

Assessing the impact of rewetting agricultural fen peat soil *via* open drain damming: an agrogeophysical approach

Dave O'Leary^{1,2}, Patrick Tuohy¹, Owen Fenton³, Mark G. Healy⁴, Hilary Pierce², Asaf Shnel¹, Eve Daly²

5 ¹ Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Cork, Ireland

² HYRES Research Group, Earth and Life Sciences, School of Natural Sciences, University of Galway, Galway, Ireland

³ Teagasc, Crops, Environment and Land-Use Programme, Johnstown Castle, Wexford, Ireland

⁴ Civil Engineering and Ryan Institute, College of Science and Engineering, University of Galway, Ireland

10 *Correspondence to:* Dave O'Leary (DaveOLEaryPhD@gmail.com)

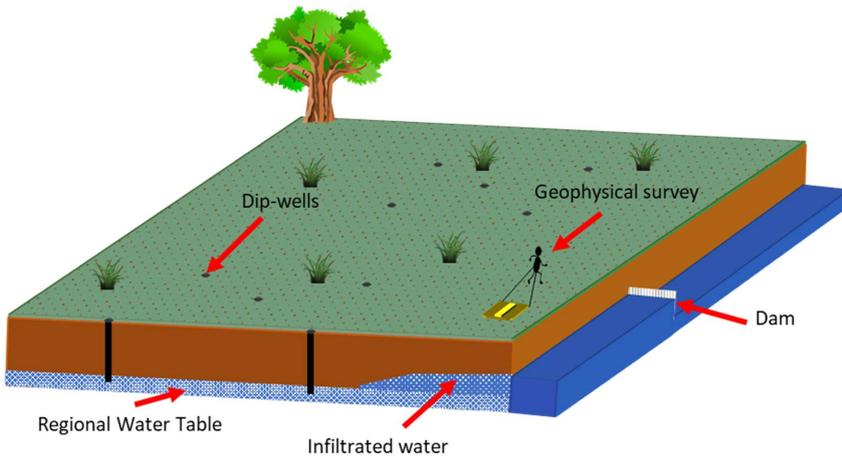
Abstract.

Open drainage ditch (i.e., open drain) damming aims to raise the water table in agricultural grassland peat soils thereby reducing greenhouse gas (GHG) emissions. A current knowledge gap is how to examine the spatial and temporal effectiveness of such an action, i.e., assessing the behaviour of the water table in the adjoining field. To address this gap, at a drained agricultural grassland site with shallow fen peat soils (ranging from 0 to 2 m depth), water level in an open drain was raised by installing a dam. Associated changes to the water table depth (WTD) were monitored using two nests of dip-wells installed at two locations (Rewetted and Normal-Control areas) in the adjoining field. Soil profile volumetric water content (VWC) data were obtained in these two areas in addition to the temperature, salinity, pH, and electrical conductivity signature of the water in the open drain. These data were integrated with geophysical (electromagnetic induction (EMI)) survey data ~~conducted~~ conducted in June and December during summer and winter. Results from the dip wells (located > 20m from dam) indicated that no measurable change in WTD occurred due to the dam installation, aligning with previous studies suggesting limited spatial influence in agricultural fen peat soils. VWC profiles, while consistent with peat physical properties, showed no deviation attributable to drain damming. The EMI results identified a distinct zone with electrical conductivity values similar to those of open drain water, suggesting localised water infiltration within ~20 m of the dammed drain during summer. This spatial impact was less evident ~~during winter in December~~, likely due to increased precipitation and regional groundwater influence. This study demonstrates that EMI surveys, shown here in combination with other high-resolution data capture, can detect rewetting effects when combined with neural network clustering and Multi-Cluster Average Standard Deviation analysis, highlighting its value for rapid site assessment. Moreover, the results underscore the importance of survey timing, as ~~summer June~~ summer June measurements provided clearer evidence of drain damming impact than ~~the December winter~~ the December winter measurements.

30

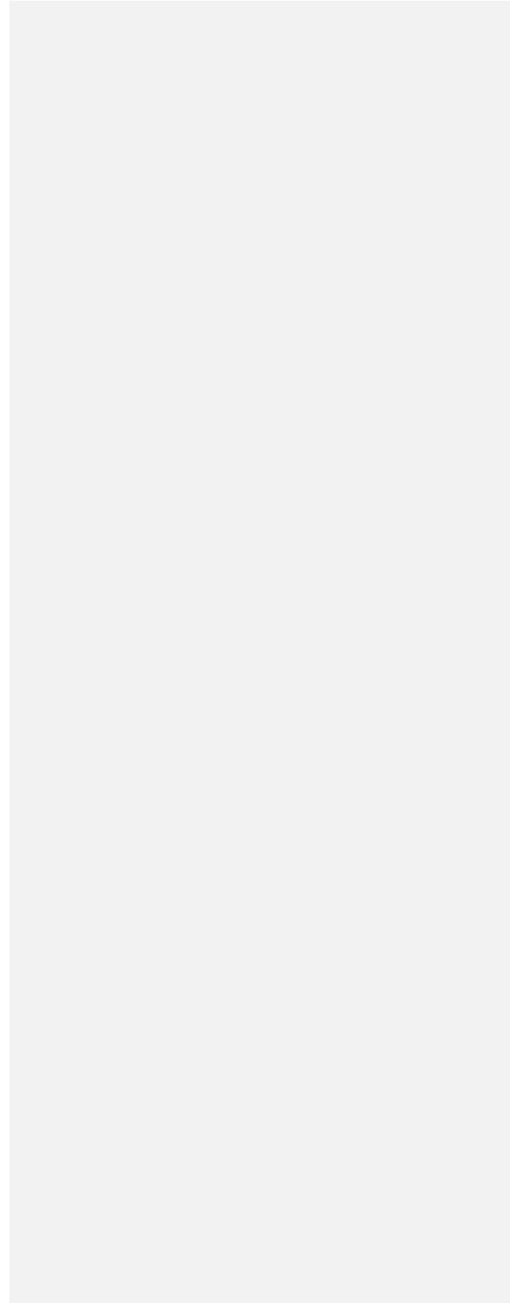
Graphical Abstract

35



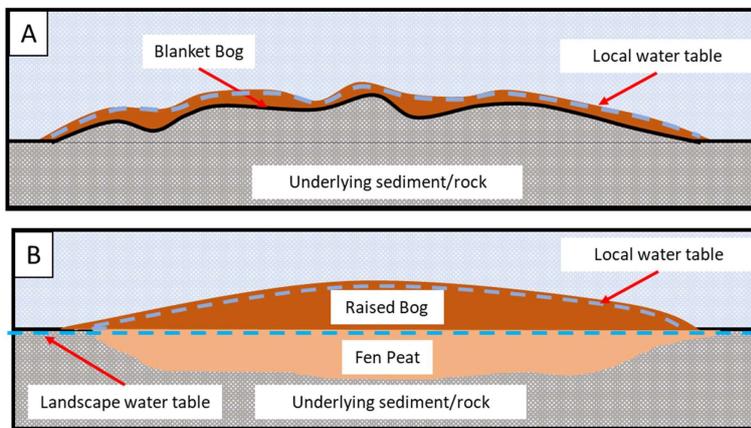
40

45



50 **1 Introduction**

Organic, or peat, soils are recognised as important terrestrial stores of carbon (Page and Baird, 2016; Ramsar, 2018). Globally, these soils are estimated to be present on ~ 3 % of the land surface (Xu et al., 2018; UNEP, 2022) and contain ~ 30 % of terrestrial carbon (Minasny et al., 2023). These soils are present at many latitudes, from tropical to arctic, and are often divided into landscape descriptors (e.g., fen, wetland, raised bog, blanket bog (Figure 1)), which are dependent on the local environment and soil-forming conditions (Lourenco et al., 2022). Peat soils form in anoxic waterlogged conditions, where the decay of plant material is slowed due to a lack of oxygen.



60 Figure 1: Conceptual diagram of generalised peat soil types. A) Blanket bog, typically found in highland/mountainous areas. B) Fen peats underly raised bogs. Fen peat becomes exposed when raised bog is extracted/removed and are typically ~~linked~~ in contact with landscape water table dynamics (Minasny et al., 2023).

Peat soils have been extensively drained in Europe over the last century mainly due to their importance in energy production (Minasny et al., 2023) and conversion for use in agriculture and forestry (Fluet-Chouinard et al., 2023; Habib and Connolly, 2023). High levels of drainage (i.e., open drains and in-field pipe drains) and maintenance are required to effectively control the water table in peat soils over time (Tuohy et al., 2023). Effective drainage introduces oxygen to the soil and encourages the biological decay of plant material, which results in a release of carbon dioxide to the atmosphere (Koch et al., 2023; Lindsay, 2010). Globally, drained peatlands are estimated to account for ~ 5 % of all anthropogenic greenhouse gas (GHG) emission (FAO, 2020). As such, international treaties, such as the Paris Agreement (UNFCCC, 2018) and the European Union Nature Restoration Law (EU, 2022), recognise the potential for peat soils as nature-based solutions for reducing GHG emissions (Strack et al., 2022).

Reintroducing water-saturated conditions is considered to be fundamental to efforts in reducing the emission of GHG from peat soils (Strack et al., 2022; Monteverde et al., 2022). The term “rewetting”, which is defined as the deliberate action of raising the water table closer to ground level in peat soils (Wilson et al., 2016), is considered the main tool through which this reduction can be achieved, and is often the main component of national strategies to reduce emissions from peat soils. In Ireland, the Climate Action Plan (DECC, 2024) seeks to reduce management intensity on 80,000 ha of agricultural grassland on drained organic soils by 2030. Reduced management intensity is an umbrella term for activities including abandoning drain maintenance, water table manipulation and “rewetting” by raising the water table to be, on average, within 30 cm of the ground level. Currently, rewetting is mainly achieved *via* the blocking or damming of open drains which often surround such fields.

Damming occurs by installing a man-made or ~~earth~~^{natural} structure in the open drain to partially impede water discharge. The damming of open drains in blanket bogs, raised bogs, and fen peat is not a straight-forward or uniform practice, and the efficacy of the damming on both the water table and GHG emissions is not always as expected. For example, little is known about the spatial and temporal influence of damming open drains on nearby peat soils. A study in Norway (Stachowicz et al., 2025) analysed water table levels on three raised bogs where damming had taken place and found that the influence of these efforts ~~that~~ extended 17.2 m into the surrounding peat soils on average. However, in Germany, a study on grassland fen peat soil found that drain damming had almost no influence on the water table levels (Heller et al., 2025), concluding that the low hydraulic conductivity of the peat resulted in minimal infiltration of dammed water into the surrounding soils.

Agricultural grassland peat soils tend to be fen peat. Fens are peat forming-systems that are different to bogs (i.e., raised or blanket) as they are fed by groundwater or moving surface water and can occur as isolated pockets of peat soil in river valleys, poorly drained basins, in hollows and beside open stretches of water (Fossitt and Heritage, 2000). They are often found around the edges, or what remains, of a raised bog (Gilet et al., 2024; Minasny et al., 2023). These soils represent small pockets of organic material that are connected with ~~regional~~ groundwater and the larger landscape (Figure 1), making them difficult to rewet effectively. As rewetting is considered the means by which peat soil restoration may be achieved, an understanding of the spatial influence of the rewetting method being applied is of vital importance. This is particularly relevant to the agricultural industry, where only partial drain damming may serve as a compromise due to the need to balance agricultural productivity with restoration efforts (Tuohy et al., 2023).

Agrogeophysics (Garré et al., 2021) is an emerging discipline focused on the use of geophysics within precision agriculture (Monteiro et al., 2021). Electromagnetic Induction (EMI), which measures the electrical conductivity of the subsurface, is a proven method for soil characterisation (Doolittle and Brevik, 2014). Modern EMI instruments offer the means to analyse both the vertical and spatial distribution of soil properties (Everett and Chave, 2019), with field scale (~ 1 – 10 ha) applications in mapping soil texture (Brogi et al., 2019; O’Leary et al., 2024), soil compaction (Romero-Ruiz et al., 2024), soil salinity

(Koganti et al., 2018), and soil moisture (Huth and Poulton, 2007). EMI surveys have also been utilised in peat soils studies, identifying peat depth (Adetsu et al., 2024), peat layer properties (Altdorff et al., 2016) and the role of pore water content on electrical conductivity in peat soils (Henrion et al., 2024). The possibility of ~~expanding-analysing~~ EMI survey results ~~into~~ the temporal domain via multiple repeat surveys ~~has~~ allowed for the assessment of, for example, hydrological dynamics ~~in~~ agricultural settings (Blanchy et al., 2020; Moghadas et al., 2017), especially in areas where there is little change from other external sources (land management, soil textural changes) (Boaga, 2017), ~~but has not been explored in the context of agricultural grassland peat soils and rewetting~~. Additionally, the combination of EMI data with machine learning unsupervised classification has allowed for a simplified interpretation of the results of EMI surveys, which allow non-expert users to take advantage of this survey method (O’Leary et al., 2024; von Hebel et al., 2018).

The aim of this study is to assess the spatial and temporal impact of drain damming on an agricultural grassland on a fen peat soil at field-scale in Ireland using two EMI surveys conducted during different hydrological conditions (~~summer-June~~ and ~~winter-December~~). The electrical properties of the water in an open drain on site was measured and compared to EMI survey results, with a view to identifying areas of the site where water had infiltrated from the dammed open drain. The geophysical methods presented in this study could similarly be applied to less instrumented agricultural fields or undergoing different rewetting methods (e.g., subsurface irrigation (Heller et al., 2025)). This may provide a tool, and reduce the overall cost, for both the mapping and monitoring of the rewetting process at field-scale (~ha). This is vital for both land managers and policy makers in assessing the impact of rewetting, and for reporting of GHG emissions and quantifying restoration efforts.

2 Methods

2.1 Site Description and in-situ measurements

The study site, identified as peat soils (O’Leary et al., 2025), is a grassland fen peat agricultural field (~~Figure 2~~~~Figure-2~~). It is located close to the town of Birr (53.095425°N, 7.908787°W) in County Offaly, Ireland. The exact site location is not given to protect the privacy of the landowner. Vegetation within the field is classified as “cultivated land” within the national landcover map (Tailte Éireann, 2023), however is a grassland, used for the intermittent grazing by cattle during the growing season. This site is part of a multi-site project (Teagasc, 2023) and was selected for this study as it is topographically flat and peat depth is typically uniform throughout, except for an area to the south of the site, where the peat is thinner. These factors limit the potential variation in measured geophysical signal to the hydrological conditions of the peat soil layer.

The field is approximately 1.2 ha in size and flanked to the east and north by deep open drains (~ 2 m deep and below the average Water Table Depth (WTD)). Several field drains were installed in the northern half of the site ~~in~~ca. 2020, which were unrelated to the commencement of this project. These consisted of trenches filled with stone aggregate and are visible on the surface. Prior to geophysical fieldwork undertaken in this study, this field has been instrumented with ten × 2 m deep ~~fully-~~

140 ~~screened dip-wells (Baird and Low, 2022) with Seametrics LevelSCOUT water table loggers (VanWalt, 2025a), and two × 1.2 m deep gropoint probes (VanWalt, 2025b), measuring the percentage of water volume, or volumetric water content percentage (VWC) inat 0.15 m depth intervals, starting at the surface (Figure 2Figure-2A). A tipping bucket rain gauge is also located in this field to provide local rainfall. weather station is also located in this field providing meteorological data, such as rainfall. All data are recorded at 15 min intervals and stored in a database.~~

145 The peat depth at this site (Figure 2Figure-2B) was measured in a two-stage process via refusal of a peat probe (stopped by hard substrate) (VanWalt, 2023a) and validated by Russian auger (VanWalt, 2023b). Twenty-one locations were probed for peat depth and validated by three locations sampled by Russian auger. A peat thickness map has been interpolated to a 1 × 1 m grid using bSpline function in QGIS v 3.30 (Figure 2Figure-2B).

150 ~~A dam and water flume were installed at this site on 29th March 2023 (Figure 2), damming the water in the open drain to the south. This acts to divide the field into two experimental areas, Rewet (W) and Normal (D), with a nest of dip wells and a soil moisture probe in each area. The choice of location of the D dip wells (Figure 2) was designed to act as a study “control” where no rise in WTD was expected due to rewetting. The W dip wells were specifically located upstream of the dam in an area of the site assumed to be affected by open drain damming.~~

155 ~~WTD, VWC, and rainfall data were extracted, providing a snapshot of the in-situ measured hydrological conditions that coincides with the acquisition of geophysical data (See section 2.2). The daily average WTD and VWC was calculated. Additionally, a Multi-Parameter probe (YSI, 2025) was used to measure temperature, salinity, pH, and electrical conductivity of the water in the open drain during the geophysical surveys. These measurements were taken from south of the dam (SD), between the dam and flume (ND), and north of the flume (NF) (Figure 2).~~

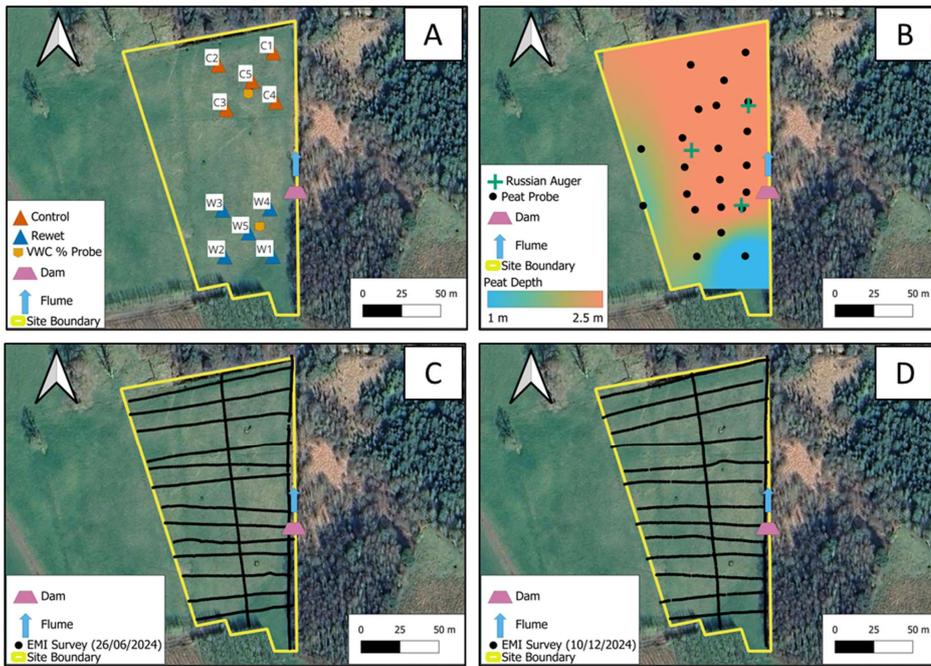


Figure 2: Site description. A) The site divided into **CD** (**ControlNormal**) and W (Rewet) by the location of the dam and flume in the open drain. Dip-well nests are shown in each area, and VWC % probes are installed close to **CD5** and **W5**, B) Locations of peat depth probe and Russian auger validation measurements and interpolated peat thickness map. C) EMI survey points (26/06/24), D) EMI survey points (10/12/24). Basemap: © Google Maps 2019.

A dam and water flume were installed at this site on 29th March 2023 (Figure 2), damming the water in the open drain to the south. This acts to divide the field into two experimental areas, Rewet (W) and Control (C), with a nest of dip-wells and a soil moisture probe in each area. The choice of location of the C dip wells (Figure 2) was designed to act as a study “control” where no rise in WTD was expected due to rewetting. The W dip wells were specifically located upstream of the dam in an area of the site assumed to be affected by open drain damming.

Daily averaged WTD, VWC, and rainfall data were extracted, providing a snapshot of the in-situ measured hydrological conditions that coincides with the date of acquisition of geophysical data (See section 2.2). The daily average WTD and VWC was calculated. Additionally, a Multi-Parameter probe (YSI, 2025) was used to measure temperature, salinity, pH, and

175 electrical conductivity of the water in the open drain during the geophysical surveys. These measurements were taken from
180 south of the dam (SD), between the dam and flume (ND), and north of the flume (NF) (Figure 2).

Formatted: Normal, Left

2.2 Electromagnetic induction (EMI)

180 EMI is a geophysical method used to estimate subsurface apparent electrical conductivity (ECa) by inducing electromagnetic
fields in the ground (Everett and Chave, 2019). ECa refers to a bulk estimate-measurement of apparent electrical conductivity
which, although sensitive to a particular depth, is affected by the soil through which the electromagnetic field passes. A
transmitter coil (Tx) generates a primary magnetic field via an alternating current. This primary field induces electrical currents
in conductive materials (i.e., soil) beneath the surface. These currents, in turn, produce a secondary magnetic field, which is
185 detected by a receiver coil (Rx). The strength and phase shift of the secondary field, as measured at Rx, provides information
on the electrical conductivity of the subsurface materials. The depth of investigation is controlled by the frequency of induced
electromagnetic field, the orientation of Tx and Rx (vertical, horizontal, coplanar), the spacing between the transmitter coil
(Tx) and the receiver coil (Rx), and the electrical conductivity of the subsurface.

190 Often EMI surveys are used for soil mapping and monitoring as they are lightweight, non-contact instruments which can easily
be moved around a site, allowing for dense spatial data to be gathered (Boaga, 2017). Additionally, in recent years, the
development of multi-coil/multi-frequency instruments has allowed for multiple depths to be investigated simultaneously
during an EMI survey (Brogi et al., 2019). However, the need for high spatial and vertical resolution should align with the
expected degree of variation of the intended target property in the subsurface. For this study using a multi-coil instrument to
195 assess the expected vertical variation in electrical conductivity, the spatial resolution was chosen as a balance between the
assumed area of impact of the drain damming of only several metres (Heller et al., 2025) and the required time and effort to
acquire the data. Other EMI surveys have achieved a very high spatial resolution with ~2 m line spacing (O'Leary et al., 2024;
Adetsu et al., 2024) using quad bikes and sleds, however such resolution cannot be achieved without considerable manual
effort in the absence of motorised vehicles.

200 A CMD Mini-Explorer (GF Instruments (Czechia)) was used to estimate the spatial and vertical distribution of ECa across
this site. This instrument has a fixed frequency Tx coil and six Rx coils, spaced at 0.2, 0.33, 0.5, 0.72, 1.03 & 1.5 m, and was
operated in "Hi" mode, or horizontal coplanar coil orientation, giving an estimated depth of investigation of $1.5 \times$ the coil
spacing (McNeill, 1980). The CMD Mini-Explorer is factory calibrated and was mounted on a wooden sled and set to sample
205 rate of 10 Hz. This sled was manually pulled by the operator and the 0.2 m coil data were removed due to noise. A Trimble
R2 unit was also mounted on the sled, providing GNSS readings at 1Hz sampling interval. The EMI surveys were conducted
on 26th June (summer) and 10th December (winter) 2024. Both surveys consisted of distinct lines, 2 parallel and several
perpendicular to the open drain (Figure 2Figure-2C/D).

2.2.1 Data processing, clustering, and Inversion

210 At the beginning of each survey day, the CMD was warmed up over a period of 30 mins to ensure temperature stabilisation of
the electronic components. The instrument was then set to record with and without the presence of the sled to provide a
correction factor. [No in-field calibrations were performed](#). Each survey line was acquired and processed as a separate data file.
Processing of each data file included correction for the presence of the sled, resampling to 1 Hz, averaging of duplicate
readings, application of a histogram filter (von Hebel et al., 2014) and a principle component analysis filter (Minsley et al.,
215 2012), filtered based on the first principle component. The individual data files were then appended together into a single
survey file.

In order to identify the spatial and vertical distribution of ECa across this site, clustering (Kaufman, 2005) was applied.
Clustering is an unsupervised machine learning method to organise complex multi-dimension data into groups with similar
220 characteristics and returns a single representative datapoint for each cluster (Wang et al., 2021). For this study, Self-Organising
Maps (Kohonen, 2013), a neural network based clustering algorithm, and the Multi-Cluster Average Standard Deviation
(MCASD) metric (O’Leary et al., 2023; O’Leary et al., 2024), developed for use on geospatial data, was used to determine the
appropriate number of clusters for each EMI survey. MCASD tests the stability of the cluster centres over multiple clustering
attempts. In order to derive the MCASD statistics, 1 – 20 clusters were assessed 100 times each. Processing and clustering of
225 ECa data were performed in MATLAB 2024a.

Clustering returns a single representative ECa data point for each group. These ECa data can be converted to a 1D true vertical
distribution of electrical conductivity (ECt) via a mathematical processing called inversion (Binley et al., 2015). This is a
process which seeks to create a model of subsurface ECt that best describes the acquired ECa data. This is an iterative process
230 where initially, an estimated 1D model of the subsurface ECt is provided. The Maxwell Equations (Everett and Chave, 2019)
are then applied to this model to return the modelled ECa (forward modelling). These modelled ECa are compared to acquired
ECa from the EMI survey [by optimising the objective function](#) (Sasaki, 2001). The ECt model is updated and the forward
modelling performed again. This is repeated until the error between modelled and acquired ECa is minimised and an ECt
model is produced.

235 In this study, the cluster centre ECa data are inverted using EM4SOIL (EMTOMO, 2013) to provide a representation of the
vertical and spatial distribution of true electrical conductivity (ECt) within the study area. Each cluster centre was inverted
using a 1D clustering algorithm, a damping factor of 0.10, [the S2 inversion algorithm](#), and the full solution (FS) Maxwell
equations for forward modelling.

240 **3 Results**

3.1 In-situ measurements

3.1.1 Rainfall data

245 Generally, the meteorological condition in Ireland reported that the spring and summer were cool and dry (Met Eireann, 2024) and that autumn and winter were mild with below average rainfall (Met Eireann, 2025). Meteorological data from 14 days prior to each EMI survey (Table 1) show that the cumulative rainfall at both survey dates was not significantly different (~ 5 mm), however the December survey had increased number of rainfall occurrences closer in time to the EMI survey, compared to June.

250

255

Table 1: Recorded rainfall in two weeks prior to each EMI survey date

	<u>June Survey</u>	<u>December Survey</u>
<u>Days before Survey</u>	<u>Rainfall (mm)</u>	<u>Rainfall (mm)</u>
<u>14</u>	-	-
<u>13</u>	<u>9.4</u>	-
<u>12</u>	<u>3.2</u>	<u>1.8</u>
<u>11</u>	<u>3.4</u>	<u>2.8</u>
<u>10</u>	-	<u>0.4</u>
<u>9</u>	-	<u>3.0</u>
<u>8</u>	-	-
<u>7</u>	-	-

6	-	1.6
5	-	8.0
4	-	2.6
3	6.6	6.8
2	-	-
1	-	-
Survey (Cumulative)	22.6	27.0

260

3.1

Formatted: Normal

3.1.13.1.2 WTD in Rewet (W) and Control (C) Normal areas

265

The standard deviation of the 15-minute interval recorded WTD for all dip-wells on 26/06/24 (summer/June) was between 0.1 and 0.6 cm and between 0.1 and 0.7 cm on 10/12/24 (winter/December) confirming a temporally stable water table during acquisition, indicating that the daily mean WTD from each dip-well is appropriate for comparison with EMI survey results.

270

Surface elevation data (Table 2/4) are taken from the point where the dip-well is at the surface and shows a standard deviation of ~ 20 cm across this site, however it is noted that the control area has significantly less topographical variation than the rewet area. This indicates the field is relatively flat and therefore topography is not considered in further analysis. Daily mean WTD data from each well during summer/June and December/winter dates (Table 2/4) indicate a spatially consistent WTD across this field (standard deviation ~ 3 cm). The exception to this is W1, which shows a deeper WTD. This well is fully screened from the peat through to the underlying mineral substrate, and so is likely to be capturing a composite water level dominated by the substrate, rather than the peat, indicative of the water table in the substrate below the peat, and not within the peat layer, and is therefore removed from analysis.

275

There is a difference in the WTD of 0.3 m in the peat layer (without W1) between the two dates with the water level 0.67 m below the surface during summer/June survey and 0.37 m below the surface on the winter/December survey. Finally, the Rewet (W) and Control Normal (C) experimental areas of this site have very similar WTD (with W1 removed) during both summer/June and December/winter surveys, indicating that open drain damming is not affecting the WTD in the area where the W wells are placed.

280

Table 24: Average surface elevation, perpendicular distance from open drain, daily and site average water table depth coincident with geophysical acquisition dates. Note W1 data is removed from analysis as it penetrates below the peat layer

			26/06/24 <u>June Survey</u>	10/12/24 <u>December Survey</u>	
	Surface Elev. (m)	Distance from Open Drain (m)	Daily Mean WT Depth (m)	Daily Mean WT Depth (m)	Difference (m)
D1	84.54	14	0.70	0.53	-0.18
D2	84.55	50	0.71	0.30	-0.42
D3	84.62	44	0.66	0.41	-0.25
D4	84.54	13	0.67	0.33	-0.34
D5	84.60	28	0.63	0.34	-0.29
D wells Mean	84.57	N/A	0.67	0.38	-0.29
D well Standard Deviation	0.03	N/A	0.03	0.08	0.08
W1	85.26	16	1.19	1.04	-0.16
W2	84.84	47	0.62	0.41	-0.21
W3	84.91	48	0.67	0.34	-0.34
W4	84.69	17	0.66	0.31	-0.35
W5	84.77	31	0.66	0.37	-0.29
W well Mean	84.89 (84.80 without W1)	N/A	0.76 (0.65 without W1)	0.49 (0.36 without W1)	-0.27 (-0.30 without W1)
W well Standard Deviation	0.20 (0.08 without W1)	N/A	0.22 (0.02 without W1)	0.27 (0.04 without W1)	0.07 (0.05 without W1)
Site Average	84.73 (84.67 without W1)	N/A	0.72 (0.67 without W1)	0.44 (0.37 without W1)	-0.28 (-0.29 without W1)
Site Standard Deviation	0.21 (0.13 without W1)	N/A	0.16 (0.03 without W1)	0.21 (0.07 without W1)	0.08 (0.07 without W1)

Formatted Table

285

3-1.23.1.3 Volumetric Water Content %

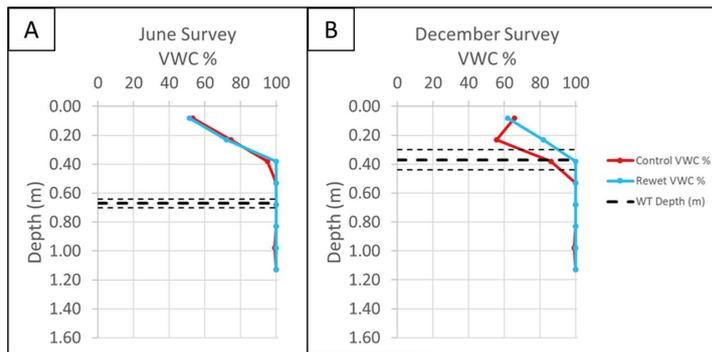
The standard deviation of 15-minute recorded VWC measurements for both probes during the summer-June date-survey was < 1 % and < 2.5 % on the winter-dateDecember survey, confirming temporally stable soil moisture conditions during EMI acquisition and indicating that the daily mean VWC with depth from each probe is appropriate for comparison with EMI survey

290

results. Full saturation of the peat soils is achieved and measured as an average VWC of 99.9 %, indicative of high porosity, low bulk density peat soils being fully saturated with water (Galvin, 1976).

295 The daily mean of the recorded data VWC data are plotted at 15 cm increments for each probe (Figure 3), coinciding with EMI acquisition dates. These results are also plotted alongside the WTD for the peat soil layer (Table 2Table 4) for comparison. VWC from both summer-June and December-winter dates follow a similar trend, with both W and CD sides reaching maximum full saturation within 0.30 – 0.45 m depth on the June-summer survey date. VWC in the CD area showing a slight deeper full maximum saturation (0.45 – 0.60 m) depth on the December-winter survey date. Generally, the VWC has increased by ~ 10 % on the December survey-winter date shows an increased VWC of ~ 10 % compared to June survey-the summer in both areas. The CD area in the December survey-winter shows a large decrease in VWC between 0.15 and 0.30 m (Figure 3B). During the summer-June survey, the site-averaged WTD is approx. 0.2 m below the depth of maximum full saturation (0.30 – 0.45 m), whereas during the winter-December survey, the WTD is similar to the depth of maximum full saturation.

300



305

Figure 3: A) 26/06/24 averaged volumetric water (VWC) content % vs. depth for the Rewet (W) and Control/Normal (CD) zones. B) 10/12/24 averaged VWC % vs. depth for the W and CD zones. Both A and B are shown with their respective site averaged and standard deviation of WTD. Note that full saturation refers to a reading of 99.9 % VWC indicative of a fully saturated peat soil.

310

3.1.3.1.4 Open drain water measurements

Multi-Parameter probe (YSI, 2025) measurement indicates that the electrical properties of the water in the open drain were stable during both EMI survey days (Table 3Table 2). The main difference in measurements in the open drain between EMI survey days are temperature and electrical conductivity (mS/m). These readings show that the water temperature in the open drain during the December-winter survey was ~ 7 °C colder than the June-summer survey. Similarly, the electrical conductivity

315

of the open drain water in Decemberwinter is ~ 20 mS/m lower than during the Junesummer survey, most likely attributed to the temperature difference between the dates (Corwin and Lesch, 2005) along with any changes in the composition of the open drain water due to run off upstream. This value was not corrected to a standard temperature in order to compare to the respective EMI survey. The other measured properties (salinity and pH) are similar for both Junesummer and Decemberwinter surveys.

320

Table 32: Multi-Parameter probe results. Electrical Conductivity is measured in milli-Siemens per metre (mS/m) SD = south of dam, NF = north of flume, SF = south of flume

Date	Time (local)	Location Code	Temp (° C)	ECT (mS/m)	SalinityAL (ppt)	pH
25/06/2024	10:45	SD	13.1	62.9	0.4	7.3
	11:30	SD	13.0	63.8	0.4	7.3
	13:05	SD	13.0	63.3	0.4	7.3
	14:00	SD	13.1	63.2	0.4	7.3
	14:57	SD	13.1	63.0	0.4	7.2
26/06/2024	14:02	SD	13.5	61.8	0.4	7.5
	10:07	NF	14.2	73.0	0.4	7.4
	11:17	NF	14.1	75.9	0.5	7.4
	12:25	NF	14.1	79.5	0.5	7.4
	13:51	NF	14.2	81.3	0.5	7.4
	15:40	NF	14.5	65.8	0.4	7.0
	Mean		13.6	68.5	0.4	7.3
10/12/2024	11:03	SD	7.1	52.5	0.4	7.1
	12:36	SD	7.1	51.1	0.4	7.1
	11:06	ND	6.7	50.6	0.4	7.0
	12:38	ND	6.8	50.2	0.4	7.1
	11:08	NF	6.4	49.8	0.4	7.0
	12:40	NF	6.8	49.8	0.4	7.0
		Mean		6.8	50.7	0.4

Formatted Table

325 **3.1.4 Rainfall data**

(Met Eireann, 2024, 2025) Meteorological data from 14 days prior to each EMI survey show that the cumulative rainfall at both survey dates was not significantly different (~ 5 mm), however the winter survey had increased number of rainfall occurrences closer in time to the EMI survey, compared to summer.

330 Table 3: Recorded rainfall in two weeks prior to each EMI survey date

	26/06/24	10/12/24
Days before Survey	Rainfall (mm)	Rainfall (mm)
14	-	-
13	9.4	-
12	3.2	1.8
11	3.4	2.8
10	-	0.4
9	-	3.0
8	-	-
7	-	-
6	-	1.6
5	-	8.0
4	-	2.6
3	6.6	6.8
2	-	-
1	-	-
Survey (Cumulative)	22.6	27.0

3.2 Electromagnetic induction

3.2.1 ECa

335 The processing flow (Section 2.2.1) was applied to five data layers for both EMI surveys and resulted in 1,266 (June/summer) and 1,283 (December/winter) distinct ECa measurements across the site (Figure 4).

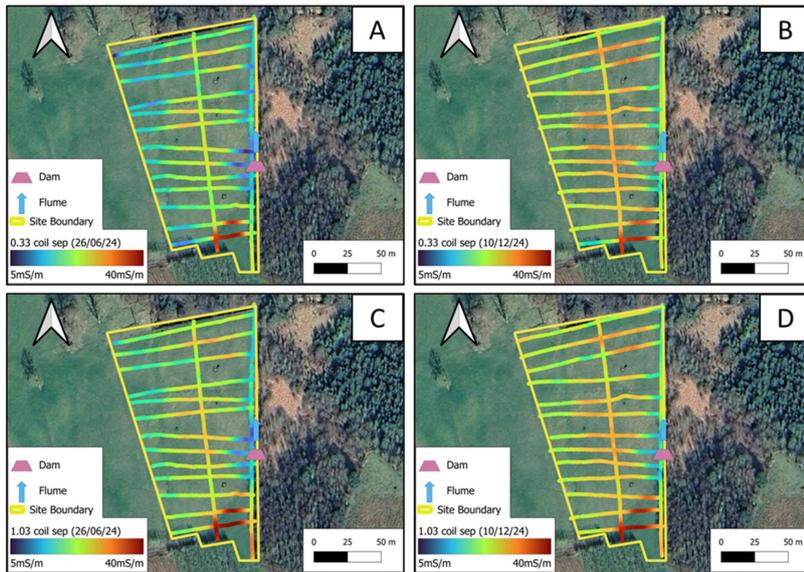


Figure 4: Processed EMI ECA data from. A) 26/06/24 - 0.33 m coil separation (~ 0.5 m depth), B) 10/12/24 - 0.33 m coil separation, C) 26/06/24 - 1.03 m coil separation (~ 1.5 m depth), D) 10/12/24 - 1.03 m coil separation. Basemap © Google Maps 2019

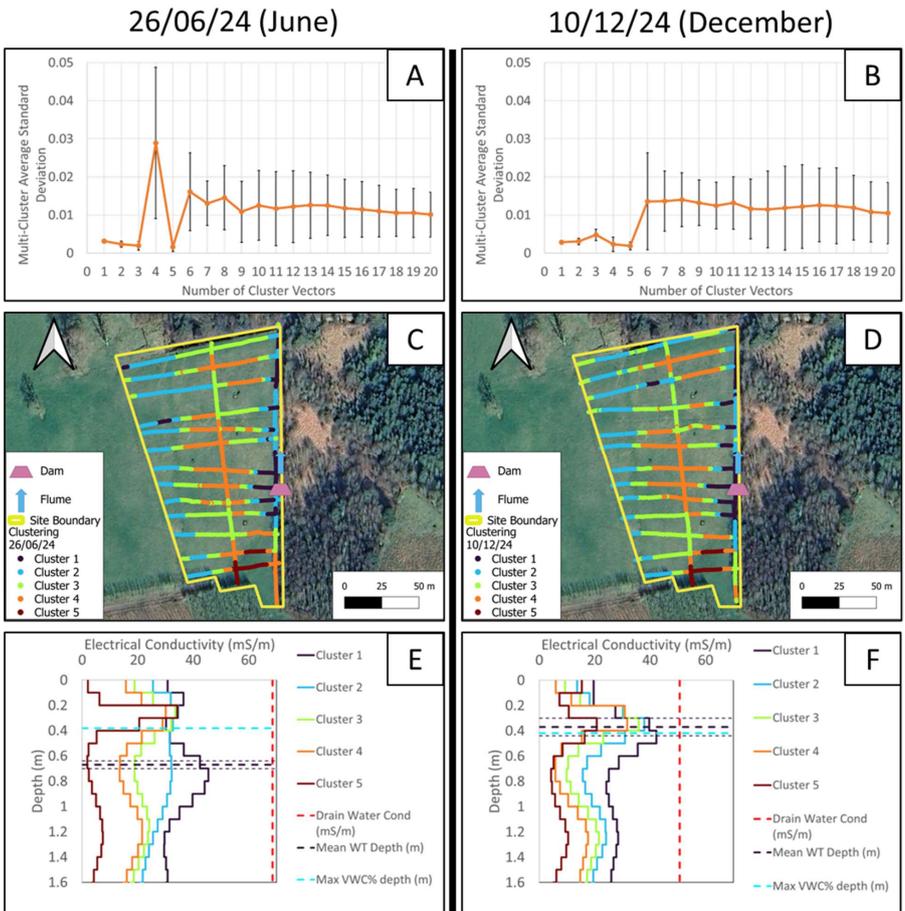
The EMI survey data show a general lowering of ECA from **Junesummer** to **December surveyswinter** (similar to Multi-Parameter probe results). Spatial and vertical distribution patterns of ECA measurements are similar in both **Junesummer** and **Decemberwinter** surveys. An area of low ECA is present to the south of the site, which corresponds to reduced thickness of the peat soil layer (Figure 2Figure-2B). Both surveys also show the presence of relatively high ECA measurements in proximity to the installed dam and flume to the east of the site, although this is more clearly noticeablethe contrast in ECA values is greater in the **Junesummer** compared to the **Decemberwinter** survey.

3.2.2 Clustering and Inversion

MCASD metrics indicated that five clusters were appropriate for both **Junesummer** and **Decemberwinter** EMI survey data (Figure 5A, B). In both cases, a lower number of clusters (one to four) had lowerhigher MCASD stability metrics, indicating a good clustering solution,-compared-to the 5-cluster result, and higher cluster numbers resulted in large instability of the resulting-cluster centres indicating a poor clustering solution.

The spatial distribution of the 5-cluster results for both survey days (Figure 5C, D) is coloured to match the corresponding inverted cluster centre (Figure 5E, F) and indicate areas of similar ECt. The spatial distribution of the clustered data is very similar on both survey dates, with cluster numbers from the June-summer comparable to cluster numbers from the winter survey/December survey. Cluster 5 (both June-summer and December survey/winter) has good agreement with the area of thinner peat (Figure 2/figure-2B). Cluster 1 is located in the area of higher ECa noted in both summer-June and December/winter surveys close to the dam and flume (Figure 4), which is considered the area affected by rewetting measures. Cluster 2 is located at the eastern and western edges of the site, with clusters 3 and 4 distributed through the middle of the site.

All cluster centre data were successfully inverted (Figure 5E, F), with an average Root Mean Squared Error (RMSE) between acquired and forward modelled ECa of 0.15 mS/m (June-summer survey) and 0.28 mS/m (December/winter survey). Figure 5 illustrates the inverted cluster centre data alongside the site averaged peat soil WTD (from Table 2/Table-1), depth of fullmax saturation (from Figure 3), and electrical conductivity of the open drain (from Table 3/Table-2) for each survey date. Generally, the inverted clusters have a similar ECt in the top ~ 0.40 m of the surface, during the respective survey dates. This corresponds to the depth where the soil is not fully saturated based on VWC results (Figure 3). Below this depth, in the June-summer survey, the WTD is relatively deep and there is large variation between the ECt across the clusters. In the December/winter survey, with a relatively shallow WTD, this variation is reduced, resulting in more uniform vertical distribution of ECt across the clusters. Cluster 5 represents an area of thin peat and so is difficult to compare to the other cluster results. However, this cluster is comparable between the two survey dates. Below the depth of max saturation, the ECt results are very similar. Above this depth, there are significant differences in the ECt results, indicating a difference in the shallow peat soil electrical conductivity between survey dates. This seasonal variation is captured in all cluster centre results in this shallow area, above the depth of max saturation. On both survey dates, Cluster 1 ECt values are closer to the electrical conductivity values measured in the open drain (red dashed vertical line) compared to other cluster ECt values (Figure 5E/F). This is particularly notable in the June-summer survey data (Figure 5E). Cluster 2 ECt results also appears to be notably different from the other clusters, particularly during the June-summer survey, appearing as intermediate values between Ccluster 1 and Cclusters 3 and 4.



380 Figure 5: Clustering and inversion results for summer (left) and winter (right) surveys. A/B) MCASD graphs indicating the appropriate number of clusters. C/D) Spatial distribution of clusters. E/F) 1D inverted cluster centres including site averaged water table depth and VWC % max saturation depth. Basemap © Google Maps 2019

4 Discussion

4.1 Water table depth

385 ~~Low hydraulic conductivity of peat soils (Galvin, 1976) combined with the tendency for fen peats to be controlled by landscape~~
~~water table dynamics, indicates that open drains have limited ability to effectively drain such grassland fen peat sites (Tuohy~~
~~et al., 2023). It is therefore assumed that damming such open drains will also have limited spatial effect on rewetting. This is~~
~~evident on this fen site by the WTD differences noted between survey dates in this study (Table 2), which appear to be~~
~~controlled by landscape water table dynamics as opposed to any local water table control attempts (i.e., open drain and dam).~~

390 ~~In this experiment,~~ The individual locations of the dip wells were designed to act as a partial spatial assessment of open drain
damming effect, whereby W wells closer to the dam were expected to be more affected than W wells further away. This
experimental design also assumes the main drainage is taking place via direct discharge into the open drain.

395 ~~The drain.~~ The WTD was stable across the study site during both the summer and winter survey dates (Table 2), with
no indication that drain damming was affecting the WTD in the rewet area. The closest dip well to the open drain dam, taken
to be the combined effect of the dam and flume installations, is well W4 (Figure 2) with a perpendicular distance of
~ 17 m from the open drain, and a line-of-sight distance of ~ 20 m from the dam and ~ 30 m from the flume. A
study on raised bogs from Norway concluded that the spatial influence of drain damming was 17.2 m (Stachowicz et al., 2025)
400 and a study on agricultural fen peats from Germany concluded a more modest estimate of “a few metres” of spatial impact
from drain dam due to low hydraulic conductivity of peat soils (Heller et al., 2025). Tuohy et al. (2023) undertook a review of
various geographic, peat soil and drainage system combinations and conclude that the effective drainage is spatially
constrained to within a few metres of the drain, which would infer a similar constraint when damming an open drain. The
results show here (Table 2) appear to agree with these findings with no spatial influence of drain damming evident in
405 water table depths across the site during either the summer or winter survey dates.

~~Low hydraulic conductivity of peat soils (Galvin, 1976) combined with the tendency for fen peats to be controlled by landscape~~
~~water table dynamics, indicates that open drains have limited ability to effectively drain such grassland fen peat sites (Tuohy~~
410 ~~et al., 2023). This is evident on this fen site by the WTD fluctuations noted between survey dates in this study (Table 1).~~

4.2 Controls on Volumetric Water Content %

Peat soils have a very high porosity, low bulk density and tend to have high VWC (Galvin, 1976; Holden, 2005). The specific
yield, or the amount of water expected to be stored as the WTD is lowered, for peat soils is also expected to be very

415 high due to capillary action holding the water within the matrix of the peat soil (Galvin, 1976; Pierce et al., 2025). This
can result in peat soils storing large quantities of water, even above the WTD (Holden, 2005; Price et al., 2003) and such an
effect can be seen at this site, particularly during the summer survey date (Figure 3).

420 During the June survey, both the W and CD experimental areas of the site show similar VWC vertical profiles with
depth, indicating no difference between these areas. During the winter-December survey date, there is a general reduction in
the VWC (~ 10%) for the CD area VWC vertical profile compared to the W area (Figure 3) and a sharp reduction in VWC at
~ 0.20 m depth. While this result may be attributed to successful rewetting efforts, the WTD results (Table 2) do not
support this conclusion. Therefore, it is assumed this result is due to WTD being close to the surface, allowing for the drainage
of water via in-field drains, which are understood to be located ~ 8 m from the location of the VWC probe, acting to lower the
425 VWC in the CD experimental area.

However, VWC, combined with WTD and meteorological information, may provide an insight into the success of a rewetting
method. A study from Germany concluded that precipitation on drained/degraded fen peat soils had a greater influence on
WTD compared to a rewetted fen peat (Ahmad et al., 2021), due to specific yield and water storage capacity differences. In
430 this Irish example of a fen peat soil, there doesn't appear to be a difference in VWC, or WTD, between the W and CD
experimental areas when analysed here in a static manner. However, analysis of temporal dynamics and relationship between
WTD, rainfall and VWC is needed.

4.3 Temporal EMI surveys with cluster guided Inversion

435 The use of EMI surveys, combined with clustering and MCASD, has provided a quick and data driven means to return an
understanding of the ECt variation on this site, spatially, vertically, and temporally. This is often difficult to achieve on spatial
EMI datasets due to the complexity in performing a full 3D inversion on EMI data (O'Leary et al., 2024) due to volume of
data to be inverted and restrictions in performing in-field calibration of EMI instruments, with studies often opting to use ECa
440 as the primary measurement (Brogi et al., 2019). ECa can give an indication of soil property variation spatially across a site
(Figure 4), however ECt are needed to study the vertical variation (Figure 5). The use of representative 1D ECa data (cluster
centres) simplifies the inversion process and still provides representative distribution of ECt across this site. This vertical
variation can also be better understood by undertaking a repeat survey, such as done here. Physical properties of the soil, such
as peat layer thickness and soil texture, are not expected to change from one survey to the other, and so any variation in the
445 electrical conductivity may be attributed to hydrological changes within the subsurface (WTD or water content changes).
While this would be particularly impactful for an EMI survey performed prior to and after dam installation, the methodology
and results of this study effectively demonstrate the ability of temporal EMI surveys to identify areas of hydrological change.

It should be noted that other soil characteristics which change on similar timescales, such as compaction, may influence temporal EMI survey results, however no evidence of additional influencing factors (e.g., iron, saline intrusion) are present in this study.

One of the assumptions of rewetting is that by damming the water in the open drains water will infiltrate into the surrounding soils, effectively rewetting them, a new level for the water table would be established for the surrounding soils, via infiltration of the dammed water (Heller et al., 2025). Therefore, it can be assumed that some of the physical properties of this open drain water will be present in the water content of these infiltrated soils, specifically electrical conductivity. In this study, the inclusion of the Multi-Parameter probe measurements of open drain water physical properties electrical conductivity (Table 3 Table-2) has provided a constraints when interpreting on of EMI survey results, via a measured known ECt for water which is assumed to have may have infiltrated into the soil. This value is compared to the inverted cluster centre ECt profiles to highlight which areas of the site are impacted by this infiltration. The inclusion of these data, or similar, measurement of open drain water electrical conductivity should be included with using EMI measurements to determine the effect of drain damming on agricultural fen peat soils.

Observations from the EMI survey clustering and inversion results show that some impact is observed ~ 20 m from the open drain immediately upstream of the installed dam and flume (Figure 5). Although the spatial distribution of the cluster centres (Figure 5C, D) show a very similar spatial pattern and indicate impact from drain damming on both surveys, the inverted cluster centres (Figure 5E, F) are not similar. For example, in the summer-June survey, Cluster 1 (Figure 5E, F) is significantly different to the other cluster numbers, with ECt values at the depth of the mean water table to be closer to the measured electrical conductivity of the open drain (Table 3 Table-2). During the summer-June survey, the WTD in the field is deeper, thereby changing-creating a large the gradient between the in-field WTD position and the open drain water level. Water from the open drains infiltrates into the subsoil of the adjoining field, immediately around the dam and flume, resulting in electrical conductivity readings of the groundwater being closer to that of the water in the open drain. While this effect is still present in the December-winter survey, it is not as obvious. This is due to the shallower WTD in winter, with less and so less infiltration off from the water in the open drain into the surrounding soils. This would result in the pore water content being proportionally more ground water influenced, resulting in and so the electrical conductivity (Henrion et al., 2024), of the peat soil layer to be more uniform in winter across the site, as observed in this study.

The inclusion of VWC data, and the subsequent comparison to WTD, can be used to constrain the interpretation of EMI survey results across a site as electrical conductivity is sensitive to water content. They provide an understanding of the hydrological status of peat soils at the time of the survey. EMI surveys can also be used to determine other peat soil characteristics, such as peat depth. Cluster 5 (Figure 5), which is present in both June-summer and December-winter surveys, is linked to the area of thinner peat. The inclusion of the temporal element of this study allows for the identification of this cluster as one of little

hydrological change between these survey dates, leading to focused analysis of this cluster. ~~Prior knowledge of this may have resulted in the drain damming being located further north, to maximise the impact of rewetting efforts~~ EMI surveys in combination with peat depth via probe campaigns should be done prior to any rewetting efforts as they can cover large areas quickly and can yield spatial information on peat soil characteristic changes.

EMI surveys, when combined with clustering and inversion, can provide a means to assess the impact of rewetting by assessing areas of high hydrological change through the inclusion of multiple repeat surveys. While the most intra-site variation is present during the ~~June~~summer survey, when the water table is low, and the effect of infiltrated water from the open drain is evident, the temporal analysis highlights areas of hydrological change between seasons, which can be employed to help determine the optimum location for monitoring instruments, maximising the ability to monitor rewetting efforts over time.

5 Conclusions

This study demonstrates that EMI surveys can effectively assess spatial impacts of drain damming on agricultural fen peat soils. EMI results revealed localised infiltration from the dammed open drain within approximately 20 m, particularly during the summer survey, aided by the use of neural network clustering and Multi-Cluster Average Standard Deviation analysis. The EMI survey results were constrained by the presence of WTD, VWC, open drain water electrical conductivity, and peat depth information across this site. A significant observation from this study is the influence of seasonal timing on rewetting assessments. ~~Summer~~ EMI surveys, conducted during deeper water table conditions, provided clearer evidence of drain damming impact compared to ~~winter~~ surveys, where increased precipitation and regional groundwater dynamics masked localised effects. This emphasises that survey timing is crucial for detecting rewetting effects in peat soils. The results also highlight practical applications for rewetting projects. If performed prior to rewetting, EMI surveys can inform more effective placement of drain damming structures, maximising the potential impact. These surveys can also guide the strategic installation of dip wells for long-term monitoring, ensuring they are placed within zones most likely to experience hydrological change. Overall, this study demonstrates how combining geophysical methods with modern data analytics can provide rapid, spatially comprehensive assessments of rewetting impact. By illustrating the strengths of EMI for rewetting monitoring, this work supports the adoption of geophysical techniques in peatland restoration projects. More broadly, it contributes to improving the effectiveness of nature-based solutions for climate change mitigation and sustainable land management.

6 Author Contributions

DO'L: Conceptualisation, Formal analysis, Methodology, Visualization, Writing – original draft preparation. **AS:** Data curation, Resources. **PT:** Funding acquisition, Project administration, Writing – review & editing. **OF:** Funding acquisition,

Conceptualisation, Writing – review & editing. **MH**: Funding acquisition, Writing – review & editing. **HP**: Investigation, Writing – review & editing. **ED**: Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

7 Competing interests

The lead author (Dave O’Leary) is a member of the guest editorial board for this SI "Agrogeophysics: illuminating soil's hidden dimensions".

8 Acknowledgements

The research conducted in this publication was funded by the Department of Agriculture, Food and the Marine (DAFM) under grant number 2021R454. It contains Irish Public Sector Data (Teagasc) licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence. Access to Local field sites data was provided by Teagasc. The authors wish to thank Asaf Shnel (Teagasc) for providing the Peat depth data, and the landowner for access to their agricultural land (ReWET site). All code is available via standard MATLAB© Deep Learning toolboxes.

9 References

- Adetsu, D. V., Koganti, T., Petersen, R. J., Pedersen, J. B., Zak, D., Greve, M. H., and Beucher, A.: Sensor-based peat thickness mapping of a cultivated bog in Denmark, *Geoderma*, 452, 117091, <https://doi.org/10.1016/j.geoderma.2024.117091>, 2024.
- 525 Ahmad, S., Liu, H., Alam, S., Günther, A., Jurasinski, G., and Lennartz, B.: Meteorological Controls on Water Table Dynamics in Fen Peatlands Depend on Management Regimes, *Frontiers in Earth Science*, Volume 9 - 2021, <https://doi.org/10.3389/feart.2021.630469>, 2021.
- Altdorff, D., Bechtold, M., Van Der Kruk, J., Vereecken, H., and Huisman, J. A.: Mapping peat layer properties with multi-coil offset electromagnetic induction and laser scanning elevation data, *Geoderma*, 261, 178–189, <https://doi.org/10.1016/j.geoderma.2015.07.015>, 2016.
- 530 Baird, A. J. and Low, R. G.: The water table: Its conceptual basis, its measurement and its usefulness as a hydrological variable, *Hydrol Process*, 36, e14622, <https://doi.org/10.1002/hyp.14622>, 2022.
- Binley, A., Hubbard, S., Huisman, J., Revil, A., Robinson, D., Singha, K., and Slater, L.: The emergence of hydrogeophysics for improved understanding of subsurface processes over multiple scales, *Water Resources Research*, 51, 3837–3866, <https://doi.org/10.1002/2015WR017016>, 2015.
- 535 Blanchy, G., Watts, C. W., Richards, J., Bussell, J., Huntentburg, K., Sparkes, D. L., Stalham, M., Hawkesford, M. J., Whalley, W. R., and Binley, A.: Time-lapse geophysical assessment of agricultural practices on soil moisture dynamics, *Vadose Zone J*, 19, e20080, <https://doi.org/10.1002/vzj2.20080>, 2020.
- Boaga, J.: The use of FDEM in hydrogeophysics: A review, *Journal of Applied Geophysics*, 139, 36–46, <https://doi.org/10.1016/j.jappgeo.2017.02.011>, 2017.
- 540 Brogi, C., Huisman, J. A., Patzold, S., Von Hebel, C., Weihermuller, L., Kaufmann, M. S., Van Der Kruk, J., and Vereecken, H.: Large-scale soil mapping using multi-configuration EMI and supervised image classification, *Geoderma*, 335, 133–148, <https://doi.org/10.1016/j.geoderma.2018.08.001>, 2019.
- Corwin, D. L. and Lesch, S. M.: Apparent soil electrical conductivity measurements in agriculture, *Comput Electron Agr*, 46, 11–43, <https://doi.org/10.1016/j.compag.2004.10.005>, 2005.
- 545 Climate Action Plan 2024: <https://www.gov.ie/en/publication/79659-climate-action-plan-2024/>, last

- Doolittle, J. A. and Brevik, E. C.: The use of electromagnetic induction techniques in soils studies, *Geoderma*, 223, 33–45, <https://doi.org/10.1016/j.geoderma.2014.01.027>, 2014.
- EM4Soil: Software for Electromagnetic Tomography.: <http://www.emtomo.com/home/>, last access: 28/07/2023.
- 550 Eu: Nature restoration law – For people, climate, and planet, Publications Office of the European Union, <https://data.europa.eu/doi/10.2779/86148>, 2022.
- Everett, M. E. and Chave, A. D.: On the physical principles underlying electromagnetic induction, *GEOPHYSICS*, 84, W21–W32, <https://doi.org/10.1190/geo2018-0232.1>, 2019.
- Fao: Peatland mapping and monitoring, FAO, Rome, Italy, 82 pp., <https://doi.org/10.4060/ca8200en>, 2020.
- 555 Fluet-Chouinard, E., Stocker, B. D., Zhang, Z., Malhotra, A., Melton, J. R., Poulter, B., Kaplan, J. O., Goldewijk, K. K., Siebert, S., Minayeva, T., Hugelius, G., Joosten, H., Barthelmes, A., Prigent, C., Aires, F., Hoyt, A. M., Davidson, N., Finlayson, C. M., Lehner, B., Jackson, R. B., and McIntyre, P. B.: Extensive global wetland loss over the past three centuries, *Nature*, 614, 281–286, <https://doi.org/10.1038/s41586-022-05572-6>, 2023.
- Fossitt, J. A. and Heritage, C.: A Guide to Habitats in Ireland, Heritage Council of Ireland series, Heritage Council/Chomhairle Oidhreachta2000.
- 560 Galvin, L. F.: Physical-Properties of Irish Peats, *Irish J Agr Res*, 15, 207–&, 1976.
- Garré, S., Hyndman, D., Mary, B., and Werban, U.: Geophysics conquering new territories: The rise of “agrogeophysics”, *Vadose Zone J*, 20, e20115, <https://doi.org/10.1002/vzj2.20115>, 2021.
- CMD Electromagnetic conductivity meter user manual V. 1.5 & 2.1: http://www.gfinstruments.cz/index.php?menu=gi&cont=cmd_ov, last access: 01/08/2023.
- 565 Gilet, L., Morley, T. R., Flynn, R., and Connolly, J.: An adaptive mapping framework for the management of peat soils: A new Irish peat soils map, *Geoderma*, 447, 116933, <https://doi.org/10.1016/j.geoderma.2024.116933>, 2024.
- Habib, W. and Connolly, J.: A national-scale assessment of land use change in peatlands between 1989 and 2020 using Landsat data and Google Earth Engine—a case study of Ireland, *Regional Environmental Change*, 23, 124, <https://doi.org/10.1007%2Fs10113-023-02116-0>, 2023.
- 570 Heller, S., Tiemeyer, B., Oehmke, W., Gatersleben, P., and Dettmann, U.: Wetter, but not wet enough—Limited greenhouse gas mitigation effects of subsurface irrigation and blocked ditches in an intensively cultivated grassland on fen peat, *Agricultural and Forest Meteorology*, 362, 110367, <https://doi.org/10.1016/j.agrformet.2024.110367>, 2025.
- 575 Henrion, M., Li, Y., Koganti, T., Bechtold, M., Jonard, F., Opfergelt, S., Vanacker, V., Van Oost, K., and Lambot, S.: Mapping and monitoring peatlands in the Belgian Hautes Fagnes: Insights from Ground-penetrating radar and Electromagnetic induction characterization, *Geoderma Regional*, 37, e00795, <https://doi.org/10.1016/j.geodrs.2024.e00795>, 2024.
- Holden, J.: Peatland hydrology and carbon release: why small-scale process matters, *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 363, 2891–2913, <https://doi.org/10.1098/rsta.2005.1671>, 2005.
- 580 Huth, N. I. and Poulton, P. L.: An electromagnetic induction method for monitoring variation in soil moisture in agroforestry systems, *Aust J Soil Res*, 45, 63–72, <https://doi.org/10.1071/SR06093>, 2007.
- Kaufman, L.: Finding groups in data an introduction to cluster analysis, Hoboken, N.J. : Wiley-Interscience, Hoboken, N.J., <https://doi.org/10.1002/9780470316801>, 2005.
- 585 Koch, J., Elsgaard, L., Greve, M. H., Gyldenkerne, S., Hermansen, C., Levin, G., Wu, S., and Stisen, S.: Water-table-driven greenhouse gas emission estimates guide peatland restoration at national scale, *Biogeosciences*, 20, 2387–2403, <https://doi.org/10.5194/bg-20-2387-2023>, 2023.
- Koganti, T., Narjary, B., Zare, E., Pathan, A. L., Huang, J., and Triantafyllis, J.: Quantitative mapping of soil salinity using the DUALEM-21S instrument and EM inversion software, *Land Degrad Dev*, 29, 1768–1781, <https://doi.org/10.1002/ldr.2973>, 2018.
- 590 Kohonen, T.: Essentials of the self-organizing map, *Neural Networks*, 37, 52–65, <https://doi.org/10.1016/j.neunet.2012.09.018>, 2013.
- Lindsay, R.: Peatbogs and carbon: a critical synthesis to inform policy development in oceanic peat bog conservation and restoration in the context of climate change.
- 595 Lourenco, M., Fitchett, J. M., and Woodborne, S.: Peat definitions: A critical review, *Progress in Physical Geography: Earth and Environment*, <https://doi.org/10.1177/03091333221118353>, 2022.
- McNeill, J. D.: Electromagnetic terrain conductivity measurement at low induction numbers, *Geonics Technical Note TN-6*, <https://cir.nii.ac.jp/crid/1572543024212993792>, 1980.

- Climate Statement for Summer 2024: <https://www.met.ie/climate-statement-for-summer-2024>, last access: 28/07/2025.
 Climate Statement for Winter 2024/2025: <https://www.met.ie/ga/climate-statement-for-winter-2024-2025>, last access: 28/07/2025.
- 600 Minasnay, B., Adetsu, D. V., Aitkenhead, M., Artz, R. R. E., Baggaley, N., Barthelmes, A., Beucher, A., Caron, J., Conchedda, G., Connolly, J., Deragon, R., Evans, C., Fadnes, K., Fiantis, D., Gagkas, Z., Gilet, L., Gimona, A., Glatzel, S., Greve, M. H., Habib, W., Hergoualc'h, K., Hermansen, C., Kidd, D. B., Koganti, T., Kopansky, D., Large, D. J., Larmola, T., Lilly, A., Liu, H., Marcus, M., Middleton, M., Morrison, K., Petersen, R. J., Quaipe, T., Rochefort, L., Rudyanto, Toca, L., Tubiello, F. N., Weber, P. L., Weldon, S., Widyatmanti, W., Williamson, J., and Zak, D.: Mapping and monitoring peatland conditions from global to field scale, *Biogeochemistry*, <https://doi.org/10.1007/s10533-023-01084-1>, 2023.
- 605 Minsley, B. J., Smith, B. D., Hammack, R., Sams, J. I., and Veloski, G.: Calibration and filtering strategies for frequency domain electromagnetic data, *Journal of Applied Geophysics*, 80, 56–66, <https://doi.org/10.1016/j.jappgeo.2012.01.008>, 2012.
- Moghadas, D., Jadoon, K. Z., and McCabe, M. F.: Spatiotemporal monitoring of soil water content profiles in an irrigated field using probabilistic inversion of time-lapse EMI data, *Advances in Water Resources*, 110, 238–248, <https://doi.org/10.1016/j.advwatres.2017.10.019>, 2017.
- 610 Monteiro, A., Santos, S., and Gonçalves, P.: Precision Agriculture for Crop and Livestock Farming-Brief Review, *Animals*, <https://doi.org/10.3390%2Fani11082345>, 2021.
- Monteverde, S., Healy, M. G., O'leary, D., Daly, E., and Callery, O.: Management and rehabilitation of peatlands: The role of water chemistry, hydrology, policy, and emerging monitoring methods to ensure informed decision making, *Ecological Informatics*, 69, 101638, <https://doi.org/10.1016/j.ecoinf.2022.101638>, 2022.
- 615 O'leary, D., Brown, C., Healy, M. G., Regan, S., and Daly, E.: Observations of intra-peatland variability using multiple spatially coincident remotely sensed data sources and machine learning, *Geoderma*, 430, 116348, <https://doi.org/10.1016/j.geoderma.2023.116348>, 2023.
- O'leary, D., Brogi, C., Brown, C., Tuohy, P., and Daly, E.: Linking electromagnetic induction data to soil properties at field scale aided by neural network clustering, *Frontiers in Soil Science*, 4, <https://doi.org/10.3389/fsoil.2024.1346028>, 2024.
- 620 O'leary, D., Brown, C., Hodgson, J., Connolly, J., Gilet, L., Tuohy, P., Fenton, O., and Daly, E.: Airborne radiometric data for digital soil mapping of peat at broad and local scales, *Geoderma*, 453, 117129, <https://doi.org/10.1016/j.geoderma.2024.117129>, 2025.
- Page, S. E. and Baird, A. J.: Peatlands and Global Change: Response and Resilience, *Annu Rev Env Resour*, 41, 35–57, <https://doi.org/10.1146/annurev-environ-110615-085520>, 2016.
- 625 Pierce, H., Fenton, O., Daly, E., Shnel, A., O'leary, D., Healy, M. G., and Tuohy, P.: Assessing localised rainfall and water table depth relationships in agricultural grassland peat soils, *Science of The Total Environment*, 994, 180074, <https://doi.org/10.1016/j.scitotenv.2025.180074>, 2025.
- Price, J., Heathwaite, A., and Baird, A.: Hydrological processes in abandoned and restored peatlands: an overview of management approaches, *Wetlands Ecology and Management*, 11, 65–83, <https://doi.org/10.1023/A:1022046409485>, 2003.
- 630 Ramsar: Resolution XIII.13, Restoration of degraded peatlands to mitigate and adapt to climate change and enhance biodiversity and disaster risk, “Wetlands for a Sustainable Urban Future” Dubai, United Arab Emirates, 21–29 October 2018, 13th Meeting of the Conference of the Contracting Parties to the Ramsar Convention on Wetlands 2018.
- Romero-Ruiz, A., O'leary, D., Daly, E., Tuohy, P., Milne, A., Coleman, K., and Whitmore, A. P.: An agrogeophysical modelling framework for the detection of soil compaction spatial variability due to grazing using field-scale electromagnetic induction data, *Soil Use and Management*, 40, e13039, <https://doi.org/10.1111/sum.13039>, 2024.
- 635 Sasaki, Y.: Full 3-D inversion of electromagnetic data on PC, *Journal of Applied Geophysics*, 46, 45–54, [https://doi.org/10.1016/S0926-9851\(00\)00038-0](https://doi.org/10.1016/S0926-9851(00)00038-0), 2001.
- Stachowicz, M., Lyngstad, A., Osuch, P., and Grygoruk, M.: Hydrological Response to Rewetting of Drained Peatlands—A Case Study of Three Raised Bogs in Norway, *10.3390/land14010142*, 2025.
- 640 Strack, M., Davidson, S. J., Hirano, T., and Dunn, C.: The Potential of Peatlands as Nature-Based Climate Solutions, *Current Climate Change Reports*, 8, 71–82, <https://doi.org/10.1007/s40641-022-00183-9>, 2022.
- National Land Cover Map: <https://www.epa.ie/our-services/monitoring-assessment/assessment/mapping/national-land-cover-map/> last access: 02/02/2025.
- 645 ReWET: <https://sites.google.com/view/rewet>, last access: 10/04/2024.

- Tuohy, P., O' Sullivan, L., Bracken, C. J., and Fenton, O.: Drainage status of grassland peat soils in Ireland: Extent, efficacy and implications for GHG emissions and rewetting efforts, *Journal of Environmental Management*, 344, 118391, <https://doi.org/10.1016/j.jenvman.2023.118391>, 2023.
- 650 Unep: Global Peatlands Assessment – The State of the World's Peatlands: Evidence for action toward the conservation, restoration, and sustainable management of peatlands. Main Report., United Nations Environment Programme, Nairobi, 2022.
- Unfccc: The Paris Agreement, 2018.
- Peat Probes: <https://www.vanwalt.com/equipment/peat-probes/>, last access: 10/04/2024.
- Russian Auger: <https://www.vanwalt.com/equipment/russian-peat-corer-set/>, last access: 01/07/2024.
- Seametrics LevelSCOUT Smart Sensor: <https://www.vanwalt.com/equipment/levelscout/>, last access: 28/01/2025.
- 655 GroPoint Profile: <https://www.vanwalt.com/equipment/gropoint-profile/>, last access: 28/01/2025.
- Von Hebel, C., Rudolph, S., Mester, A., Huisman, J. A., Kumbhar, P., Vereecken, H., and Van Der Kruk, J.: Three-dimensional imaging of subsurface structural patterns using quantitative large-scale multiconfiguration electromagnetic induction data, *Water Resources Research*, 50, 2732–2748, <https://doi.org/10.1002/2013WR014864>, 2014.
- Von Hebel, C., Matveeva, M., Verweij, E., Rademske, P., Kaufmann, M. S., Brogi, C., Vereecken, H., Rascher, U., and Van Der Kruk, J.: Understanding Soil and Plant Interaction by Combining Ground-Based Quantitative Electromagnetic Induction and Airborne Hyperspectral Data, *Geophysical Research Letters*, 45, 7571–7579, <https://doi.org/10.1029/2018GL078658>, 2018.
- 660 Wang, Y., Ksienzyk, A. K., Liu, M., and Brönnner, M.: Multigeophysical data integration using cluster analysis: assisting geological mapping in Trøndelag, Mid-Norway, *Geophys J Int*, 225, 1142–1157, <https://doi.org/10.1093/gji/ggaa571>, 2021.
- 665 Wilson, D., Blain, D., Couwenberg, J., Evans, C. D., Murdiyarso, D., Page, S. E., Renou-Wilson, F., Rieley, J. O., Sirin, A., Strack, M., and Tuittila, E. S.: Greenhouse gas emission factors associated with rewetting of organic soils, *Mires Peat*, 17, <https://doi.org/10.19189/MaP.2016.OMB.222>, 2016.
- Xu, J. R., Morris, P. J., Liu, J. G., and Holden, J.: PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis, *Catena*, 160, 134–140, <https://doi.org/10.1016/j.catena.2017.09.010>, 2018.
- 670 Professional Plus (Pro Plus) Multiparameter Instrument: <https://www.ysi.com/proplus?srsid=AfmBOopf0n-IERY9OtOittyBYt746fkxso2VJyTuD18ARPECc9yi80zw>, last access: 20/01/2025.