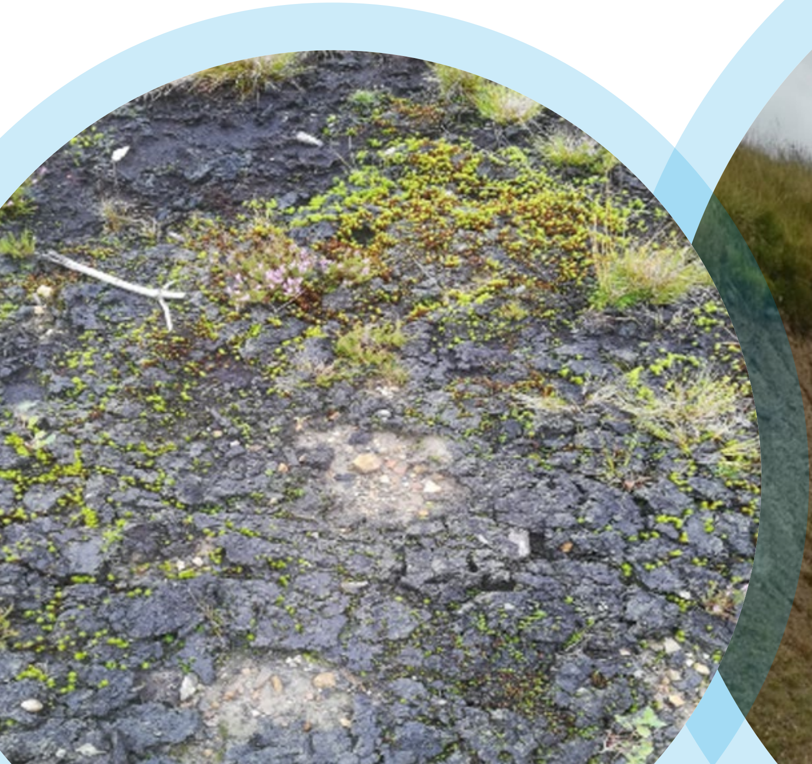
CENTRE OF EXPERTISE FOR WATERS

Effectiveness of construction mitigation measures to avoid or minimise impact to groundwater dependent wetlands and to peat hydrology



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Effectiveness of construction mitigation measures to avoid or minimise impact to groundwater dependent wetlands and to peat hydrology

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Executive Summary

Research question

How effective are the standard methods used during construction to mitigate impacts on hydrology, which may affect groundwater dependent wetlands and peat?

Background

The decarbonisation of energy generation in Scotland has resulted in increased construction on peatlands and wetlands through major infrastructure projects and renewable energy developments in rural areas. These entail potential impacts on the hydrology and ecology of affected peatlands and wetlands. While water related legislation from Scotland (e.g., Water Environment and Water Services (Scotland) Act 2003) and EU (e.g., EU Water Framework Directive 2000/60/EC) promote sustainable water management, little is known about the effectiveness of the mitigation measures after construction on these vulnerable ecosystems. Therefore, the overall aim of the project was to review the effectiveness of standard mitigation measures to maintain the hydrological conditions within peat soils and wetland habitats. The findings of this work will assist the Scottish Environment Protection Agency (SEPA) to provide knowledge and guidance to developers in relation to appropriate construction techniques and enhance practice around avoidance, impact minimisation, habitat creation and restoration.

Research undertaken

This research identified the most common impacts from construction activities as well as the efficacy of different mitigation methods in minimising those construction impacts on peatlands and wetlands. The work involved a literature review of evidence of the impacts of construction on habitats and groundwater in groundwater dependent wetlands and peat. Developers and contractors were consulted regarding the effectiveness of different approaches; on remedial actions taken during monitoring or observation and on identifying ongoing issues. The research was also used to develop policy and regulatory relevant recommendations.

Key findings

Key impacts from construction activities on peatlands

- Lowering of the water table: This can lead to an increased rate of decomposition of peat and, therefore, release of stored carbon.
- Changes to streamflow due to site drainage: This includes drainage ditches which can increase the rate of runoff and areas of hardstanding associated with access tracks and foundations, which can block or alter flow pathways.
- Changes in water quality locally: potential decrease in water quality as a result of changing drainage pathways and decreased water residence time within peatlands.
- Potentially negative implications for water quality downstream as runoff patterns are changed.
- Lowering of water levels and changes in water quality may have a negative impact peatland habitat both in the short and long term.
- Direct habitat loss in the construction footprint.

Key mitigation measures when constructing on peatlands

- Design of infrastructure layout which avoids disturbing deeper peat.
- Ensure adequate drainage under roads/tracks to avoid excessive ponding and allow surface flow.
- Using silt traps to avoid road drainage polluting watercourses.
- Adequate handling of surface layer (acrotelm) is critical. This includes keeping the vegetated turves wet during storage, avoiding stacking of layers and reinstating as soon as possible.
- Monitoring groundwater levels pre, post and during construction activities is key to evaluate the effectiveness of the mitigation measures at a site.

Key impacts from construction activities on wetlands

- Reducing the volume of water infiltrating wetlands.
- Road runoff pollution can enter wetlands and result in contamination of groundwater and surface water.
- Altering the characteristics of the source water by interrupting the water supply from base-rich springs.
- Road constructions adjacent to wetland may result in destruction or disturbance of the wetland plant community and lead to wetland degradation.

Key mitigation measures when constructing on wetlands

- Avoiding construction on wetland where possible.
- Ensuring that wetlands are crossed at their narrowest and shallowest point.
- Reducing soil compaction during construction, by minimising the number of construction vehicles and the frequency of their passing.
- Marking routes with substantial fencing
- Scheduling construction in seasons with least impact to wildlife.

Key determinants of the effectiveness of construction and mitigation techniques, as identified from the feedback from interviews with contractors and operators of construction projects on peat and wetlands:

- Detailed (hydrological and ecological) surveys of the site are required to enable effective planning.
- Detailed design and careful planning in implementation of on-site excavation and construction.
- Adequate level of experience of the contractor and the competence of the operative.
- Early engagement and good communication between stakeholders to ensure timely and effective application of expertise. Knowledge exchange at early stages is key.
- Avoidance of deep peat and sensitive locations during the design process. This involves a full understanding of the whole site to determine orientation, location, access and borrow pit requirements.
- Careful removal, storage and replacement of turves for successful reinstatement of vegetation.
- Adequate water and silt management to avoid pollution of groundwater and surface water.

Recommendations

The main recommendation focuses on the central importance of collecting relevant and detailed site investigation data at an early stage of the application process to enable a full understanding of the site character, and to inform a more accurate design process. This will reduce or avoid impacts on the environment, minimise risk and produce a more informed construction strategy.This will positively impact on the Construction Environmental Management Plan (CEMP) and Construction Management System (CMS), allowing for detailed scrutiny as part of the planning process. This will increase the communication at the pre-application stage between consultants, planners, contractors, Environmental / Ecological Clerk of Works (EnvCoW/ECoW) and other stakeholders.

In addition, recommendations are provided for the following key areas:

Planning: Design and management stage

A detailed site investigation at an early stage of the design process, considering all the infrastructures of the development, is key. These could be e.g., hard standing, access tracks, etc. Consulting an experienced EnvCoW/ECow early in the construction design stage is important/ recommended to minimise any environmental impact of the development. Ideally, the planning should include a site walkover with the EnvCoW/ ECoW, engineer, contractor and any other relevant site investigator.

Topography and hydrology should be mapped in detail to a relevant scale, agreed prior to construction. This is essential to assess slope, contours, geology, location of flushes, water runoff, catchment areas and habitat types. The mapping will inform aspects such as: the correct size of culverts, design of drainage systems and settlement lagoons. The track design should follow that of the topography, where possible, to avoid producing a linear track. Tracks are likely to interrupt hydrological flow and fragment habitats, therefore, advanced site information can inform the track design and layout to avoid or minimise such impacts.

Consolidated guidance

Specific consolidated guidance with input from all relevant stakeholders (e.g., SEPA, NatureScot) should be collated in a single document. The guidance should also include a Standard Operating Procedure document as an appendix for contractors. This will avoid the confusion and information overlap, resulting from multiple documents and improve communication and understanding of contractors.

Water quality baseline data collection

Groundwater quality data should be collected at the early pre-planning stage to establish a baseline. Similar surveys should be carried out during construction and post-construction phase to determine the potential impacts. Groundwater tables should be monitored for at least 12 months before construction to establish the reference variability between seasons, and continued post-construction, to evaluate and mitigate potential impacts of the construction.

Access tracks: Cut and fill

The design of tracks and drainage systems should be carried out by a suitably qualified engineer and take into consideration site topology and location of sensitive habitats downslope. The location of these specific drainage systems should be included within the design in the CEMP/CMS. It is essential that this is a key consideration of the early consultation and design process. This will help avoid landform disruption and water pollution from track drainage.

Access tracks: Floating tracks

Floating tracks should be implemented wherever possible as these tend to cause least disruption and impact on hydrological flows. A typical floating track will use a 5-degree cross slope to avoid slippage, and for higher slope angles, a piled load transfer platform can be considered. Where a subsurface hydrological flow path has been identified, a series of small culverts should be placed under the track to maintain the hydrological regime.

Penstock

Clay plugs should be used to stop the penstock becoming a preferential flow path. A specified minimum number should be recommended by the designer based on drainage surveys. If no clay nor other suitable material is available on site, sandbags can be used.

Storage of turves

A full Standard Operating Procedure should be provided for turf removal as some contractors struggle to handle turves appropriately due to varying skill levels and understanding. The top vegetation layer (300 mm approx.) containing the seed layer should be stripped and placed to the side with the vegetation facing up, and in a single layer. This should be kept moist until reinstatement. Peat below the top layer should be then excavated and laid out beyond the turves.

1.0 Introduction

1.1 Background

The EU Water Framework Directive 2000/60/EC (WFD) and the Water Environment and Water Services (Scotland) Act 2003 promote long-term sustainable water management and aim for good ecological status of surface and groundwater bodies. The UK Peatland Strategy and Scotland's National Peatland Plan (Scottish Natual Heritage, 2015a) demonstrate the long-term commitment to restoration and protection of peatlands. Responsible authorities, managing developments, support the delivery of Scottish Government Climate Emergency 2035 targets to protect Groundwater Dependent Terrestrial Ecosystems (GWDTE). While water related legislation from Scotland (e.g., Water Environment and Water Services (Scotland) Act 2003) and EU (e.g., EU Water Framework Directive 2000/60/EC) promote sustainable water management, little is known about the effectiveness of the mitigation measures implemented after construction on these vulnerable ecosystems. Therefore, the overall aim of the project was to review evidence of the effectiveness of standard mitigation measures used during construction to maintain the hydrological conditions within peat soils and wetland habitats in Scotland. This work explored the key challenges when minimising construction impacts on peatlands and wetlands through the selection of appropriate mitigation methods. The intention is that the findings of this work will assist Scottish Environment Protection Agency (SEPA) in providing knowledge and guidance to developers in relation to appropriate construction techniques and enhance practice around avoidance, impact minimisation, habitat creation and restoration.

1.2 Project aim and objectives

The overarching aim of this project is to determine the effectiveness of standard methods used during construction to mitigate impacts on hydrology which may affect groundwater dependent wetlands and peatland habitats. The specific objectives were:

1. Review evidence on the effectiveness of mitigation measures in protecting groundwater dependent wetlands and peatlands.
2. Gain insights via consultation with contractors and developers on successful and unsuccessful methods, and remedies employed, if monitoring or observation identifies that mitigation procedures have not been appropriate.
3. Provide policy and regulatory-relevant recommendations and disseminate findings to a wider audience to inform future joint actions and approaches.

1.3 Outline of the report

Section 1 introduces the project background together with the aim and objectives. Section 2 outlines the three-stage methodology followed. Section 3 presents the findings of the literature review (objective 1). Section 4 presents findings from interviews with developers and contractors (objective 2). Section 5 provides conclusions and high-level recommendations based on the literature review and interviews (objective 3).

2.0 Research undertaken

A three-stage methodology was adopted:

Stage 1: Assess the impact of construction on habitat and groundwater in groundwater dependent wetlands and peat (for methodology adopted for this stage see subsection 3.1).

Stage 2: Consult with developers and contractors (for methodology see subsection 4.1.)

Due to Covid-19 restrictions during the project's delivery, capturing the experience of developers and contractors was undertaken as a series of individual online interviews, rather than as a workshop as originally proposed. The interviews were recorded and analysed using theme analysis to capture the composite experience of the 17 interviewees.

Stage 3: Provide policy and regulatory-relevant recommendations.

3.0 Literature review on impacts of construction

3.1 Approach

A comprehensive review of reports and grey literature available from Scotland and abroad was carried out. This included information from utility companies and any results of existing trials of mitigating measures. A range of scenarios were considered such as disruption to hydrology due to excavation for borrow pits, tracks (cut and fill and floating), cable trenches, penstock routes, residential developments, foundations and drainage installed for water management. These techniques are discussed in section 3.3.

In addition, a review of published research and guidance documents on the impact of construction activities on the hydrological regime of peatlands and wetlands was carried out. The latter informed the development of a standard list of questions that would form the semi-structured interviews with practitioners with experience of working on peatlands and wetlands.

3.2 Construction on peatland

3.2.1 Characteristics and properties of peatland

Peatlands cover more than 20% of Scotland's total land area with approximately 2 million hectares in total, making it one of the richest countries in Europe in terms of peat (Scottish Natural Heritage, 2015a). Peatlands contribute significantly to terrestrial carbon storage both in the UK and internationally (Grieve and Gilvear, 2008). In Scotland, peatlands store a total of 2735 million tonnes of carbon (Scottish Executive, 2007). Peatbogs are ombrotrophic (rain fed) where a consistently high water table plays an important role in the overall health of peatlands (Rahman et al., 2017). Healthy peatlands are carbon and nitrogen sinks, primarily due to slow rates of decomposition aided by saturation (Sampson and Scholes, 2000). Saturation is maintained by a high water table, which controls both plant and microbial species composition through oxygen availability. Price et al. (2003) reported that a water table 400 mm below ground level in summer months is generally accepted as a critical level for growth of raised bog plant communities. This highlights the significance of the water table in maintaining a healthy peatland. Hydraulic conductivity in peat is anisotropic (i.e., differs vertically and horizontally), and field and laboratory measurements in Canada suggest that hydraulic conductivity of peat can increase by between 2 and 3 orders of magnitude between the acrotelm (surface layer of the peat) and the catotelm (bottom layer) (Quinton et al., 2008). High conductivity results in the formation of peat pipes, where the macropores in peat with a lower bulk density facilitate water movement. Macropores in low to moderately decomposed peat soils are formed by the undecomposed plant material which functions as a channel/pipe system (Lennartz and Lui, 2019). Water predominately flows horizontally through the fibrous acrotelm as the catotelm is mostly below the water table, which forces water to flow horizontally at a rate similar to that of a more granular material, like gravel or coarse sand, and percolates vertically at a lower velocity. In the lower, amorphous catotelm, hydraulic conductivity is very low, similar to more fine-grained material such as a fine silt with hydraulic conductivity in the range of 10^{-5} to 10^{-8} ms^{-1} (Quinton et al., 2008).

3.2.2 Impacts of construction on peatland

Construction on peatlands typically involves excavation activities and establishing access tracks (Figure 1) (see section 3.3. for details) which can potentially alter or block groundwater flow. Thus, construction on peatland may result in negative impacts (Grieve and Gilvear, 2008, Smith, 2016). Firstly, any construction where lowering the water table of peatlands occurs, either directly for deeper excavations such as borrow pits, or indirectly where the groundwater flow is altered or blocked, will result in a loss of carbon given the importance of saturation on limiting peat decay. Additionally, any change in peatland hydrology leads to changes in soil hydraulic conditions in the long-term (Schumann and Joosten, 2008). Processes induced by peatland drainage include subsidence, compaction, fissuring through shrinkage, decomposition (where the organic matter in the peat is lost through oxidisation and mineralisation), and where organic matter is converted into plant-available forms of nitrogen. These processes may decrease the peatland's ability to store and regulate groundwater flow. The formation of fissures impedes capillary water flow and can lead to drying out of peat at greater depths. Drained peat soils can become loosened and fine-grained through increased activity of soil organisms. These may eventually become much more difficult to rewet, given the changes in permeability that have taken place as a result of the processes induced by peatland drainage (Schumann and Joosten, 2008).

Figure 1: Access track to a wind farm.

In Scotland, an increase in macronutrient (dissolved carbon, nitrogen and phosphorus) load in streamflow has been associated with wind farm construction. Forest felling and borrow pits were highlighted as causing a significant disruption (Heal et al., 2019) as these both alter significantly existing flow pathways. Even after careful reinstatement, the ground surface may undergo irreversible changes (as shown in Figure 2). Losses in carbon and other nutrients from the soil have been shown to negatively impact soil fertility, and hence vegetation growth and peat-forming species (Quinton et al., 2010). This, in turn, typically limits plant and animal biodiversity.

In Figure 2, it is observed that the peat spread on top of granular fill material around the concrete base of the wind turbine is bare, cracking and drying out, with no sign of recovery. The habitat at the edge of the turbine base illustrates a thin layer of oxidised peat, with peat loss and with no significant hydrological properties to aid in regeneration of bog vegetation.

Figure 2: An example of the impact of a windfarm on peat.

3.3 Types of construction on peatland

3.3.1 Road construction

Road construction can be categorised into two main construction techniques – cut and fill and floating. In shallower peat depths, cut and fill techniques are generally employed where peat is removed until a suitable bearing layer is uncovered. In deeper peat layers, floating roads are employed where a mixture of granular fill and geotextile placed on top of the peat layer provides a foundation for the road. Pre-loading is sometimes necessary to allow the peat to consolidate, a process in which water is squeezed out of the peat under loading over a period of time to increase bearing capacity. NatureScot (previously Scottish Natural Heritage) and Scottish Forestry have compiled guidance on floating roads. The guidance identifies that floating roads tend to be employed on peat more than 0.5 m depth, although consideration of other site-specific factors are important (Scottish Natural Heritage and Forestry Commission Scotland, 2010).

The type of construction adopted is determined by water table depth within the peat. Scottish Natural Heritage (2015b) compiled a report on tracks constructed in the Scottish Uplands, where the above techniques are discussed. Cut and fill tracks are the most disruptive to groundwater (Stunnel, 2009) as the peat overlying suitable bearing material is removed, and therefore both subsurface and surface drainage are entirely blocked. Gunn et al. (2002) noted that pre-loading of tracks for floating road construction reduces the volume of the acrotelm by approximately 50% during consolidation, which in turn reduces permeability and slows down subsurface groundwater flow through the acrotelm. There was no information on the amount of peat material affected, in terms of distance from the track, although it is likely that reduction in permeability will be localised around the track construction and will depend on factors including: the footprint of the track, the amount of fill material used and anticipated loading conditions. These tracks can also cause ponding on the upslope side which blocks surface water flow. The introduction of alkaline aggregate fill material can have an impact on water quality (Labadz et al., 2010) especially as typical bog species require acidic conditions. Given that the footprint of any floating road must consider the ability to spread the traffic load over a larger area, more of the peat is disturbed. Both types of road construction can influence groundwater flow and can result in the drying of peat and oxidisation.

Cut and fill tracks result in a complete loss of habitat and can cause large scale disturbance and fragmentation of habitats (Scottish Natural Heritage, 2015b). Fragmentation of habitat is also an issue with floating roads, however, much of the peat stays intact, albeit with a reduced permeability (Scottish Natural Heritage, 2015b). Imported fill material, depending on its geological origin, can also encourage additional plant species to grow. This may be to the detriment of the existing peatland habitat (Stunnel, 2009).

3.3.2 Foundations

Foundations, either temporary or permanent, are required where structures are constructed on peatlands. In the case of wind farms, foundations are normally constructed by using temporary cofferdams to excavate layers of peat until a suitable bearing stratum is found. Cofferdams, which are enclosures built to create a dry working environment (by pumping water out of the enclosed area), are required to keep the excavation dry (Lindsay and Freeman, 2008, Stunnel, 2009). The concrete base is cast and then more backfill is laid on top of the concrete foundation.

Similarly, with cut and fill road construction, by removing the peat layers entirely and using cofferdams, the subsurface flows are blocked entirely. The exposed peat faces will drain and oxidise as a result of being exposed to the atmosphere (Stunnel, 2009). Additionally, peat surrounding foundation excavations is also drained to avoid uplift on the foundation (Lindsay and Bragg, 2005). The amount of peat that is dewatered will be site specific. This is likely to cause further drying out of peat deposits surrounding foundations.

Excavating peat in large volumes causes a direct loss of habitat similar to the loss of habitat associated with cut and fill road construction. If concrete pads are left exposed, it is likely that the concrete will attract a bryophyte flora uncharacteristic of the blanket mire. However, this has no potential to spread into peatland areas (Stunnel, 2009). Although excavated peat is reinstated following construction of foundation, disturbance to peat results in negative impact to habitats.

3.3.3 Borrow pits

Borrow pits are excavations that are used to source fill material to reduce the reliance on imported fill. Borrow pits are excavated to a depth to access suitable construction material that underlies peat deposits. As with other excavations, lowering the water table during the creation and operation of borrow pits will cause the surrounding areas of peat to dry out, oxidising the upper layers. Exposed faces will also dry out and oxidise. To avoid water ingress to the quarrying area, surface and subsurface water may be diverted e.g., upslope cut-off drains which carry the water a short distance around to downslope of the borrow pit then discharge to the ground in a diffuse manner via a swale or similar.

Excavation results in a total loss of habitat and can be significant in volume depending on the depth of peat excavation that is required.

3.3.4 Trenches and ditches

Trenches can be constructed to lay pipelines, cables or for drainage ditches. Holden et al. (2006) suggested that the degradation of peatlands associated with the installation of open-cut drainage ditches (see Figure 3, as an example) has been one of the most significant threats to the sustainability of both upland and lowland peatlands. Trenches often provide a preferential path for drainage of water from within the peat body, diverting away from previous flow paths. To avoid this, it is standard practice to require clay plugs at intervals along the trench with the spacing determined by slope.

Figure 3. Culvert maintaining surface water flow.

The depth of the ditch, the distance between ditches and the permeability of the peat can have a significant impact on groundwater flow, as noted in a review of peat drainage by Price et al. (2003). In fibrous peat, water may be drawn to the ditch from up to 50 m away, although there was little to no significant impact of water movement in more decomposed peatlands (Boelter, 1972). This is due to the low hydraulic conductivity in more decomposed peat compared with fibrous less degraded peat.

Excavation can result in a total loss of habitat. Furthermore, drainage ditches on slopes may significantly increase the risk of erosion, causing more habitat loss. A study in the UK has also shown that an increase in the rate of runoff as a result of drainage ditches can severely impact the local water quality, with catchment waters showing a higher concentration of dissolved organic carbon (DOC) (Wallage et al., 2006).

3.4 Mitigation measures and their associated impact on construction on peatland

Mitigation methods to reduce the impact of construction on peatland are listed below:

- Avoid deep peat: avoid areas of deep peat for road construction as well as construction/excavation for all infrastructure. This should be considered during the design stage of the project.

- To avoid peat excavation: use piled foundations or controlled modulus columns. This would be most suited to sites where peat depth is significant, and the structure being supported is sensitive to significant settlement. This will present challenges, however, including costs and temporary works.
- For floating roads: ensure adequate drainage underneath the road to avoid excessive ponding and allow some access for surface water flow. In remote areas where maintenance access may present challenges, it might be more suitable to install drainage that requires less maintenance, such as secured in place liners, as opposed to corrugated pipework which is more likely to become blocked by debris. A regular maintenance schedule should be considered to avoid potential issues with blockages. Inspections should follow periods of intense rainfall or in areas of significant changes to may increase runoff.
- Avoid using borrow pits to source fill material unless absolutely necessary.
- Use silt traps to prevent runoff polluting watercourses (Figure 4).
- Careful removal of the acrotelm layer during excavation to preserve the integrity of the vegetated peat turves.
- Keep vegetated peat turves wet during storage and reinstate as soon as practicable after excavation. Store the right way up and only in a single layer. Always avoid stacking.
- Block historic drains to prevent further drying out of peatlands.
- Monitor groundwater levels pre, post and during construction activities.
- Carry out continuous monitoring post-construction.
- Batters are the side slopes that connect the road surface to the contour of the surrounding land. Use a shallower angle in track edges of cut tracks and in batters to enable revegetation.
- Undercut the vegetated layer above steep cuts or batters, then reprofile to a shallower angle and roll the vegetated layer over and peg down. A 1 in 2 (or 50%) slope is considered to be the steepest slope that will still enable vegetation growth. Studies have shown that soil erosion, and hence the ability for vegetation to grow, increases almost linearly with slope gradient (Kapolka and Dollhopf, 2001). Measures to prevent erosion, such as using geotextile, may encourage more vegetation growth.
- Place turves neatly in close contact.
- Peg turves into geotextile matting on slopes.
- Reseed with nurse crop grass and bog vegetation mix during growing season. This is only where there

Figure 4: Left panel: Silt-trap. Right panel: Silt trap out of line with culvert.

are not sufficient turves to reinstate the surface vegetation.

- Introduce sphagnum propagules, in instances where there are not sufficient turves. For this to be effective, the water table needs to be restored (within 40 cm). It is important to ensure that high rates of evapotranspiration do not occur, to avoid propagules drying out before becoming established. Mulch can be used to keep the ground from drying out and a loose layer of brash can be used to reduce evapotranspiration of propagules.
- An alternative method, when there are insufficient turves, is carpet spreading of heather tips and peatland seeds harvested from nearby donor sites.
- Taper the height above existing ground level where excavated peat is reinstated so that it blends into adjacent land and compress the edges to avoid lateral water loss through bare exposed 'cliffs'.

3.5 Construction on wetlands

Wetlands in the wider countryside (non-designated sites) are protected through legislative and regulatory mechanisms established under the European Water Framework Directive 2000/60/EC (WFD), Nature Conservation (Scotland) Act (2004) and Habitats Directives for Natura sites (Scotland's Environment, 2014).

3.5.1 Characteristics of wetlands

Construction on or near wetland environments has the potential to alter the wetland's physical and chemical balance which, in worst cases, could extend to miles from the construction site and persist for years after the construction. Changes in physical and chemical balance could negatively impact the biological and ecological processes and functioning of wetlands. Twenty wetland water supply mechanisms (WETMECs) have been identified by Wheeler et al. (2009), in which interruption/reduction of each element could lead to a loss/change in the type of wetland vegetation. Depending on the type of construction, impacts can vary (Table 1).

Monitoring the effectiveness of wetland mitigation measures relies on the collection of data (short and long-term) related to mitigation measures after construction. Two main approaches have been introduced to monitor the effectiveness of wetland mitigation measures, namely:

(i) Hydro-GeoMetric (HGM) (classifying the wetlands into a narrowly defined regional subclass according to their common hydrological, soil, and vegetative characteristics). This approach is a practical geomorphologically based design tool that can also assist in the planning of wetland restoration projects and relies on subjective categorical or qualitative data (Richardson, 2005).

(ii) Ecological Functional Assessment (EFA) is a quantitative functional assessment technique that groups wetland functions into five ecosystem-level categories of: i) hydrologic flux and storage, ii) biological productivity, iii) biogeochemical cycling and storage, iv) decomposition and v) community and wildlife habitat. A set of indicators representing the five categories in the impacted wetland are selected and measured. These thresholds are then used to assess whether any form of compensation for wetland habitat loss is required, or not, based on a comparison from reference sites (Richardson, 2005).

The above techniques are applied post-construction to monitor the effectiveness of mitigation measures during construction, or if no mitigation measures were in place during construction, will inform what compensation is required as a result of wetland habitat loss.

Different types of construction on wetlands and their associated impacts are summarised below. In addition, a discussion is provided summarising mitigation measures and their associated impact on wetland habitat and groundwater.

3.5.2 Pipeline construction

Pipeline construction can result in multiple and interconnected impacts on wetland habitats and their groundwater dynamics (e.g., Yu et al., 2010). Therefore, assessing the impact of pipeline construction is key as a single pipeline project can cross a number of wetlands resulting in cumulative impacts on a wide ecosystem. In addition, if a pipeline construction is not appropriately designed, it could become a preferential drainage path, diverting drainage from original flow pathways and thus altering groundwater flow and recharge.

Soil and groundwater hydrology of wetlands are directly affected by pipeline construction activities. These effects include increasing soil bulk density as well as reduction in porosity and hydraulic conductivity (Olson and Doherty, 2012). This interrupts the hydraulic connection between surface water and groundwater and prevents natural water percolation into the groundwater system. This interruption in turn produces changes in soil pH, organic matter content, and nitrogen content at, or in the vicinity, of the pipeline trench. If not protected, disturbed soil along the pipeline trench is vulnerable to erosion and this could lead to destruction of the wetlands ecological function. In addition to the effects on groundwater recharge and flow, changes to soil chemical properties described above (e.g., pH, organic matter content and nitrogen content) are likely to alter groundwater quality.

Table 1 Twenty wetland water supply mechanisms (WETMECs) Wheeler et al. (2009)

Wetland water supply mechanisms' (WETMECs)	Key characteristic
1. Domed Ombrogenous Surfaces ('raised bog' sensu stricto)	Summer-wet, often domed surface, remote from and/or elevated well above telluric water tables (WT); often over low permeability deposits.
2.Buoyant Ombrogenous Surfaces (quag bogs)	Quaking, summer-wet surface or raft elevated slightly above telluric water tables; often in basins, over potentially high or low permeability deposits.
3.Buoyant, Weakly Minerotrophic Surfaces ('transition bogs')	As [2], but surface little above influence of telluric water. [2]and [3] may both occupy the same basin, [3] as a lagg fen .
4. Drained Ombrotrophic Surfaces (in bogs and fens)	Surface 'dry' year-round – telluric water in drains well below surface. No obvious or proximate Groundwater (GW) sources. Often over low permeability material.
5. Summer-Dry Floodplains	Surface often fairly dry in summer, but wet or flooded in winter. May experience episodic flooding from watercourses. Peat infill 'solid' and low hydraulic conductivity (K) (cf. [6]).
6. Surface Water Percolation Floodplains	Surface usually quite wet in summer and wet or flooded in winter. Peat top-layer often loose, sometimes buoyant and mostly high K.
7. Groundwater Floodplains	Floodplains of GW-fed water courses, often rather dry. Often complex alluvial sequence with only shallow peat. Water supply and relationship to river and aquifer mostly uncertain
8. Groundwater-Fed Bottoms with Aquitard	Troughs or basins, usually on quite deep peat upon aquitard; if on floodplains, usually isolated from river. WT often below solid surface. Often marginal springs/seepages. Distinguished from [16] by topography and deeper peat.
9. Groundwater-Fed Bottoms	Similar to [8] but no aquitard and marginal springs / seepages often less evident. GW supply often inferred from hydrogeological data. Distinguished from [12] by topography and deeper peat.
10. Permanent Seepage Slopes	Summer-wet surface, usually sloping and shallow peat; springs / seepages usually visible, over permeable substratum.
11. Intermittent and Part-Drained Seepages	As [10] but WT well below surface in summer or year-round; also more often on flat surfaces or in sumps. Latter are transitional to [9] but have shallower peat.
12. Fluctuating Seepage Basins	Small sumps with strongly fluctuating WT, often from well below surface to flooded, which may relate to aquifer levels. Like [11] but topography permits sustained inundation.
13. Seepage Percolation Basins	Unconsolidated (quaking / buoyant) surface in GW-fed basins and sumps etc. Similar surface to [6] but GW-fed, and to [14] but flatter and more 'water collecting'.
14. Seepage Percolation Troughs	Soft or quaking (rarely buoyant) surfaces in GW-fed valley heads and troughs. More sloping than [13] (which may occupy sumps embedded in [14]).
15. Seepage Flow Tracks	GW-fed flow paths in mires, often embedded in [14] but occasionally alone. Unconsolidated watery surface
16.Groundwater-Flushed Bottoms	Surfaces in GW-flushed valley heads and troughs. Often similar to [14] but over aquitard and often with thinner peat. Marginal springs / seepages often evident.
17. Groundwater-Flushed Slopes	GW-flushed slopes (rarely flats) with thin peat over aquitard, below springs or seepage line (often narrow).
18. Percolation Troughs	Like [14] but fed mainly by relative growth rate (RGR) or streams, or importance of GW not clear. May be some GW outflow from a minor, superficial aquifer.
19. Flow Tracks	Like [15] but fed mainly by RGR or streams, or importance of GW not clear. May be some GW outflow from a minor, superficial aquifer.
20. Percolation Basins	Like [13] but fed mainly by RGR or streams, or importance of GW not clear. Some inflows may be sourced from GW outflows above the site.

Pipeline construction is likely to negatively impact wetland habitats both close to the construction as well as further away into the wetland ecosystem.

Disturbance of a wide range of plant species due to the construction of pipelines in wetlands has been reported (Yu et al., 2010). If hydrological links from base-rich springs or seepages are interrupted, the wetland communities dependent on this would be negatively impacted. According to Olson and Doherty (2012), construction of natural gas pipelines resulted in more compact and drier soils. Similar disturbance to plant species in the vicinity of road construction adjacent to wetlands was reported by Li et al. (2014). Along the trench, shoots and roots of plants are eradicated, and the surrounding plant roots are also affected. Construction workers trampling on plant species in vicinity of the pipeline area result in destruction of plant shoots while roots have proven to remain active (Li et al., 2014).

Unmanaged pipeline construction in wetlands can result in the total local extinction of rare species or loss of local genotypes. Conversely, construction can result in the establishment and spread of exotic species which may displace native species (Findlay and Bourdages, 2001; Li et al., 2014). Should aquatic species exist in the wetland, pipeline construction can affect biological habitat and fish behaviour and physiology (Lévesque and Dubé, 2007), with changes to groundwater quality also disturbing fish populations (Yu et al., 2010). Consequently, this may result in the avoidance movement by fish, altered distribution of populations (Newcombe and Jensen, 1996) and reduce population sizes and species numbers.

In a study by Olson & Doherty (2012), it was observed that the mitigation measures followed during the construction of a natural gas pipeline through a wetland resulted in a net increase in species diversity and quality at sites with invasive species and/or low initial vegetation diversity.

3.5.3 Road construction

Road construction interrupts hydrological paths and directly impacts groundwater and habitats depending on groundwater dynamics.

Short-term impacts of highway construction on wetlands include increase in salinity, phosphorus concentration and sediment delivery. Moreover, changes in the macrophyte community composition, algal productivity as well as negative effects on macroinvertebrates and fish are only a few of the aspects of ecological impact of road construction (Richardson et al., 2003). Moreover, given the multiple interlinked impacts by roads on animal behaviour and survival, it is unlikely that ecological effects of roads can ever be completely mitigated or remediated, as suggested by the review by Trombulak and Frissell (2000).

Long-term impacts of road construction on wetlands have been linked a deterioration of groundwater quality. Road features (e.g., the road sub-base) can act as a preferential drainage route for surface water, delivering poor quality surface water to the groundwater body sustaining the wetland. As observed by Wang et al. (2018) roadside leaching of heavy metals and ions (e.g., Na^+, K^+ and Cl^-) can cause groundwater pollution in the vicinity (15-100 m distance from the road). The longer the operation time of the road, the longer lasting the impact on groundwater quality.

3.5.4 Overhead powerline construction

Overhead powerline construction creates relatively less impact compared to pipelines and roads in terms of area of land affected/modified. However, although the use of piled foundations reduces the overall negative impact, some towers are built on concrete platforms which are not piled. Therefore, the impact of powerline construction on the wetland groundwater dynamics (due to the towers) and the habitat (due to the electric wires) must be taken into consideration.

Although land disturbance resulting from power line construction is less than that resulting from pipeline and road constructions, groundwork associated with construction of power transmission towers imposes risks to the physical and chemical balance in soil and water. Where power transmission towers are installed along power line corridors, changes in the hydrologic regime of wetlands may occur. Impacts would be similar to the impacts reported for pipeline and road construction projects. However, overhead line towers are spaced at intervals and are not continuous so the effects on hydrology may be less than in pipeline or road projects (e.g., Woo, 1979). Nevertheless, without careful protection of groundwater fed hydrological pathways, hydrological flows could be interrupted during construction and/or operation.

The impact of overhead powerlines on the wetland habitat/ecology was found to increase death and injury of birds due to electrocutions and collisions with wires (Richardson et al., 2017). In addition, power line construction has been reported to result in abandonment of territories where the risk of electrocution is high (Sergio et al., 2004; Richardson et al., 2017); increase risk of botulism from bird carcasses (Malcolm, 1982; McNeil et al., 1985; Richardson et al., 2017); and increase scavenger activity and population size of scavengers along and near the power line corridor (Richardson et al., 2017).

3.5.5 Foundations

The construction of foundations is an inseparable part of any form of construction in wetlands. Permanent foundations include wind turbine foundations, transmission tower foundations, and building foundations for substations, housing and commercial buildings. Temporary foundations include any form of foundation to provide support for temporary constructions. The impacts on groundwater hydrology and habitat result from the different construction activities such as placement of foundations, transportation of materials, excavation and the use of inadequate construction materials.

The movement of groundwater within a wetland, through processes such as capillary attraction, is an important factor in maintaining soil biology (Adu Gyamfi et al., 2018). The construction of foundations may negatively influence the capillary zone and, as a result, adversely affect soil biology around the impacted area. Also, the associated transportation of materials for foundation construction could result in significant habitat damage within the wetlands.

Excavation during the construction of foundations creates drainage pockets with negative impacts on the groundwater hydrology. Often, concrete is used for construction of foundations. Depending on the nature and location of the wetland, the cement type could be unsuitable for the local environment's pH. As a result, if consideration is not given to appropriate selection of cement type, in accordance with the soil pH, harmful chemical reactions between concrete and the wetland chemical components could take place and may result in the release of toxic substances into the groundwater system (Avili, et al., 2019).

3.5.6 Borrow pits

Sourcing fill material for construction purposes within the wetlands results in the creation of borrow pits (an example of a reconstruction of a borrow pit, Figure 5). Although sourcing fill material from within the wetland eliminates the ecological and biological impacts of transporting unwanted exogenous species into the wetland environment, borrow pits are known to be associated with a negative impact on habitat and groundwater.

The groundwater table in the wetland is often higher than the water table in the borrow pits (e.g., Skaggs et al., 2007). As a result, water within the wetland drains into the borrow pits until a hydrological equilibrium is reached. This change affects the transport of water and nutrients within the wetland ecosystem, which may result in reduction or even termination of biological activities that rely on nutrients carried in the water. Additionally, borrow pits if designed inappropriately could become a barrier for wildlife moving across the wetland.

Figure 5. Restoration at the borrow pit showing signs of early recovery with vegetative growth such as *Juncus* spp. grass varieties, and some *Polytrichum* spp. and *Sphagnum* spp. Juncus species colonisation and dominance in some settings is problem due to the hollow stems of the reeds enabling transport of oxygen from above the ground to below, leading to higher rates of decomposition of soil organic matter. Controlling reeds is part of the post reinstatement/restoration maintenance.

3.6 Mitigation measures and their associated impacts on construction on wetlands

Mitigation measures during and after construction on wetlands have been identified to reduce risks and potential impacts on biodiversity and ecosystem services. For mitigation measures, four areas have been taken into consideration; avoidance of sensitive habitat, minimisation of impacts, restoration of habitat and offsetting project impacts, if necessary (Sahley et al., 2017).

3.6.1 Pipeline and road construction

Suggested steps to minimise short-term impacts of pipeline and road construction projects across wetland construction are summarised below (see Krone, 1985):

- Avoid wetland site selection for permanent and temporary infrastructure and access routes.
- Minimise clearing on the Right-Of-Way (ROW - the stretch of land to be used for construction and operation of the pipeline) and use existing ROW, if available.
- Cross wetland at its narrowest and shallowest point.
- Plan construction outside of wildlife breeding season.
- Design and plan construction where water is at its lowest level to minimise turbidity.
- Carry out immediate stream bank repair following construction to control erosion and saltwater intrusion (in coastal areas).
- Contour using bulkheads, culverts, earthen dams, wires etc., to re-establish drainage pattern.

- Reduce soil compaction during construction by minimising the number of construction vehicles and their frequency of pass.
- Backfill trenches in timely manner to restore contours and avoid canalisation.
- Segregate topsoil from the trench spoil and replacing after completion of construction.
- Revegetate sites. This requires provision of freshwater flow, with the appropriate hydro-chemical characteristics into areas disturbed by construction to allow re-establishment of vegetation.
- Where roads or pipelines could interrupt hydrological pathways, integrate measures to maintain the flow to receiving wetlands. For long-term mitigation measures, post-construction environmental monitoring plays a key role to inform adaptive management.

3.6.2 Overhead powerline construction

Mitigation measures to minimise the impacts of power line construction on biodiversity were presented by Richardson et al. (2017):

- Reroute to avoid species or communities of conservation concern or use established corridors.
- Schedule construction in seasons with least impact.
- Use native species seeds for regeneration of vegetation in affected areas. This will apply to revegetation in all construction projects.
- Remove topsoil prior to construction and replace post-construction to maintain microbial communities in soil. Where possible, remove turves, store the right way up and replace as soon as possible.
- Reduce the size of disturbed area.
- Control invasive species throughout the life of a project.
- Avoid pollution and unnecessary human activities.

3.6.3 Foundation construction

Mitigation measures related to wetlands for construction of foundations are provided below:

- Ensure appropriate design of foundation by considering groundwater regime at the construction site (Adu Gyamfi et al., 2018).
- Prevent the area excavated for foundation construction acting as a drainage pocket for groundwater within the wetlands. This can be done by installing watertight material such as a damp-proof membrane around the excavated area.
- Select appropriate cement type for foundation construction depending on the wetland pH, as it is proven that concrete can have a significant impact on wetland water chemistry (Wright et al., 2017).
- Reduce foundation construction time and conduct the construction in drier months of the year to minimise impacts of construction on the wetlands (Richardson et al., 2017).
- Ensure suitable transportation of the material to the construction site to minimise negative impact to the wetlands. In some cases, the most suitable method of transportation may be using air transport (via helicopter).

3.6.4 Borrow pits

A summary of mitigation measures related to wetlands for borrow pits is provided below:

- Consider local typology and hydrology when locating borrow bits to avoid borrow pits becoming a destination for runoff that feeds the wetland.
- Carry out pre-construction monitoring (e.g., for a year approximately) and analysis to avoid creation of borrow pits along the main corridor for wildlife movement within the wetlands.
- Carry out post-construction monitoring to evaluate impacts resulting from borrow pits.
- Where appropriate, artificially create wetlands in borrow pits, to minimise negative impacts of the borrow pits (e.g., Kuczynski and Paszkowski, 2012).

3.7 Conclusions from the literature review: summary of impacts on peatland and wetlands

In conclusion, the most significant impacts construction activities will have on peatlands include:

- Lowering the water table. This can lead to an increased rate decomposition and therefore release of stored carbon.
- Changes or interruptions of the hydrology within the peat from new/deepened drainage ditches associated with roads or other infrastructure.
- Change in the downstream water quality as a result of changes to runoff patterns.
- Impacts on peatland habitat by changing water level and water quality.

The most significant impacts construction activities will have on wetlands include:

- Changes to volume and characteristics of the source water by interrupting the water supply from a base-rich spring.
- Destruction or disturbance of plant species in the vicinity of road construction adjacent to wetlands.
- Erosion of disturbed soil along the pipeline trench can lead to destruction of the wetlands ecological function of providing wildlife habitat, controlling erosion, and storing and purifying water.
- Road runoff pollution and increased sedimentation during construction phase can enter wetlands and result in contamination of groundwater.

4.0 Interviews

4.1 Approach

Semi-structured interviews were undertaken with 17 practitioners (7 hydrologists/ ecologists, 5 environmental consultants, 2 contractors, 2 planners, 1 developer) to gain feedback on their experience with techniques and mitigation measures when designing a construction on GWDTE (Groundwater Dependent Terrestrial Ecosystems, e.g., wetlands) or peatland. The interview questions (see Appendix A) were developed based on the literature review findings.

The 17 interview responses have been combined under topic headings and can be found in Appendix B. The interviews have been summarised in this way so that comments from the interviews are not attributed to an individual interviewee and to mimic a coherent discussion as would have been possible in a workshop. Under each section, a summary of key points related to the level of effectiveness of construction and mitigation has been compiled and incorporated into an evaluation matrix based on the interviews conducted.

4.2 Findings

The interviewees identified some of the key issues relevant to the effectiveness of construction techniques on peatlands and wetlands in terms of impact on groundwater and on habitat. The interviews covered both the impact of construction techniques and experience of mitigation. Combining these interrelated discussions resulted in the occurrence of several key issues.

The key issues related to the effectiveness of construction and mitigation, as identified by the interviewees are presented in Figure 6. The number shown in the figure is the number of times these are identified as key to effectiveness in an interview. The combined key issues relating to the effectiveness of construction and mitigation (Figure 6 A), highlight that detailed design and careful planning was a key consideration throughout the interviews. Figure 6 B illustrates issues that impact the effectiveness of construction techniques and Figure 6 C illustrates issues that impact the effectiveness of mitigation techniques. Thus, Figure 6 B and C present a further breakdown of the discussion with the interviewees which shows that detailed surveys of the site are required to enable effective planning. The level of experience of the contractor and the competence of the operative was identified as key for the effectiveness of implemented approaches. Communication between all the stakeholders was considered important together with early engagement of all stakeholders throughout the process. Sharing of knowledge and early engagement of the key parties ensured that expertise was shared at the best time to be most effective.

Avoidance of deep peat and sensitive communities and habitats was identified as a key part of the design process. This involved a full understanding of the site location to determine orientation, location, access and borrow pit location. Careful removal, storage and replacement of turves was identified as key for successful reinstatement of vegetation. These techniques alongside water management and silt management were all discussed and emphasised as important factors for effectiveness by the participants.

4.3 Conclusions from interviews: Key determinants of the effectiveness of construction and mitigation techniques

Key determinants of the effectiveness of construction and mitigation techniques identified by interview participants were:

- Detailed design and careful planning prior to implementation. This should include early engagement of the contractor and EnvCoW/ ECoW during the design phase and construction programming. Interviewees identified the importance of the level of experience of the contractor and the competence of the operative.
- Detailed surveys of the site are required to enable effective planning. Construction activity programming and planning contingency are needed to accommodate change in weather, space to microsite and temporary access options.
- Communication between and early engagement of all the stakeholders together throughout the process. This sharing of knowledge and early engagement of

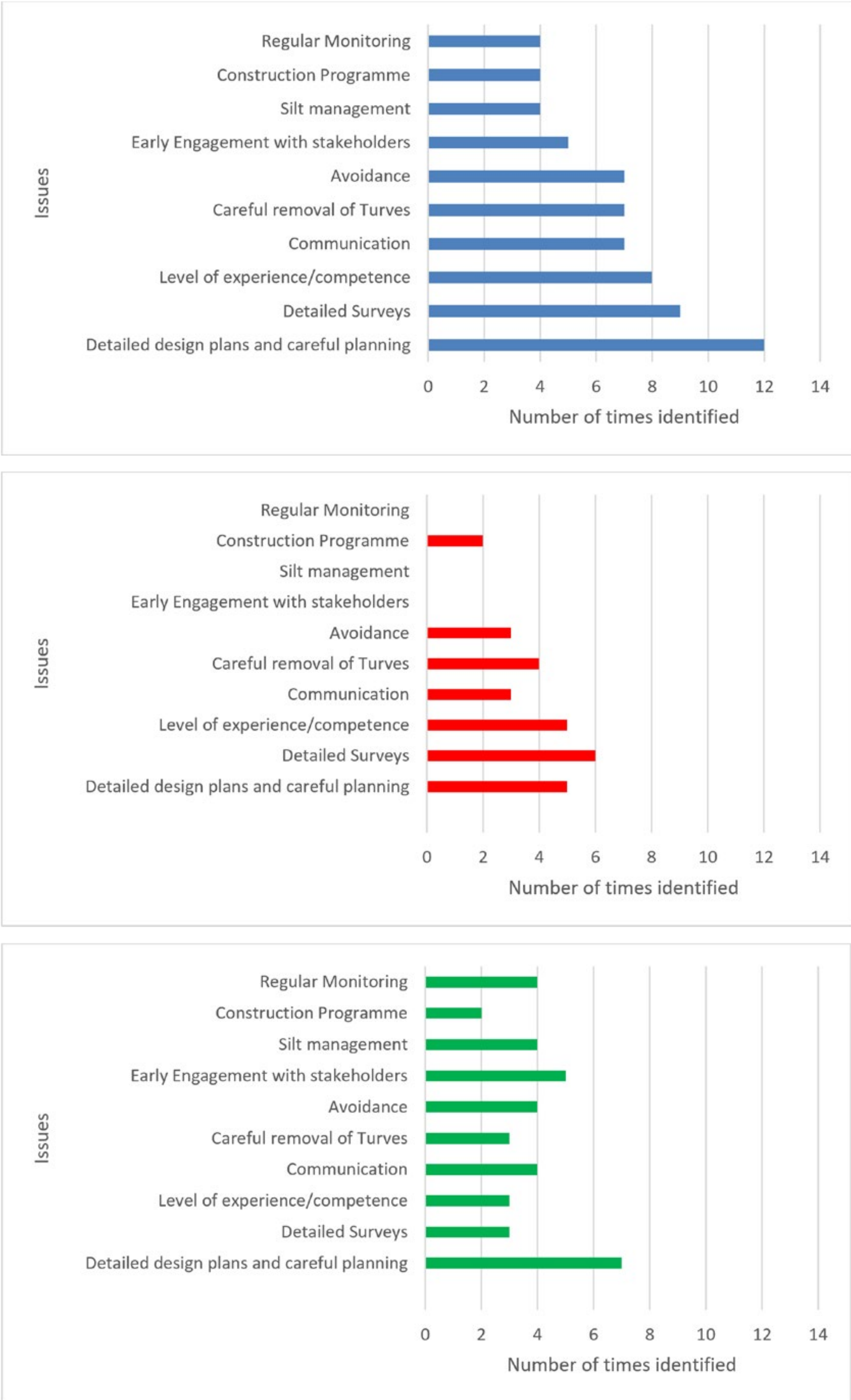

Figure 6. A) (Top panel) Key issues related to the effectiveness of construction and mitigation as identified by interviewees. B) (Middle panel) Issues that impact the effectiveness of construction techniques. C) (Bottom panel) Issues that impact the effectiveness of mitigation techniques.

key parties ensures that expertise is applied at the best time to be most effective.

- Avoidance of deep peat and sensitive locations during the design process. This involves a full understanding of the whole site to determine orientation, location, access and borrow pit requirements.
- Careful removal, storage and replacement of turves for successful reinstatement of vegetation. Separating turf, acrotelm and catotelm for effective reinstatement and revegetation, and to ensure necessary hydrological conditions are met for successful reinstatement.
- Water management and silt management. Drainage design and implementation including how to avoid creating preferential flow paths when dealing with slopes for track drainage.
- Monitoring baseline and post-construction condition in the medium and long-term, for reinstatement, mitigation and habitat restoration.

5.0 Conclusions and recommendations

The aim of this study was to determine the effectiveness of standard methods used during construction to mitigate impacts on hydrology, which may affect groundwater dependent peatland and wetlands habitats. The conclusions reached in this study are presented according to objectives 1 to 3 (see section 1.2) in subsections 5.1 (literature review), 5.2 (interviews) and in 5.3 key recommendations are made.

5.1 Effectiveness of mitigation measures in protecting groundwater dependent peatlands and wetlands

Construction activities such as linear infrastructure projects, wind farms, housing developments etc., all have the following techniques in common; a mixture of cut and fill and floating tracks, excavations for foundations, or to source fill material, and trenching for drainage/ laying utilities. All these activities alter the hydrological regime to varying degrees by either blocking or partially blocking surface and subsurface water flows. In peatlands, lowering of the groundwater table by altering surface and subsurface water flows will result in oxidisation of the peat and losses in stored carbon. Linear infrastructure, such as cut and fill roads have the greatest impact. By removing the peat, the flow paths are cut off entirely. The impact of excavations can be varied, mostly depending on the quality of reinstatement as well as the applied mitigation measures, such as separating catotelm and acrotelm layers. Any foundation is likely to have some impact, but the impact is much lower than linear infrastructure because water tends to flow around the obstruction and therefore some flows are maintained. These impacts are also localised around the foundation, although there is little research to indicate how much of an area surrounding a foundation is impacted. Similarly, with borrow pits, any impacts will be localised. Trenches can have a significant impact, given the likelihood that these will become preferential flow paths for drainage and interrupt existing flow pathways, potentially changing both the volume and chemical characteristics of source water to a wetland. Research has shown that the groundwater table can be affected up to 50 m away from drainage trenches.

5.2 Feedback from developers and contractors on their experience with techniques and mitigation measures when designing a construction on peatland or wetlands

The 17 developers were interviewed providing a broad range of experience and observations on current mitigation methods for construction on GWDTE. The key issues identified within the interviews supported the main findings from the literature review:

- There is a need to inform a more accurate design process, which includes obtaining detailed site investigation data, ultimately leading to a more robust design at an early stage, as emphasised throughout the interviews.
- Detailed site investigation surveys are required to characterise a site and to enable effective planning and implementation.
- The level of experience of the contractor and the competence of the operative was identified as a key consideration when ensuring the effectiveness of the implementation of approaches contained within the standard guidance from multiple key agencies.
- Early engagement and communication between all the stakeholders throughout the process is a key consideration. Pre-application engagement and sharing of knowledge at an earlier stage ensures that the right expertise is applied at the right time to be most effective.
- Careful removal, storage and replacement of turves was identified as a key consideration for successful reinstatement of vegetation. These techniques, alongside water and silt management were discussed and emphasised as important factors for effectiveness of mitigation methods by the participants in the interviews.

- A more detailed topography and hydrology survey to allow for more accurate mapping (at a pre-determined scale) is often needed. This is essential to assess slope, contours, geology, location of flushes, water runoff, catchment areas and habitat types. This will then inform aspects such as the correct size of culverts, design of drainage systems and settlement lagoons.
- The track location design should follow that of the topography, where possible, to avoid producing a linear track. Tracks are likely to interrupt hydrological flow and fragment habitats, therefore advanced site information can inform the track design and layout to avoid or minimise such impacts.
- Avoidance of deep peat and sensitive locations or receptors during the design process.
- Consider water management and silt management plans through detailed drainage design.

5.3 Recommendations to inform future joint actions and approaches

Recommendations have been developed following data analysis from the interviews and the literature review. A synthesis of the data collected on mitigation measures to minimise negative impact of construction on peatlands and wetlands resulted in the following recommendations.

5.3.1 Planning: Design and management stage

- Place more emphasis on site investigation prior to the final construction design: this should happen early in the planning. Developers and contractors stated that current site investigations prior to construction was not adequate. To ensure compliance, this can be part of planning recommendations where an additional level of (or more detailed) site investigation is carried out to assist the design and decision on the location of turbines, hard-standings, tracks, cables, pipelines, trenches and other infrastructure. This would ensure that the design considers avoidance of sensitive areas and maintains the hydrological flow paths on site and follows avoidance in the first instance, and not retrospectively.
- Undertake detailed mapping of topography and hydrology at an appropriate scale: this should allow features to be placed adequately. For instance, the proper design of tracks should follow the topography and where possible avoid linear tracks.
- Consult an experienced Environmental Clerk of Works early in the construction design stage: this will help minimise any impact of the development on the ecology and environment. A site walkover is advised during the planning process instead of afterwards. This would also be useful when micro-siting turbines and tracks etc. The earlier that this is done, at pre-planning and not post-consent, the more robust a plan that can be put in place, as opposed to the possibility of micro-siting at a later stage where a consultation process may be initiated, which wastes time and resources.
- Improve CEMP (Construction Environmental Management Plan) and CMS (Construction Management System): As part of the pre-planning design phase, more detailed information is required including plans or maps of all sensitive areas and descriptive CEMP and CMS should be provided. The CEMP/CMS should include detailed surface water management procedures in order that these are scrutinised and, where possible, mapped out or installed at the pre-construction stage. It is noted that, as construction starts, this is a fluid process which will require constant review, additions, and improvements. Currently, this is mostly done after planning has been granted. Therefore, it is recommended that this is done in the pre-planning phase; with scrutinisation and possible conditions applied. Design should include the separation of clean water from "dirty" water from construction activities, inclusion of lagoons (settlement ponds), and silt fencing etc. It was noted that all interviewees followed the present guidance.
- Choose machinery with characteristics appropriate for the site conditions: Certain types of machinery and size should be specified early in the design and CEMP/CMS process to ensure that the machinery is appropriate for the site conditions (e.g., to avoid compaction).
- Provide the method statements within the CMS earlier: the method statements should come under earlier scrutiny, possibly as part of the planning process, instead of post planning. The method statement would include information on any associated work and how it will be carried out; identify which areas are to be avoided and if mitigation is to be put in place. The methods involved in this process can be detailed, along with how these will reduce impact on the environment, maintain water flow and reduce the potential for a pollution event. This is a similar process to the "end of life" removal of infrastructure, which is currently required for on some developments.
- Produce more efficient design guidance: this is required to ensure understanding and compliance of the design and construction process, which can take

the form of a "*How To*" guide. This would pull in all the current guidance into a single document.

- Instead of separate guidance documents, consolidate guidance with input from all relevant stakeholders (e.g., SEPA, NatureScot) into a single document. This can also include a Standard Operating Procedure document as an appendix for contractors.
- Review costs of planning: costs in planning could be reviewed so that developers have more flexibility at the 'feasibility stage' to ensure that if any changes need to take place to the planned boundary of the construction area, to avoid sensitive habitats, wetter areas or peat, they can be carried out without the costs associated with the larger boundary required.

5.3.2 Water quality baseline data collection (physical/chemical)

- It is recommended that baseline (pre-construction) data are collected for a year at the site and at a control site with similar pre-construction physical/chemical characteristics. This would allow the comparison and determination of water quality on the site throughout a year.
- During construction and post-construction data should continue to be collected (sampling fortnightly/monthly but possibly more frequently in sensitive areas) at the site and at the control site. Any changes in the water quality parameters during construction may indicate impact of the construction activity when assessed with the previous years' data and control site data. This can then be investigated further to determine if site activity is at fault and prompt remediation can be carried out. The appropriate water quality values (Phosphorus, Ammonium, Nitrate, Nitrogen, Calcium, Magnesium, Sodium, Iron) can be found in SNH report (Spencer and Pitcher, 2019).

5.3.3 Access tracks: Cut and fill

- For access tracks that require to be cut in, a specific type of drainage is required. These are usually shallow drainage ditches put in place ahead of the track construction. Their role is to divert the surface water flow or rainwater away from the track works. This reduces fast dewatering of subsurface flows.
- The location of the drainage ditches should be part of the CEMP/CMS and should form part of the earlier consultation and design process. Moreover, to ensure that the construction drainage of "dirty" (waste) water is kept separate from the clean water, culverts can be placed from one side of the track to the other (see example Figure 7). This also reduces the load of water to be treated via settling ponds and silt fencing. Surface cross drains or SuDS (Sustainable Drainage Systems) can also be used for the flow of water on a track during rainfall or heavy traffic use. Some interviewees did not think this was carried out early enough and many contractors pointed out that installing these was time consuming. This suggested that surface cross drains/SuDS should be designed rather than reactively placed during construction. Therefore, it is recommended that hydrological connectivity is evaluated and any measures to maintain it are included within the planning stage.

Figure 7. Culvert maintaining surface water flow.

5.3.4 Access tracks: Floating tracks

- Floating tracks should be implemented, where possible, as these tend to have the least impact on hydrological flows. They cause relatively less disruption with less material removed. A floating track utilises a 5-degree cross slope as its limit, to avoid slippage, as anything other than this would require a cut and fill track. Where there is a subsurface hydrological flow path, then a series of small drains can be placed under the track to maintain the hydrological regime. Floating tracks should be designed with a good specification of Geotech material, as they are known to sink gradually over time and use with site traffic. The quality of the floating track should be monitored over time and if the track shows tendency to become a preferential flow path, it should be repaired.

5.3.5 Penstock

- Clay plugs are normally used to stop the penstock from becoming a preferential flow path for water. It is advised that a specified number of clay plugs are recommended by the designer based on drainage surveys. If no clay nor other suitable material is available on site, sandbags can be used.

5.3.6 Storage of turves

- A full Standard Operating Procedure guide should be provided for turf removal, as it would seem some contractors struggled with this due to varying skill levels and understanding of the turf management process.
- The top vegetation layer (300 mm approx.) which contains the seed layer, should be stripped and placed to the side with the vegetation facing up, and in a single layer. This should be kept moist until reinstatement. If there is a peat layer, then this is excavated and laid out beyond the turves (or sometimes on the other side of the track dependent on slopes). Peat and turves should be kept moist at all times. If peat is left to dry out it will oxidise, and carbon will be released. Early reinstatement of soil and turves is highly recommended.

5.4 Overall conclusion

The need to carry out site investigation surveys earlier, was the main theme arising from the literature review and interviews. Site investigations will inform a more robust design at an earlier stage in the project development process. This should be supported by the early engagement of an Environmental Clerk of Works and a detailed site visit. This in turn will help to determine sensitive receptors on site (e.g., sensitive flora), reduce environmental risk, and create useful input into the drainage design plan and to make sure that the CEMP/CMS plans are properly informed.

Including additional physicochemical data at the pre-planning survey period was one of the key site investigation methods discussed in the interviews. This would allow the ability to characterise the site by its physiochemical profile and include a description of the watercourses and their water quality parameters at the pre-construction stage. Baseline data of the site, and inclusion of a control site, can be used to determine the impact of the development. This set of robust data could be used as an operational tool to determine if the construction mitigation methods are effective on site.

The need for a 'How To' document or a single, easy to use, source for all guidance documentation was identified by the interviewees as key. The present guidance documents available to the construction sectors, for a variety of scenarios (e.g., wind, hydro, tracks, roads, etc.) are usually informative, but quite generic in terms of good practice guidance. The consolidation of the full guidance information (e.g., NatureScot, SEPA, Marine Scotland) in an easy to find and retrievable manual would be a beneficial resource.

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