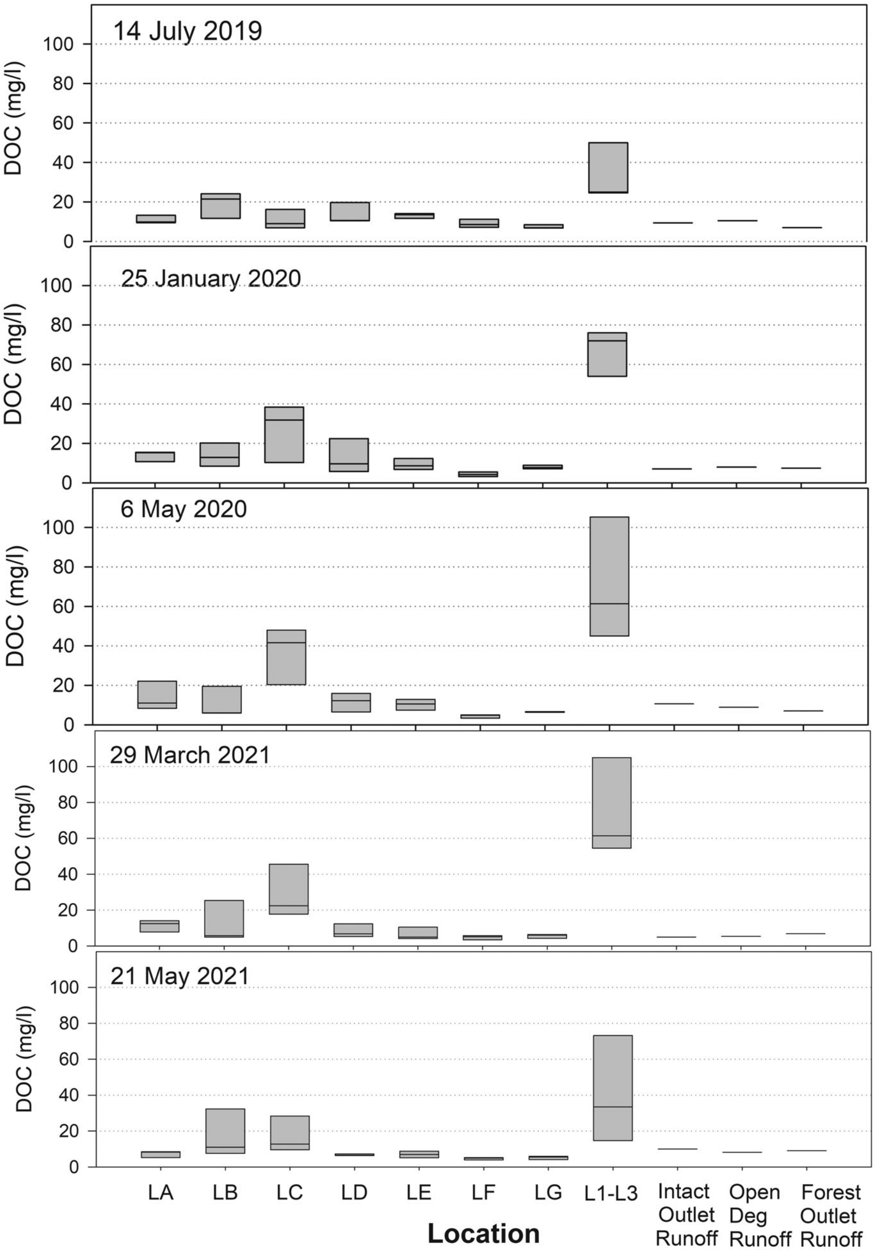

FIGURE 4 Box plots of dissolved organic carbon concentration at groundwater and surface water sampling points between July 2019 and May 2021, Letterunshin Test Site, Co. Sligo, Ireland. Labels refer to groundwater monitoring points identified in Figure 1, while intact outlet, open deg and Forest outlet refer to runoff sampling points at the outlets of the intact catchment, the open degraded catchment and the forest catchment, respectively

also providing concentrations along the Fiddanduff on the same sampling date to facilitate comparison. Data reveal a broad consistency in DOC content between sampling points in the Intact Catchment. Although concentrations displayed some variability at all locations, data suggest that greater variation occurred on sloping ground in the intact catchment (LC) and on the flood plain adjacent to a swallow hole (LB); DOC concentrations varied less at other monitoring locations. Similarly, concentrations observed in samples collected from the Fiddanduff River fall within the range observed in peat groundwater sampled from the intact catchment, including those collected at the outlet of the forested catchment. This occurs despite the higher DOC concentrations observed in groundwater samples collected from the forested catchment. Moreover, further scrutiny of groundwater concentrations reveals that DOC levels in samples collected from monitoring wells under closed canopy conditions proved consistently higher than those collected from areas of formerly afforested peatland.

Figure 5a,b summarizes the relationships between ionic content (as reflected by Ca,) and DOC with SEC for grab samples collected over the period from 2019 to 2020. Data reveal even greater variations in SEC than those indicated for the data loggers for 2019, with values reaching up to 350 μS/cm for samples collected at the Intact Catchment outlet, while those for the Forested Outlet reach in excess of 500 μS/cm. Comparison of these values with laboratory analysis reveal significant relationships with the concentrations of major ions, with correlations for Ca and Mg proving particularly strong.

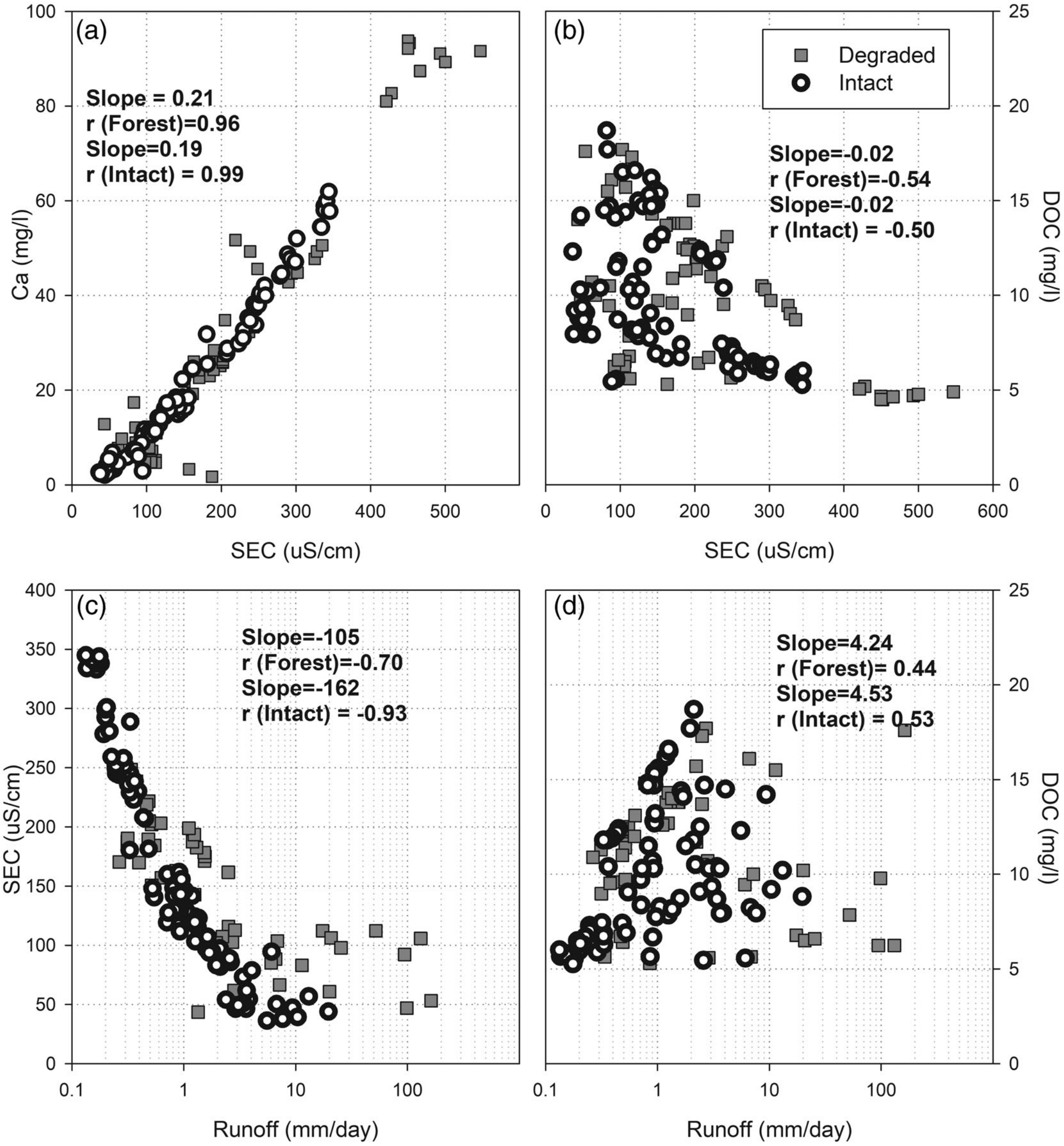

FIGURE 5 (a) Relationships between continuously monitored specific electrical conductance (SEC) and calcium concentration in runoff samples collected at the outlets of the intact catchment and Forest catchment (b) Relationships between continuously monitored SEC and dissolved organic carbon (DOC). (c) Relationships between flow and SEC, (d) Relationships between flow and DOC, Letterunshin Test Catchment, Co. Sligo, Ireland. Slopes and Pearson correlation coefficients calculated for each pairing reveal statistically significant relationship between SEC and Ca, and SEC and runoff rate for the intact catchment outlet and Forest catchment outlet

By contrast, the relationship between SEC and DOC concentration proves more complex. Although it suggests a negative correlation, high levels of data scatter exist at lower SEC values, albeit with a maximum concentration resembling that encountered in peat groundwater. The degree of scatter declines with rising SEC, as does the maximum observed DOC concentration, which is constrained by a line that declines to approximately 5 mg/L at ~400 μS/cm. Above 400 μS/cm, DOC concentrations remain fixed at 5 mg/L.

Plotting the SEC data with flow (Figure 5c) further demonstrates a strong inverse log-linear correlation with SEC for both Intact Catchment and Forested Catchment outlets. The slopes of both lines prove comparable at higher flows, while the Forested Catchment slope is gentler at lower flows, reflecting the higher SEC of the water discharged. By contrast, relationships between flow and DOC prove more irregular and do not follow a linear trend (Figure 5d). Concentrations are least variable and among the lowest during low flow periods. The increase in variability with increasing flow nonetheless remains confined with an envelope of possible concentrations, with maximum concentrations, observed at high flow, corresponding to those observed in peat groundwater samples.

Figure 6 presents the results of near-simultaneous runoff sampling. Table A1 summarize the statistical analyses carried out using the results of the laboratory analyses. Pairwise comparisons of concentrations between water collected from the outlet of the open

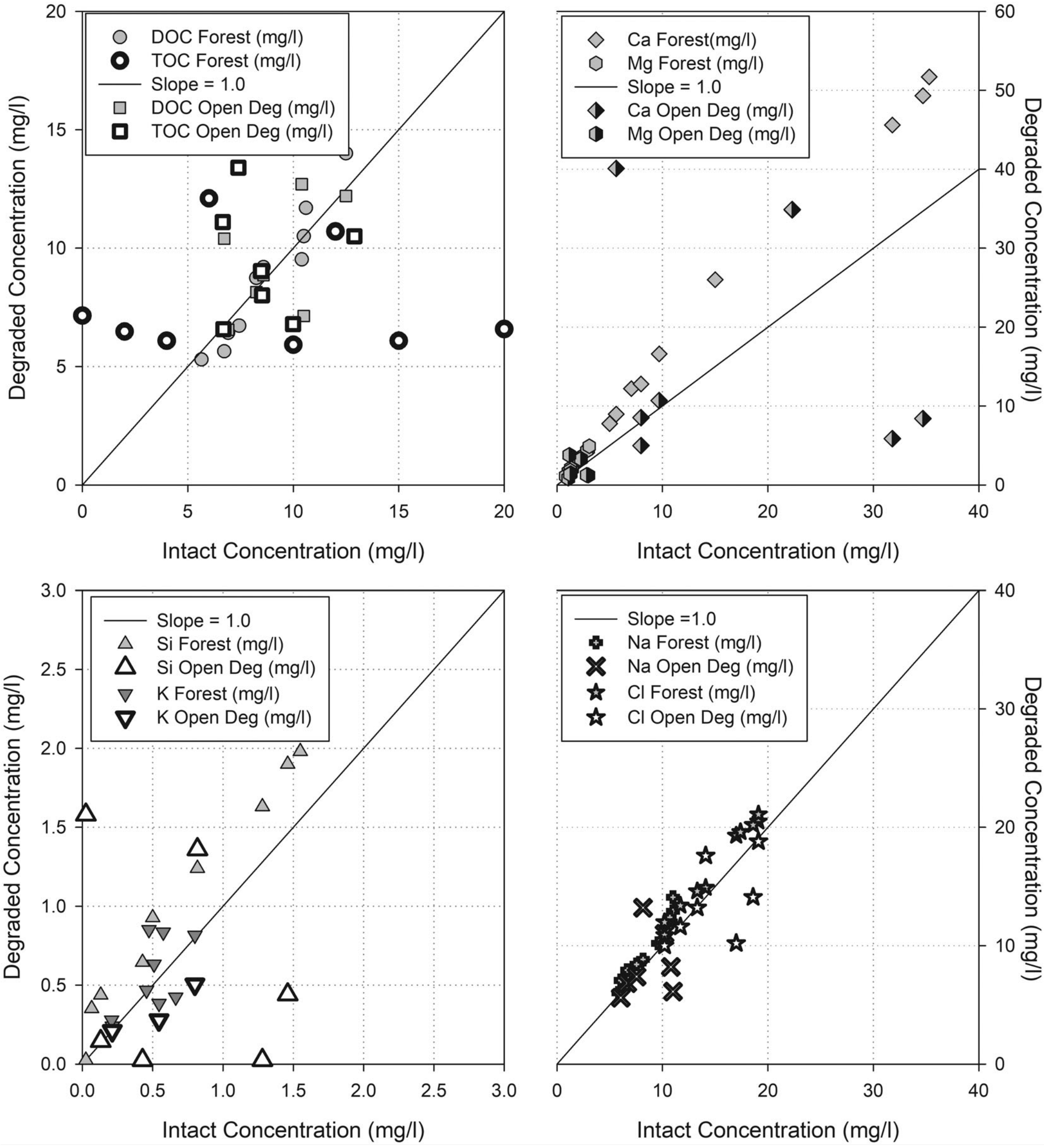

FIGURE 6 Pairwise comparison of water quality from intact catchment and degraded catchment outlets, Letterunshin Test Catchment, Co. Sligo. Points compare concentrations in runoff from the intact catchment outlet with those from open degraded outlet (labelled "Open Deg"), or with those collected from the forest catchment outlet (labelled "Forest") slopes greater than unity, as reflected by the solid black line in each plot, for chloride, calcium, silicon and magnesium reflect processes leading to higher concentrations acquired as the Fiddanduff River flows through the forest catchment

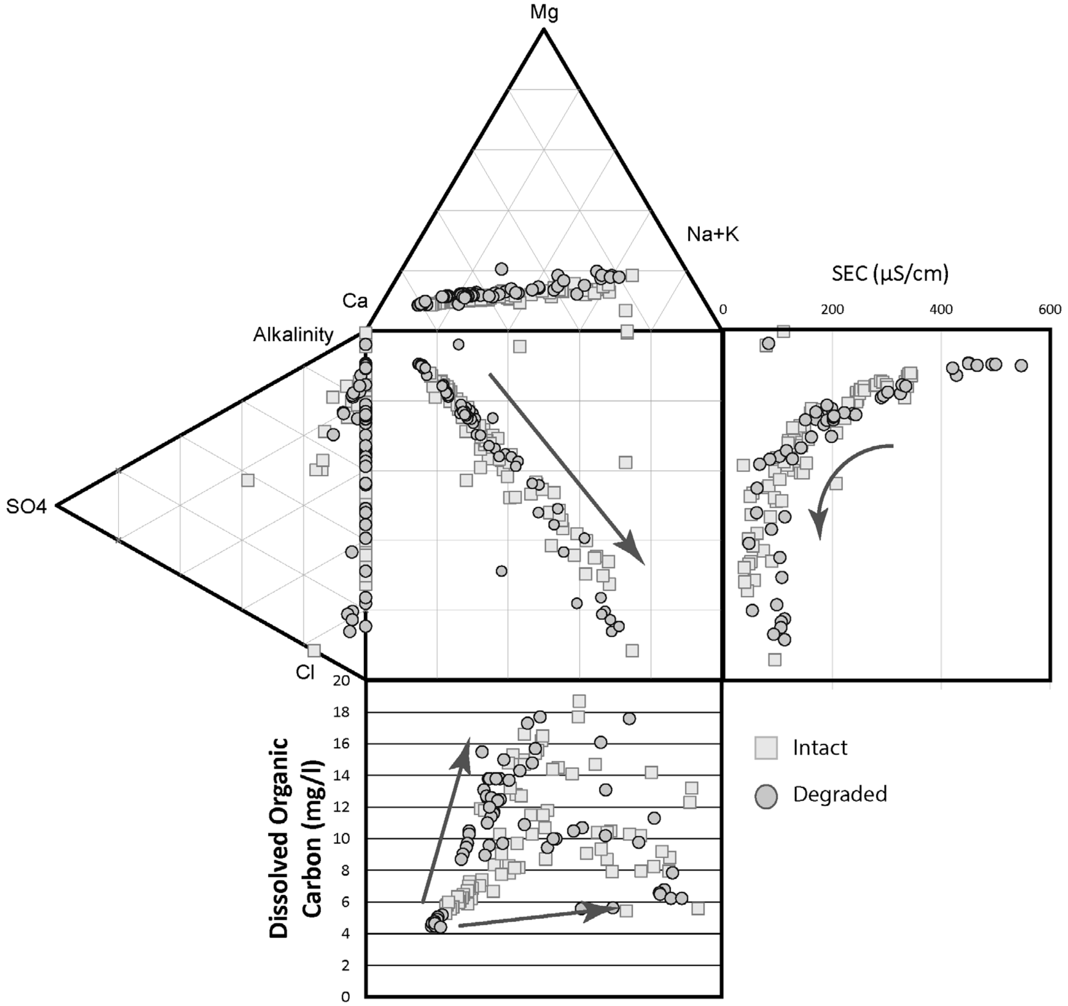

FIGURE 7 Expanded Durov plot showing the evolution of water chemistry at the outlet of the intact catchment and degraded catchment with increasing flow (indicated by arrows). Major ion chemistry (determined in meq/l) changes from low SEC, Na-Cl dominated waters at higher flows to higher SEC, Ca-HCO_3 waters at low flow

degraded catchment and the intact catchment, using paired *T*-tests, suggest no concentration difference at the 5% significance level for any of the parameters analysed. By contrast, comparison of samples collected from Intact Catchment outlet with the Forested Catchment Outlet, reveals concentrations of chloride, silicon, calcium and magnesium to be significantly higher at the downstream sampling point. This difference is reflected in slopes steeper than unity, ranging from Chloride (Cl) (1.07) to those for Calcium (Ca), Magnesium (Mg) and Silicon (Si) (1.39, 1.61 and 1.16, respectively). Conversely, sodium (Na) and potassium (K) concentrations display no significant deviation from the line 45° line.

Plotting the major ion data with SEC and DOC on an expanded Durov plot (Figure 7) summarizes the change in water quality with runoff, with water changing from higher SEC, lower DOC water, dominated by calcium bicarbonate at low flow. As discharge (and runoff) increases water becomes less mineralised, as reflected by reduced SEC, with Na and Cl becoming relatively more important. This ionic content resembles the low SEC, Na-Cl water encountered in both peat groundwater samples and rainfall, yet contains DOC, absent in precipitation.

4 | DISCUSSION

Examination of climatic records from Met Eireann weather stations at Attymass and Cloonacool indicates that weather over the monitoring period proved comparable to average conditions encountered on site during the period 1990–2020 (Figure A2). Similarly, comparison of on-site precipitation datasets with those collected at Met Eireann stations revealed that conditions at Letterunshin follow a regional orographic trend, with annual precipitation lying between that of the two Met Eireann stations; this is consistent with the site's intermediate elevation (Figure A3). Moreover, comparison of on-site rain gauge responses indicates a negligible spatial variation in precipitation across the study area.

Year-round rapid rises in groundwater levels, following precipitation, in the Intact Catchment reflect the sensitivity of peat water table levels to rainfall, even following prolonged dry periods (Figure 2). The deeper water levels observed across the site, arising in response to prolonged dry spells, demonstrate that regular inputs of recharge ensure that the water table remained close to the ground surface. Overall, the low ranges of fluctuation observed reflect a stable hydrogeological regime in the Intact Catchment peat (Figure 4), broadly corresponding to that needed to support peat-accumulating vegetation on other Irish Peatlands (Regan et al., 2020).

The occurrence of persistently high water tables, even on relatively steep sloping surfaces (e.g., LC) limits the capacity of peat to store water additional water over most of the monitoring period, despite specific yield values that can exceed 50% being measured in Irish blanket bog peats in comparable undisturbed settings (Cassidy, 2017; Flynn et al., 2021). This lack of supplemental storage capacity is reflected in rapid response of stream flow to rainfall, broadly corresponding to associated rises in groundwater level, and further confirms that blanket bogs have limited ability to buffer against storm events (Flynn et al., 2019).

Although rainfall SEC levels compare to those encountered in stream runoff, the absence of DOC in precipitation points to peat acting as the principal source of water in storm runoff, with both DOC concentrations and SEC resembling those encountered in bog groundwater samples. By contrast, the failure to detect higher SEC Ca-HCO3-dominanted water in bog and rainfall samples, yet as observed in lower flow runoff (Figure 6), implies an additional hydrological pathway contributes to flow, along which Ca and Mg accumulates at a greater rate than Na or K, leading to a change in the relative abundance of major ions.

Groundwater level data assists in explaining the source of the Ca/Mg enriched water. Comparison of deep monitoring well heads with water table elevations at monitoring points reveals a widespread downward component in the hydraulic gradient, indicative of partial groundwater flow through the base of the peat into the underlying inorganic substrate. Hydraulic conductivity and hydraulic gradient data suggest that discharge via this pathway accounts for a limited, yet persistent water loss from the peat, estimated at 25 mm/year. This compares with recharge of 35 mm/year reported for the area by the Geological Survey of Ireland (2022).

Water following this deeper pathway comes into contact with inorganic substrate materials, with which it can react (Flynn, McVeigh, et al., 2021). Reaction of acidic, low conductivity bog water with underlying minerals results in increasing ion content and a corresponding rise on SEC. Two untreated water samples collected by pumping from a domestic well in the River Easky Valley, immediately to the north of the site and underlain by the same bedrock/inorganic subsoil, revealed substrate groundwater to have an SEC of approximately 550 μS/cm, while lacking DOC, despite widespread coverage of bog/organic soils; samples, collected once water SEC and temperature had stabilized, were submitted for analysis following protocols employed for peat groundwater samples.

The sustained flow of peat groundwater to the substrate, under relatively constant gradient (as reflected by the limited variation in water table levels in the peat and significant elevation differences between recharge and discharge zones) ultimately leads to a persistent discharge of more mineralised water (Flynn, McVeigh, et al., 2021). This mixes with lower SEC bog water, which has not come into contact with deeper materials, to contribute to stream flow.

Water quality data suggest that bog groundwater (Q_{bog}) and substrate groundwater ($Q_{\text{substrate}}$) contributions dominate runoff. This may be modelled using Equation (1).

$$\mathrm{Q}_{\text{runoff}} = \mathrm{Q}_{\text{bog}} + \mathrm{Q}_{\text{substrate}} \tag{1}$$

Assuming that the differences in water chemistry prove sufficiently distinct for them to be considered invariable permits application of end member mixing analysis (EMMA), to estimate the proportions of each contributing to flow as follows:

$$\mathrm{Q}_{\text{substrate}} = \mathrm{Q}_{\text{runoff}} \frac{(C_{\text{runoff}} - C_{\text{bog}})}{(C_{\text{substrate}} - C_{\text{bog}})} \tag{2}$$

The absence of DOC in inorganic substrate groundwater in turn allows the proportion of bog groundwater (with an averaged DOC of 12 mg/L,) necessary to generate the 5 mg/L of DOC encountered in runoff at low flow to be estimated at 42% of total flow. The figure is considered an estimate in part because of the potential for DOC to react while flowing from the peat to surface water. Nonetheless, the relative stability of DOC concentrations throughout the year in the intact catchment, despite contrasting hydrological settings, suggest limited reaction rates.

Similarly, taking 75 μS/cm as representative of bog groundwater SEC and using the same flow proportions, would imply that regional groundwater (with an SEC of 550 μS/cm) would contribute 58% of flow and yield a runoff quality of 350 μS/cm. The figure is consistent with base flow concentrations observed and provides a lower limit for the proportion of bog water contributing to flow at the Intact Catchment outlet, following prolonged dry period; higher proportions would result in the lower values of SEC observed at higher flows.

The contrast in chemistry observed at the outlet of the forested catchment suggests that the proportion of flow made up by higher SEC groundwater is higher than in the intact catchment. This may in part be accounted for by the more conductive nature of the peat groundwater, observed in groundwater samples, while contributions from upstream flow also require consideration. However, SECs at low flow exceed those observed in the peat, while the ionic makeup of the runoff is dominated by Ca and HCO_3, suggesting further contributions of substrate groundwater.

Once again, mixing models permit quantification of mineralised water contributions along this stretch of the stream. For low flow conditions, runoff samples at the outlet of the Open Degraded Catchment has an SEC of 350 μS/cm. Taking substrate water quality to equal that for the intact catchment, while peat groundwater in the afforested area to has an SEC of 125 μS/cm, the observed baseflow SEC of 450 μS/cm can be generated with 40% of water derived from upstream water, while 55% of discharge consists of substrate groundwater; groundwater derived from peat in the afforested area accounts for 5% of flow.

Mixing model findings thus imply that supplemental flows entering the Fiddanduff River as it flows through the afforested part of the catchment are dominated by contributions of deeper more conductive water. This is consistent with field observations for significant discharge from drain flow in the vicinity of the river, while also being borne out by statistically significant slopes above unity for Na, Ca and Mg pairwise analyses of water quality parameters; no parameter analysed had a statistically significant slope below 1. Similarly, levels of Chloride also prove slightly higher at the forest outlet. Younger (2009) noted the utility of this parameter for estimating evapotranspiration rates, with the line slope suggesting that rates in the forest catchment may slightly exceed those of the intact catchment. Conversely, the higher concentrations of Ca and Mg cannot be attributed to concentration by evapotranspiration alone.

Mineralogical analyses of subsoil samples underlying the peat reveal low levels of Ca, suggesting that water flowed to greater depth, where more calcium-rich materials occur (Table 1, Flynn, McVeigh, et al., 2021), possibly from the karstified Limestone aquifer underlying the site. Furthermore, pairwise analysis and SEC data suggest that this mineralised water continues to make significant contributions to stream flow, even during periods of higher flow.

The increase in SEC as the Fiddanduff flows through the forest contrasts with the absence of a significant difference in DOC concentration (5 mg/L at both locations), despite the higher DOC levels observed in peat groundwater samples (∼60 mg/L). Nonetheless, the use of the flow proportions from the solute mixing model, developed for SEC, manages to generate the DOC concentration observed in low flow runoff at the degraded catchment outlet. This occurrence of comparable concentrations, despite the higher DOC levels encountered in peat groundwater, may be attributed in part to the lower hydraulic conductivity of the peat in this area, compared to the intact catchment. This limits direct discharge of peat groundwater to the stream through matrix flow.

The variation of DOC concentration, observed during higher runoff periods, suggests that the generation and discharge of groundwater from the peat is complex, giving rise to the inconsistent levels encountered for the comparable flow rates. On the other hand, the lack of a difference in DOC concentration between the outlets of the intact catchment and the degraded catchment, despite the higher flow (and runoff) encountered during peak flow, implies that significant quantities of DOC are also contributed from the afforested area at higher flows, despite the lower permeabilities observed; if pure overland flow dominated, this would have a chemistry resembling rainfall, leading to a decline in DOC concentrations in runoff.

Groundwater hydrographs, generated for monitoring wells in afforested and formerly afforested areas provide an insight into the mechanism of DOC delivery to runoff (Figure 2). The rapid rises observed in response to recharge, followed by an initial phase of rapid recession, contrast to the regime observed in the intact catchment and may be explained by the presence of systematic forest drainage. Furrows and larger drains intercept rising water tables allowing DOC-rich groundwater to discharge, while also shortening flow paths of groundwater below the intervening ridges. This is consistent with field observations during prolonged wet periods. Moreover, the head differences between intervening ridges and the adjacent furrows generate locally steep hydraulic gradients as groundwater levels rise above the base of furrows and/or drains. Delivery may be further aided by the presence of more permeable material that may be present approaching the ground surface (and not tested during the investigation programme).

Waddington et al., (2014) noted depth dependant variation in hydraulic conductivity has been encountered elsewhere. This structure can lead to feedback mechanisms in which rises in water tables to encounter more permeable horizons, which in turn lead to disproportionately high lateral discharge during periods of elevated water table. Although studies elsewhere have focused on studies in undisturbed peat, following this same principle and considering the drain fill (tree leaves and twigs) as a more permeable horizon would result in a comparable rise in water table and subsequent removal of groundwater; this explains the flashier response to rainfall observed, while also accounting for the peakier groundwater regime, compared to the intact catchment. Conversely, the absence of significant differences in DOC levels may arise due to mixing with younger water, with a lower DOC content, discharging directly to drains. More research is needed to investigate this issue.

Even though groundwater hydrographs suggest less variable water table fluctuations in the intact catchment, rainfall-runoff responses proved rapid. This occurred despite the dominance of runoff resembling bog groundwater at higher flows, as well as longer flow paths between many areas and the surface water. The speed of response is considered to arise in part due to the presence of piping, which helps rapidly deliver bog water to the Fiddanduff River's headwaters. Mechanisms of runoff generation involving peat pipes remain unclear. However, hydrogeological data suggest that reduced peat hydraulic conductivities in their vicinity limit the delivery of water to them by matrix flow, despite steep hydraulic gradients, as reflected in elevated water tables close to swallow holes. Nonetheless groundwater hydrographs suggest that water tables in the vicinity of pipes are sensitive to rainfall. However, where higher permeability peats occur in the upper parts of the (intermittently saturated) peat profile, a rapid increase in transmissivity may result from a slight rise in water table. This in turn can give rise to substantial increase in matrix flow in the uppermost part of the peat column, as observed by Waddington et al. (2014) in other northern peatlands. Connectivity of these more permeable units to swallow holes thus allows for intermittent, yet rapid variations in groundwater discharge to pipes. Where higher permeability units pinch out, groundwater may discharge at the ground surface, before entering pipe networks via swallow holes as overland flow. Both mechanisms give rise to rapid increases in stream discharge. Conversely, when water tables decline in the vicinity of pipe systems these processes quickly cease.

In a similar vein, the impact of direct discharge of peat groundwater to streams remains poorly characterized. However, greater flow path lengths between recharge zones and streams suggest that groundwater contributing to runoff by this mechanism would take longer and thus prove more sustained, leading to a more stable runoff regime. The flashy rainfall/runoff response observed in the intact catchment suggests that this contribution to stream discharge may be subordinate to that supplied by piping. Further research on this topic is necessary. Nonetheless, the findings of this study help highlight contrasts in runoff regimes of open, relatively intact blanket bog, compared to areas impacted by forestry.

5 | CONCLUSIONS

Peatlands are complex adaptive systems in which hydrological processes and vegetation influence one another (Belyea & Baird, 2006). These changes in turn influence the quality of water discharged from them and include responses to disturbance, from which peatlands can take decades to recover (Gaffney et al., 2018). Work on physically undisturbed bogs has demonstrated how trees can contribute to the lowering of water tables (Murphy et al., 2009). Conversely the removal of forest cover can raise the water table (Dubé et al., 1995), which may ultimately result to restoration of preplanting levels (Pothier et al., 2003). However, the presence of artificial drainage on plantation forestry complicates these processes.

Investigations completed by Anderson and Peace (2017) on formerly afforested peatlands have demonstrated that, as in the current study, the presence of furrows has a significant impact on water table levels. At Letterunshin, investigations in forested and formerly afforested areas reveal that artificial drainage results in hydrological regimes that differ from those observed on intact peat. Despite water table increases that can arise following removal of closed canopy cover, the continued functioning of furrow and drain networks gives rise to hydrological and hydrogeological regimes that hinder re-establishment of hydrological supporting conditions necessary for peat-accumulating species. Furthermore, lowered water tables facilitate further degradation of peat, as reflected by higher SEC and DOC levels. This occurs despite reductions in the hydraulic conductivity of the peat matrix that arise as a result of forestry (Anderson & Peace, 2017), and which would be anticipated to feedback to raise water tables (Waddington et al., 2015). At a catchment scale, the reduced permeability of the peat matrix limits its capacity to transmit bog water to streams during low flow periods. By contrast the sustained delivery of more mineralised water, derived from the inorganic deposits underlying the peat, makes a proportionately higher contribution to reduced total runoff, giving rise to a contrast in stream chemistry compared to non-afforested areas. The contrast with conditions observed during wetter periods, when differences in water quality reduce/disappear, coupled with increased storm runoff rates from the afforested areas, lead to more variable overall flow and water quality regimes. This in turn gives rise to less stable, more stressful abiotic supporting conditions for aquatic ecosystems compared to more intact conditions and helps explain the declines in water body status across Ireland in catchments with blanket peat areas containing maturing plantation forestry. The graphical abstract accompanying this article summarizes these processes.

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DATA AVAILABILITY STATEMENT

Data supporting this publication is provided in the file entitled "Supplementary Material".

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SUPPORTING INFORMATION

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