Scottish Natural Heritage
Research Report No. 1098

An assessment of the results of soil and water samples from a range of wetland sites – Bailliewhirr SSSI

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RESEARCH REPORT

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An assessment of the results of soil and water samples from a range of wetland sites – Bailliewhirr SSSI

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Summary

An assessment of the results of soil and water samples from a range of wetland sites – Bailliewhirr SSSI

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Keywords

nutrients; Bailliewhirr SSSI; diffuse pollution; wetland; SSSI; water; soil

Background

In 2012, SNH conducted soil and water sampling from 17 designated wetland sites (Sites of Special Scientific Interest and Special Areas of Conservation). The samples were collected to establish whether the sites were subject to nutrient enrichment from either diffuse or point source pollution. The aim of this report is to analyse the data collected at Bailliewhirr, in order to assess the trophic status of the designated wetland and identify any likely sources of nutrient input.

Main findings

- The surface water catchment for Bailliewhirr is relatively small and the site is fed by a combination of base-rich water from a spring (to the north-east of the site) and through seepage from the upland areas.
- Data from the ER37 and the UK TAG suggests water quality and water level requirements for a range of wetland types. The water quality recorded in this study is not consistent with the requirements of the full range of vegetation communities present at the site. High Total Nitrogen and Nitrate levels recorded in the north-west of the site suggest the groundwater quality is below guidelines for Type 3 Springs and seepages, Type 2a Marshy grassland and Type 4 Fens.
- Phosphate levels also appear to be high when compared to the UKTAG mean phosphate levels for Fen communities.
- The initial sampling would suggest the eutrophic waters are entering the SSSI on the western and northern sides, and through the issues in the north-west corner, which are penetrating into the wetland communities of the site. Water supply from the south-eastern ditch (which originates within the plantation) appears to be less eutrophic.
- High nitrogen levels in the fen communities are likely to result in deterioration of this habitat over time if the quality of groundwater that it receives does not improve. In contrast, the more tolerant requirements of the reedbed suggests that water quality is acceptable for this habitat.
- There are indications that the surface water quality within the ditches is not always consistent with the eco-hydrological requirements of the full range of wetland vegetation communities on this site (as detailed in the ER37 and UKTAG guidelines). High readings for parameters such as nitrogen and phosphate were recorded in the outflow and the

north-west inflow, beyond the levels typically found in reedbed, marshy grassland and fen.

- Surface water assessment also shows that the best water quality is located in the ditch supplied by the main springs.
- Assessment of vulnerability showed Bailliewhirr was most at risk from agricultural practices and site management operations.
- Further investigations are recommended for the site (such as monthly water quality sampling, seasonal water level recording and a full NVC survey). A range of remedial options are proposed for consideration, once additional data has been gathered.

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Acknowledgements

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1. INTRODUCTION

In 2012, SNH conducted soil and water sampling from 17 designated wetland sites (Sites of Special Scientific Interest and Special Areas of Conservation). The samples were collected to establish whether the sites were subject to nutrient enrichment from either diffuse or point source pollution. The aim of this report is to analyse the data collected at Bailliewhirr, in order to assess the trophic status of the designated wetland and identify any likely sources of nutrient input. The results will then be used to inform site management and also contribute to a wider project to develop eco-hydrological thresholds for wetland sites.

2. METHODOLOGY

The following methodology was used at all 17 sites studied under this project, including Bailliewhirr.

2.1 Sampling methodology

The soil and water samples used in this report were collected by a team co-ordinated by SNH and were undertaken in two phases.

Soil samples were collected at specific sample locations at each site by hand augering holes into the peat. Soil samples were collected at two depths:

1. From the rooting zone.
2. From within the anoxic layer below the rooting zone.

The precise depth of the anoxic layer varied from site to site according to the vegetation that was present. Generally this was approximately 15 cm depth for the root zone sample and 45-60 cm depth for the sample below the root zone.

Groundwater samples were collected using plastic bailers from slotted pipes installed within hand augured holes.

Surface water samples were also collected from strategic locations within surface water courses at each site.

The two sampling rounds took place in the weeks commencing the 6th February 2012 and the 20th February 2012.

Samples were delivered to the EnviroCentre Glasgow office and the SNH office near Perth for dispatch to the project laboratory. Samples were packed in cool boxes with ice to ensure that the samples remained cool in transit to minimise sample deterioration. Unfortunately some samples from some sites were misplaced by the laboratory and could therefore not be processed. All samples were tested using accredited methods or where accreditation was not available, using in-house procedures with routine QA / QC checks in place to ensure data quality.

The soil sample analysis was undertaken on dry samples, which were analysed for the following suite:

- Soil type
- Bulk density
- Water content
- Organic carbon content
- Extractable N and P
- Total N and P
- Total Calcium, Magnesium, Sodium and Potassium

Water samples were analysed for the following suite:

- Calcium, Magnesium and Sodium
- N species – total N, nitrate and ammonium
- P species – orthophosphate and total P, low level P (LOD – 0.02 mg/l)
- Iron species – Fe^{2+} and Fe^{3+}

2.2 Analysis of results

The following data sets were used to assess the site, where available:

- Vegetation descriptions, varying in detail from observations within site condition monitoring assessments to full National Vegetation Classification surveys (NVC)
- Groundwater chemistry
- Surface water chemistry
- Soil chemistry
- Details of the designated site features, site management statements and condition monitoring assessments

Sufficient vegetation information was available for some sites to allow classification of the wetland communities that were (or could be) present at each of the sites and their water quality requirements. For those sites containing measured species data (for example NVC quadrat data) it was possible to apply Ellenberg's Indicator Values[1], weighted to species abundance, to achieve a score for each sample near to a sampling point. This method can indicate, for example, how nutrient-rich the conditions are where the sample was recorded. Mapping these scores then gives an indication of the distribution of eutrophic fen types. Such maps allow a geographical appreciation of distribution of habitat factors, always understanding these values are inferred from the vegetation and not measured directly.

Where NVC data was not available, assumptions were made based on i) vegetation described within the field notes when samples were collected[2] and ii) from the site condition monitoring reports and citation. Each site was split into 'wetland types' (as defined by the SNIFFER report (2009), such as marshy grassland, fen, springs and seepages, or swamp. Originally it was also intended to apply the Wetland Water Supply Mechanisms (WetMecs) framework to define the types of wetland present, as described in Wheeler, Shaw and Tanner (2009). However, in the majority of cases, there was insufficient data available on both the hydrological operation of the site and the substrate present to be able to assign WetMec types with confidence.

A number of published and unpublished sources were then used to define water quality guidelines for the wetland types. This included UKTAG reports on Water Framework Directive targets but was principally based on a draft report commissioned by SNH, SEPA and SNIFFER (known here as the ER37 report) which aims to define suitable targets for wetland types in Scotland. The ER37 report provides data on groundwater, surface water and soil based on the various wetland communities sampled throughout Scotland. These draft guidelines were used to classify the SNH data collected in 2012 and to establish if the results were within normal ranges observed in Scotland.

For sites with open water bodies, the surface water results were compared to Scotland River Basin District (Standards) Directive 2014, along with JNCC targets and Ecoframe targets (Moss *et al*., 2003). In order to apply the correct standards, in was necessary to classify the lochs in terms of their depth, altitude, alkalinity and bedrock, as well as whether they were freshwater or saline, coarse or salmonid. Very limited data on some of these variables meant that assumptions were necessary in the classification process (for example, alkalinity data was rarely available to aid classification).

[1] The Ellenberg values (Hill *et al*., 1999) are a numerical rating given to each plant species according to its place on the spectrum of each determinant. So, for salinity, saltmarsh species have a high salinity value, freshwater marsh species a low one.

[2] Note that water samples were collected in February and this would necessarily limit the amount of species data able to be obtained.

Each site has been provided with an Assessment of Vulnerability to eutrophication, along with the relative importance of each nutrient source. Catchment nutrient modelling was beyond the scope of this project, and would not have been possible with the current data available. Instead, an 'interpretation' was made by eye of the available data of how each loch should be regarded in terms of trophic status. Any sites which would especially benefit from further more detailed study were flagged up within the report.

3. ASSESSMENT

3.1 Site review

Bailliewhirr SSSI (Figure 1) is located 2km west of Whithorn in the south west of Scotland and is one of the best remaining unimproved lowland grassland sites in Wigtownshire. The site, which is 34.9 ha, is bound to the north by the B7021, with the remainder of the surrounding land being a mix of woodland (California Plantation) and arable land. To the west is Gowk Hill (89 m), which limits the site expansion in this direction.

Historically, the site has been lightly grazed by sheep throughout the year and cattle between April and November (Figure 2). A light application of compound fertiliser is added to the deeper soils in the spring. Gorse, hawthorn and bramble are periodically cleared from specific areas to increase the extent of the grass available for livestock. The shooting of pheasants and rabbits also takes place.

All of the SSSI is under an SNH management agreement, which supports the current extent of species-rich grassland and the wetland interests of the site.

Figure 1. Site Boundary – Bailliewhirr

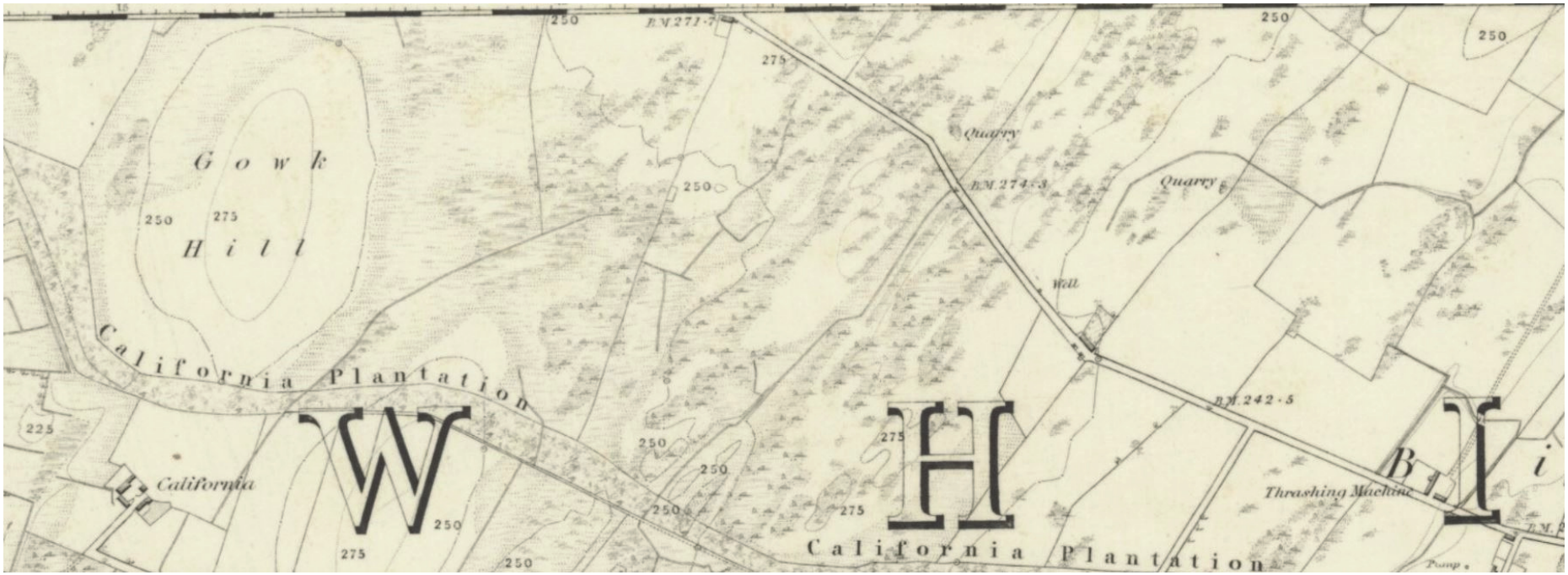

Figure 2. Ordnance Survey Six Inch 1843 – 1882 map (Source: National Library of Scotland)

3.1.1 Site designation and specific targets

Bailliewhirr is a Site of Special Scientific Interest (SSSI) and was first notified under the Wildlife and Countryside Act (1981) in December 1988. The features for which the site is designated are described in Table 1.

The site exhibits a wide variety of vegetation types including species-rich dry grassland and tall fen. The drier areas of the site are dominated by small sedges and grasses, while the wetter parts of the site contain complex mosaics of tall fen and bog communities. Quaking mire also exists in the centre of the site. *Schoenus nigricans* (which is normally found on the coast) is present here, making it one of the few inland localities in Dumfries and Galloway.

The range of conditions from acid to neutral/calcareous allows a wide range of uncommon plants to thrive. These include fen pondweed, bog pimpernel and at least five types of orchid.

Table 1. Designated features at Bailliewhirr SSSI and their pressures

SSSI features	Feature Category	Summary Condition / Latest Condition	Pressure
Lowland neutral grassland	Lowland grassland	Unfavourable No Change (Aug 2016)	a) Agricultural operations
Basin fen	Wetland	Favourable / Favourable Maintained (Aug 2002)	a) Invasive species b) Over-grazing c) Water quality

The site specific targets outlined in the recent condition assessment and objectives for management include:

1. To maintain the water table at or within 0.05 m of the surface.
2. To retain rare species where present.
3. To maintain the characteristic species and vegetation composition of site – at least 75% combined coverage of grasses, sedges, rushes and tall herbaceous dicotyledons.
4. Limit signs of disturbance / damage from vehicles (vehicle tracks).
5. Limit signs of disturbance / damage from grazing (hoof prints).
6. To maintain an average vegetation height of >0.8 m.
7. To maintain <5 % cover of tree / scrub species or no more than occasional through the sward.
8. *Epilobium hirsutum* and *Urtica dioica* species not more than occasional (or dominant over more than 10 % of the mire in stands of S28 tall-herb fen).
9. To maintain 'wetness', with dry areas no greater than 1 % of the site and no cracks in the soil surface.
10. To prevent any changes in the hydrology of the catchment (such as groundwater abstraction).
11. To prevent forestry or ploughing within 30 m of the watercourses that feed into the fen.
12. To prevent the creation of any new ditches.
13. To prevent loss in area without prior consent.
14. To maintain the extent of grassland and range of wetland vegetation through grazing (by controlling any dominance of coarse plant species). Maintaining low nutrient levels in this way will help to promote a diverse range of plants.
15. To maintain the extent of fen and bog vegetation and habitat through water level management. Stable water levels during the nesting season (with occasional flooding and drying of pools) will benefit invertebrates. Furthermore, a high water table in the fen will reduce tree and scrub invasion.
16. To maintain water levels and water quality by maintaining existing drains, through removal of accumulated sediment. Water quality will be maintained by preventing artificial enrichment.

3.1.2 Site hydrology

The surface water catchment for Bailliewhirr is relatively small (see Figure 3). The bog is fed by base-rich water from a spring (to the north-east of the site) and through seepage from the upland areas (see Figure 4). There are three ditches within the site with the main flow direction being from north-east to south-west corner, where water exits the site. The ditches are maintained to a depth of approximately 1.2 m and are described within the site management statement as being maintained within 0.05 m of the surface. Given the slope of the land on the SSSI, this retention level is presumably only achieved on the lower parts of the site. There appears to be a secondary feed of water into the SSSI from the south, via a ditch which captures seepage water from the California Plantation and then passes through an area of improved grassland.

Groundwater input from outside of the surface water catchment cannot be discounted because the site is underlain by The Machars bedrock and localised sand and gravel aquifers (part of the Solway Tweed River Basin district). In 2008, the water body and groundwater were classified as 'Good with High confidence'. There are no identified pressures on this water body. Bailliewhirr is also located within The Machars bedrock and localised sand and gravel aquifer Drinking Water Protection Zone (DWPZ) which was given a 'Pass' in 2009.

There are no SEPA surface water monitoring points, sediment or standing water monitoring points within the vicinity of the site. Historic rainfall data was also not available for Bailliewhirr.

Evaluating the impact of nutrient sources on a wetland feature depends on a good understanding of how that wetland feature functions hydrologically and ecologically. One of the best systems to describe wetland functioning developed so far is the WetMec system (short for Wetland Mechanism) developed by Wheeler *et al.* (2009). Each WetMec describes an assemblage of hydrological characteristics that determine functioning, and this is usually linked to a characteristic ecology. Crucially, wetland sites are not viewed as a single type (such as floodplain fen or groundwater fed valley fen), but are understood as inter-linked hydrology's composed of more than one WetMec type.

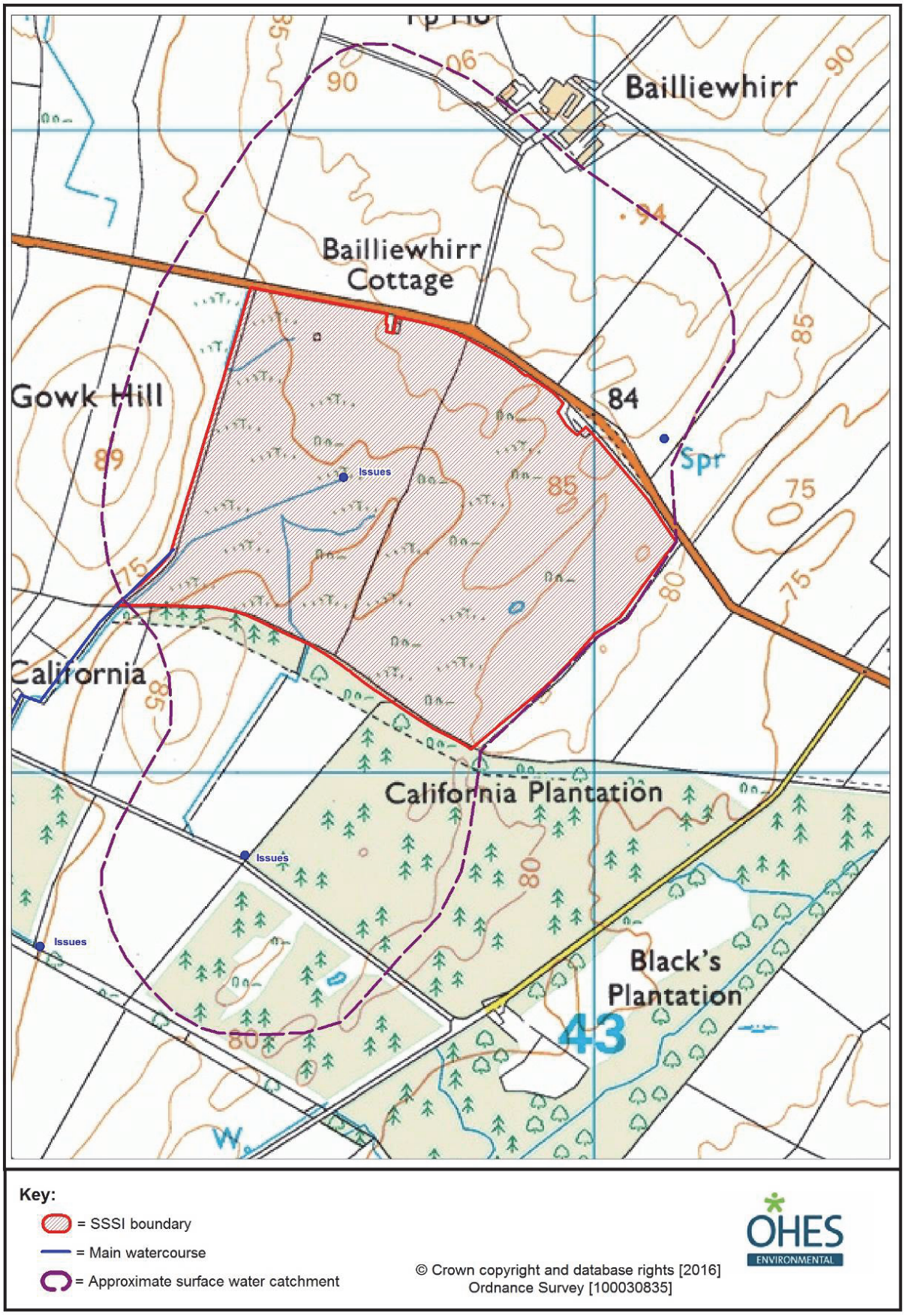

Figure 3. Bailliewhirr – approximate surface water catchment

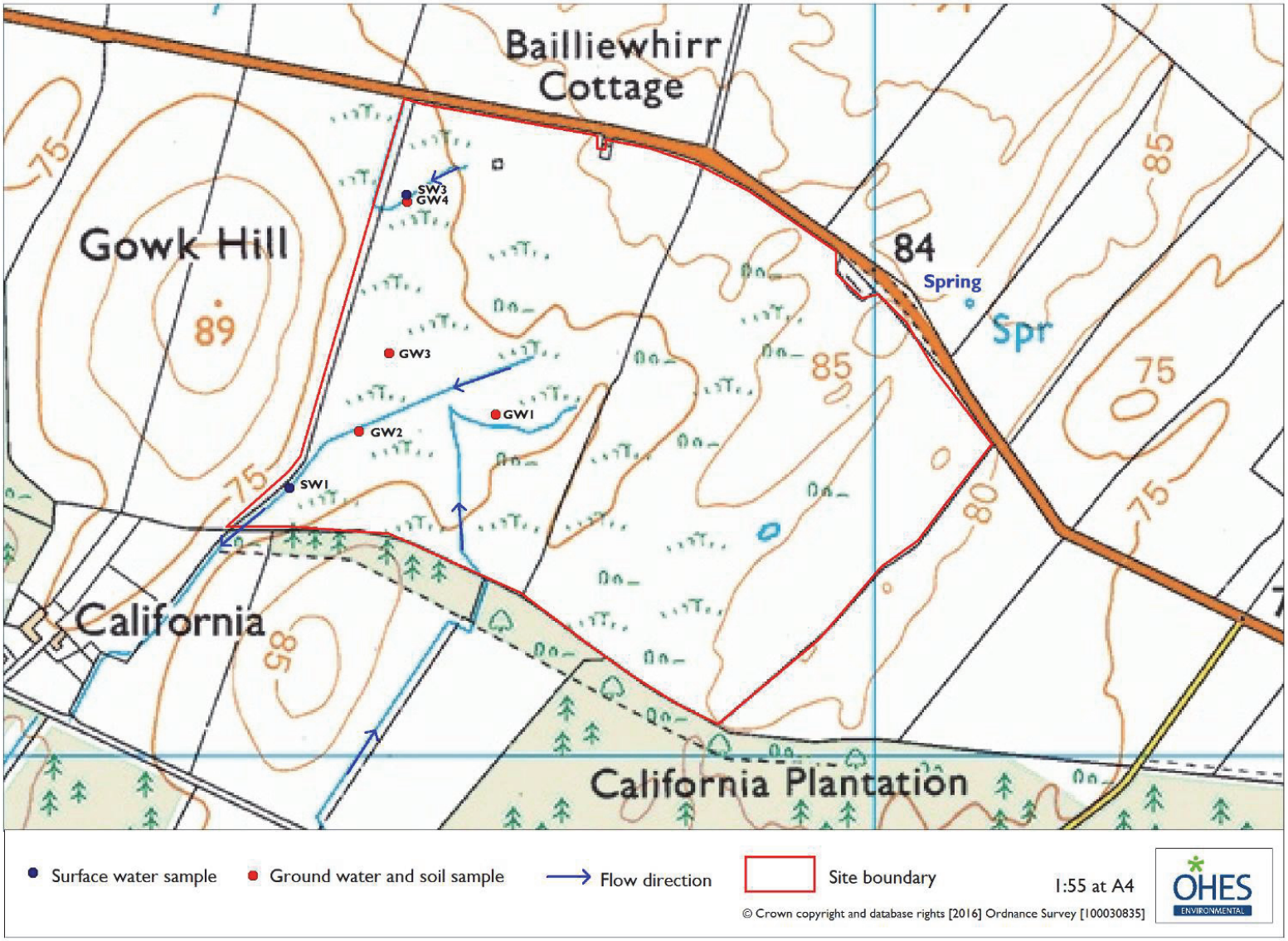

Figure 4. Bailliewhirr – Hydrology and Sample Locations

One of the limitations to this study is that little data was available to define detailed hydrological functioning for this site. Similarly, little information is available on the substrate present at Bailliewhirr (other than the apparent presence of clay and silt at the base of the slopes, over which peat has developed). Application of systems such as the WetMecs framework requires detailed information on both these factors before it can be accurately applied. As a consequence, all that can currently be stated is that the site is likely to contain either WetMec 10: Permanent Seepage Slopes or WetMec 11: Intermittent Seepage Slopes on the higher ground within the site, where springs and seepages occur. Within the lower areas, water supply will be determined by the extent and nature of the clay/silt infill (or presence of low permeability peat). If the substrate is permeable, this area would seem most likely to fall within WetMec 13: Seepage Percolation Basins (typically groundwater fed, with a buoyant surface and transmissive surface layer). If the permeability is low, this area would tend towards WetMec 20: Percolation Basins (where the status of groundwater supply is uncertain due to the extent/nature of the aquitard).

3.1.3 Site soils / sediments

Bailliewhirr is situated over the Ettrick association, derived from Lower Paleozoic greywackes and shales. Greywackes have been described as a form of sandstone, with a variety of mineral and rock fragments and a paste-like matrix of the same material, and are interbedded with finer grained siltstones and shales. They are associated with lowlands with gentle and strong complex slopes, which are slightly to moderately rocky. Figure 5 shows the distribution of soil types at Bailliewhirr.

The British Geological Survey website also shows lacustrine deposits of clay and silt across the south-east corner of the SSSI (i.e. in the lower ground).

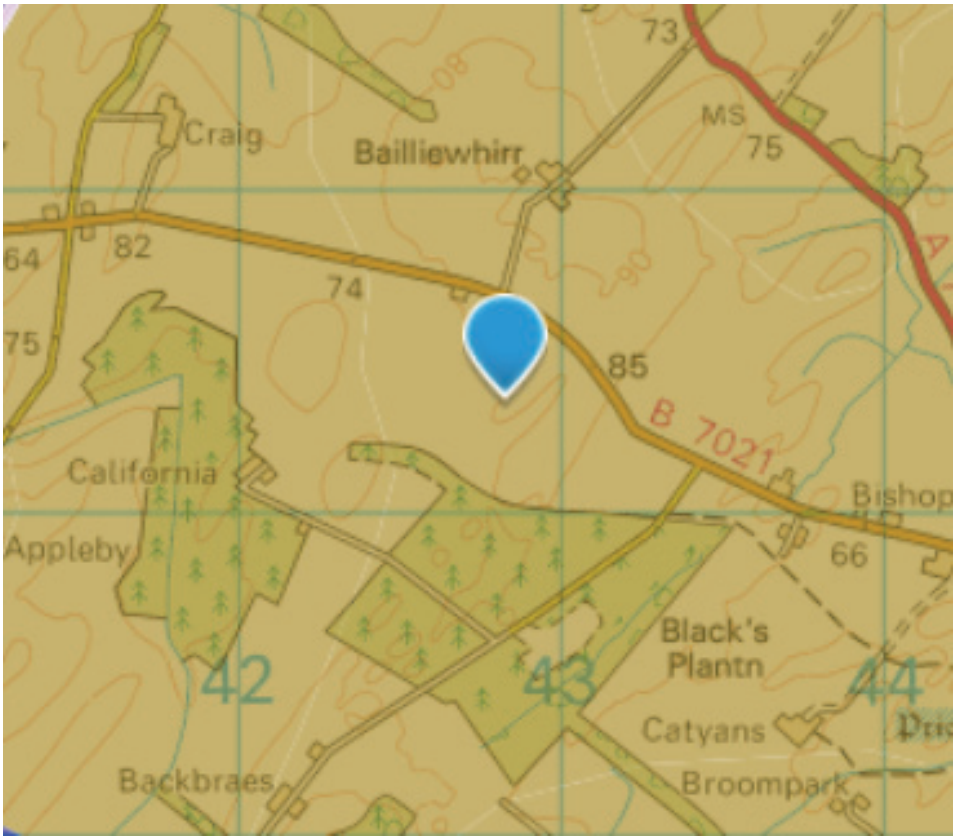

Figure 5. Bailliewhirr – Soil types (Source: Soil Survey of Scotland Staff 1981). Note: Brown shading = Ettrick Association.

3.1.4 Site specific issues

There are a number of potential sources of pollution that could impact the site (Figure 6). These are mainly hydrological and centre on enrichment from surrounding land uses. Any changes in the groundwater table through abstraction would have an impact upon the wetland species of the site if the water table were to become permanently lowered.

Sediment ‘pollution’ through ploughing of the surrounding land would also be detrimental to the site as mobilised sediment could enter the watercourses and deposit sediment within the ditches of the fen. The use of fertilisers on surrounding arable land would also cause issues at the site as artificial enrichment could cause issues with the water quality of the ditches as well as encourage species more tolerant of high nutrients. This could result in changes in the important vegetation community of the fen.

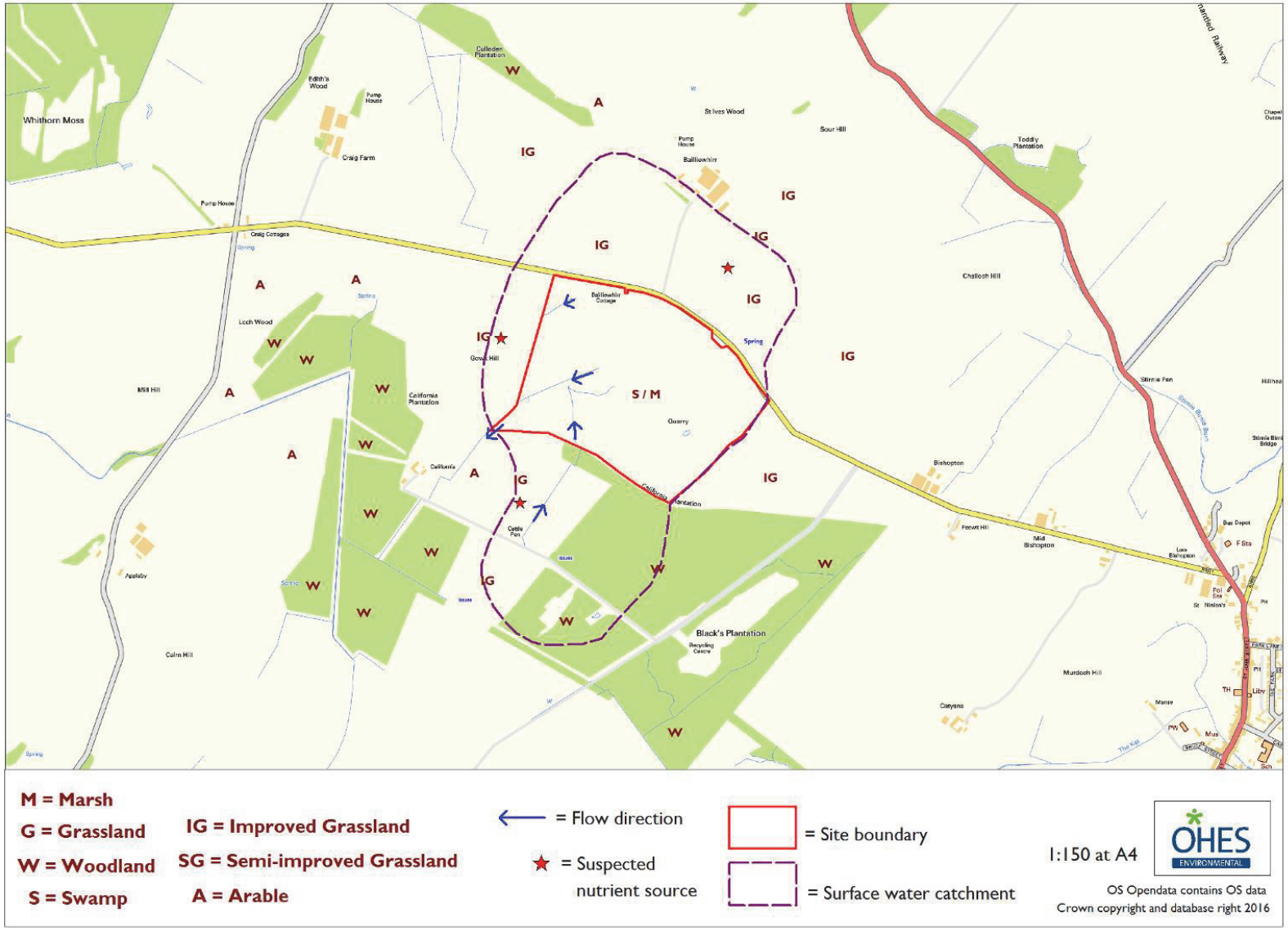

Figure 6. Land use and potential nutrient sources at Bailliewhirr

3.2 Assessment of vegetation data

Bailliewhirr contains a range of grassland and tall fen bog communities. There is no NVC data available for this site. The site condition assessments and citation suggest mixtures of acid and calcareous short fen and grassland. The evidence available would suggest the presence of M23 rush-pasture (as listed during the water sampling for GW1 & 2). However, reference is also made to rarer species such as *Potamogeton coloratus, Parnassia palustris, Schoenus nigricans, Anagallis tenella* and *Dactylorhiza incarnata* which are much more reminiscent of M13 *Schoenus nigricans* mire or, more typically of the region, M10 *Carex dioica – Pinguicula vulgaris* mire. These communities would be consistent with the calcareous springs and flushes known to occur on site.

In other parts of the SCM text, mention is made of *Carex rostrata* and *Menyanthes trifoliata*, which would be more consistent with either M9 *Carex rostrata - Calliergon cuspidatum* mire or M5 *Carex rostrata – Sphagnum squarrosum* mire Both communities inhabit soft spongy peats supplied by nutrient-poor waters (Rodwell, 1991), including floating rafts of vegetation resulting from terrestrialisation of waterbodies (as is the case at Bailliewhirr). The exact requirements between these two communities is not fully understood, but it is generally accepted that M9 tends to occupy more base-rich, calcareous conditions and therefore (together with the fact that no sphagnum was mentioned during the sample collection) M9 would seem the more likely of the two to occur on this site.

The tall fen component of the site is similarly unclear as to the specific NVC community presence. Mention is made of S28 *Phalaris* swamp and S26 *Phragmites australis- Urtica dioica* swamp but no *Urtica dioica* is mentioned during the SCM. Furthermore within the tall fen, *Angelica sylvestris, Filipendula ulmaria* and *Mentha aquatica* are recorded as frequent, with *Caltha palustris, Menyanthes trifoliata* and *Vicia cracca* listed as occasional. This description could easily fit within S4 *Phragmites australis* swamp of the *Menyanthes* sub-community (S4c) or S27 *Carex rostrata – Potentilla palustris* tall-herb fen.

There is therefore the potential for this site to contain (or to have previously contained) a richer and more ecologically valuable suite of communities than was recorded by the vegetation description during water sampling.

It is therefore assumed that the following NVC communities should be considered for the site:

- M9 *Carex rostrata-Calligeron cuspidatum /giganteum* mire
- M5 *Carex rostrata – Sphagnum squarrosum* mire
- M10 *Carex dioica – Pinguicula vulgaris* mire
- M23 *Juncus effuses /acutiflorus-Galium palustre* rush-pasture
- S4 *Phragmites australis* swamp and reed-beds
- S27 *Carex rostrata-Potentilla palustris* fen

3.2.1 Historic evidence of community change

There is insufficient data to quantify changes in the communities recorded at Bailliewhirr and it is proposed that a baseline NVC survey is a priority for this site so that any future changes can be identified accurately. It is noted however, in David Hawker's report of his SCM visit (3rd August 2002) that "The citation states that there is species-rich calcareous grassland on site but this was not recorded during the monitoring visit."

3.2.2 Community requirements

The requirements of wetland communities have been discussed in several publications over the past decade, some of which are specifically aimed at providing guidance on the implementation of WFD regulations. Considerable advances have also recently been made in determining the environmental conditions under which particular vegetation types can be found in Scotland, through a collaboration of SNH, SEPA and SNIFFER (Draft report: ER37, February 2016). The draft ER37 document presents guidance on the eco-hydrological requirements of the different Scottish wetland types as described in SNIFFER (2009). The report emphasises that "they are meant to be adequate for broad-scale appraisal but site specific data is likely to be required for more detailed assessments". Therefore, further sampling is needed for many habitats before definitive thresholds can be set, with the draft ER37 report referring to thresholds, guidelines or indicators, depending on the level of sampling that has so far been conducted for that habitat. The three confidence levels used throughout the ER37 report are described as:

Indicator: Reflects best professional judgement based upon limited data
Guideline: Reflects adequate data for risk screening but not to establish a hydroecological standard
Threshold: Represents a wide range of consistent data with confidence to set a standard.

Where there has been insufficient sampling of a particular habitat in Scotland, the tables refer back to the UK TAG figures.

The wetland types relevant to Bailliewhirr are (based on SCM descriptions):

- Type 2a: Marshy grassland
- Type 3c and d: Springs, seepages and flushes
- Type 4: Fen
- Type 6: Reedbed

The guidance below is therefore based primarily on the ER37 report findings, but with additional information on individual community types where known.

3.2.2.1 Type 2a Marshy grassland

Marshy grassland communities are present across a wide range of environmental situations with several different potential water supply mechanisms. Three types are recognised within ER37.

- Type 1: water supply by rainfall, local snow-melt, overland flow and interflow,
- Type 2: groundwater seepages or springs,
- Type 3: surface and groundwater flooding (characteristic of floodplains and other localities such as ground adjacent to loch shores)

At Bailliewhirr the main type would appear to be Type 2. The equivalent NVC communities contained within these types are considerable, but those relevant to Bailliewhirr include:

- M23 *Juncus effuses/acutiflorus – Galium palustre* rush-pasture - this community has a fairly widespread distribution across Scotland and can contain considerable plant diversity. The hydrology is typically one of a high water table close to the surface for most of the year (ER37), with periodic flooding.

SNIFFER and ER37 data for Marshy grassland are presented in Table 2. Mean nitrate results for wet grassland in good condition are given in UKTAG (2014) as 6 mg/l N. The UK

third quartile value is 5.9 mg/l N-NO_3. The SNIFFER values in groundwater for Scotland are significantly lower, with a third quartile value of 0.25 mg/l N-NO_3 (ER37).

Mean Phosphate values indicated by the UKTAG (2012) for the UK in wet grassland are 0.045mg/l for good condition and 0.024 mg/l for bad condition. However the UKTAG (2014) states "there is no clear distinction in phosphate concentrations between wetlands in good condition and those in poor condition or with a likely nutrient risk". Thus no targets are given.

Table 2. Groundwater targets for Marshy Grassland in Good Condition (Source: ER37 – DRAFT)

	Marshy grassland			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Indicator/guideline**
pH (-)	6.3	6.6	7.1	5 to 8
Dissolved Oxygen (%)	32	35	40	
Electric Conductivity (mS/cm)	0.093	0.13	0.18	
Calcium (mg/l)	8	18	24	
Magnesium (mg/l)	2.5	4.5	8.7	
Sodium (mg/l)	6.2	9.2	12	
Phosphate (mg/l)	0.041	0.06	0.065	Indicator: 0.065
Nitrogen (total) (mg/l)	2.5	4	7	
Nitrate (mg/l N-NO_3)	0.25	0.25	0.25	Guideline: 6 (or 26 mg/l as NO_3) for <175 m AOD

3.2.2.2 Type 3c and d Springs, seepages and flushes

Type 3 wetlands are directly supplied by groundwater, with a water table typically maintained at or just below the ground surface for most of the year. They generally have a very localised distribution, where groundwater outflows from a mineral aquifer due to the presence of sloping ground or a low-permeability layer (aquitards). Springs refer to point-source outflows, seepages refer to strips of groundwater outflow and flushes are areas of low-permeability substrate located below springs and seepages, where the ground is kept wet by downslope flow (ER37).

The Type 3 wetlands relevant to Bailliewhirr include:

3c: Other Springs – Springs which occur at lower altitude than montane situations. Flows can be permanent or intermittent, consisting of varying mineral content. No tufa is present under this category (ER37).

3d: Seepages and flushes – Where diffuse water output occurs across both small and large areas. Vegetation can include extensive bryophyte coverage (such as Sphagnum species) and combinations of small sedges and rushes.

Types 3c and d include H7230 Alkaline fens and H7140 Transition mires and quaking bogs, both of which are Annex 1 habitats covered by the EC Habitats Directive.

The main NVC communities listed under Type 3c and d which are known (or have potential) to occur at Bailliewhirr include:

- M5 *Carex rostrata–Sphagnum squarrosum* mire – occurring on soft, spongy peats or as a floating raft within topogenous and soligenous sites. This community is typically supplied by mildly acidic to moderately calcareous waters, which can be oligotrophic to

moderately fertile in nature. It can be found in base-poor catchments where slates and shales predominate, but is also sometimes associated with more calcareous rocks.

In successional terms, M5 can form part of a sequence from open water through to drier mineral soils, or represent localised areas of oligotrophic conditions within stands of S27 *Carex rostrata–Potentilla palustris* tall herb fen, M9 *Carex rostrata–Calliergon cuspidatum/giganteum* mire or swamps such as S9 *Carex rostrata* swamp (Wheeler, Shaw & Tanner, 2009). It has been observed by Wheeler, Shaw and Tanner that hydrochemical characterisation of this community is complicated by the short, vertical hydrochemical gradients which can occur as a result of thin layers of acidic peat overlying base-rich waters. The community has been found to show increases in species-richness associated with base enrichment, but decreases in the number of principal fen species where P enrichment occurs.

- M10 *Carex dioica–Pinguicula vulgaris* mire - usually associated with soligenous mires irrigated by base-rich, oligotrophic and highly calcareous waters (Rodwell, 1992). It is often found around suitable springs and seepages and can be seen as the northern counterpart of M13 mire. The community can be reasonably species-rich and can be transitional with communities such as M23 *Juncus effusus –Galium palustre* rush–pasture, M9 *Carex rostrata–Calliergon* mire and S27 *Carex rostrata–Potentilla palustris* tall-herb fen (Wheeler, Shaw and Tanner, 2009).

ER37 data and guidelines for springs and seepages are presented in Table 3. Under the UKTAG report (2012), mean nitrate levels in springs and seepages (excluding tufa-forming springs) is 1.8 mg/l N-NO3 for good condition and 6.4 mg/l N-NO3 for poor condition. Clearly the data from wetlands in Scotland of this type is very low compared to these targets, and below the detection limit of 0.5 mg/l N-NO3. Phosphate levels are also typically below the detection limit of 0.2 mg/l PO4 and the UKTAG report suggests there is no statistical difference between phosphate concentrations in good and poor condition. Therefore no guidelines are available for this determinant.

Table 3. Groundwater guidelines for Springs and seepages in Good Condition (Source: ER37 Draft)

	Springs/seepages			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Indicator/guidelines**
pH (-)	No data			
Dissolved Oxygen (%)	No data			
Electric Conductivity (mS/cm)	No data			
Calcium (mg/l)	5.7	42	76	
Magnesium (mg/l)	3.2	12	19	
Sodium (mg/l)	8.4	14	26	
Phosphate (mg/l)	0.09	0.1	0.1	None set
Nitrogen (total) (mg/l)	0.5	1.5	4.2	
Nitrate (mg/l N-NO_3)	0.25	0.25	0.25	Guideline: 2.05 (or 9 mg/l as NO3)

3.2.2.3 Type 4 Fen

Type 4 Fens contain a wide range of vegetation communities, which may be fed by either surface water (topogenous) or ground water (soligenous). The group includes 7230 Alkaline fens (an Annex 1 habitat covered by the EC Habitats Directive) such as M24, and 7210 Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae* (including vegetation types which can support great fen-sedge *C. mariscus).*

The main NVC communities listed in ER37 and which are found at Bailliewhirr are:

- S27 *Carex rostrata-Potentilla palustris* tall-herb fen - occurring in wet valley bottom/basin locations, where strongly sub-surface water levels are outside of normal conditions for the community. Despite containing a high number of total species, most stands are relatively species-poor (Wheeler, Shaw & Tanner, 2009). It is typically of moderate fertility, with transitions to M9 in mesotrophic conditions, and S9 in deeper, oligotrophic waters (ER37). Stands of S27 may be resistant to moderate nutrient inputs, but high levels of eutrophication lead to impoverishment, with an increased prominence of species like *Agrostis stolonifera, Juncus effusus* and *Phragmites australis* (Wheeler, B.D., Shaw, S., & Tanner, K, 2009).

- M9 *Carex rostrata–Calliergon cuspidatum / Calliergon giganteum* mire – occurs on slopes, stream-sides, lochsides and valley bottoms/basins which are fed by oligotrophic to mesotrophic waters, typically at lower altitudes (up to 800 m). The vegetation (a type of slender sedge fen) can form a soft mat of quaking or semi-floating material, with variable depths of peat/fluid underneath it. It typically occurs in transition with S9 *Carex rostrata* swamp, S10 *Equisetum fluviatile* swamp and M5 *Carex rostrata-Sphagnum squarrosum* mire. No pH data are available for Scotland but quoted as always >5 and usually >6 for all of its range (Rodwell, 1991).

ER37 data and thresholds for Fens are presented in Table 4. Under the UKTAG report (2012 & 2014), mean nitrate levels in groundwater fed fens in good condition are 3.4 and 2.9 mg/l N-NO_3 for mesotrophic and oligotrophic fen respectively, and the 3rd quartile values are 5.7 and 5.0 mg/l N-NO_3. However, ER37 reports that Nitrate levels in Scotland are significantly lower, with a 3rd quartile value of 0.25 mg/l N-NO_3 for groundwater, suggesting that most fen samples for Scotland are in good condition).

Mean Phosphate values for the UK (UKTAG, 2012) for fens in good condition are 0.033 and 0.021 mg/l P-PO_4 for mesotrophic and oligotrophic fen respectively (ER37). Mean values for fen in poor conditions are 0.034 mg/l P-PO_4 and 0.064 mg/l P-PO_4 for mesotrophic and oligotrophic groups. ER37 reports that median phosphate concentrations in Scottish fens are 0.10 mg/l P-PO_4 (for groundwater) and 0.046 mg/l P-PO_4 (for surface water). These figures exceed mean values given for good condition under UKTAG, 2012. No guideline value has currently been set for phosphate. ER37 reports however that "groundwater results are skewed by the analytical level of detection of 0.20 mg/l used in laboratory test for some of the samples".

Table 4. Groundwater thresholds for Fen in Good Condition (Source: ER37 Draft)

	Fen			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Threshold**
pH (-)	6.4	7.1	7.4	
Dissolved Oxygen (%)	18	21	28	
Electric Conductivity (mS/cm)	0.37	0.55	0.69	
Calcium (mg/l)	12	25	55	
Magnesium (mg/l)	3.4	6.4	14	
Sodium (mg/l)	5.4	9.7	14	
Phosphate (mg/l)	0.064	0.1	0.1	None set
Nitrogen (total) (mg/l)	1	3	5.1	
Nitrate (mg/l N-NO_3)	0.25	0.25	0.25	Threshold: <175 m AOD Meso = 5 (or 22 mg/l as NO3) Olig = 4.5 (or 20 mg/l as NO3)

3.2.2.4 Type 6 Reedbed

Equivalent NVC types covered:

- S4a *Phragmites australis* sub-community
- S4b *Galium palustre* sub-community
- S4c *Menyanthes trifoliata* sub-community

These are generally species-poor stands, heavily dominated by *Phragmites australis* with few associate species. They are however, valuable in their own right, particularly for bird and invertebrate species and consequently are a UK Biodiversity Action Plan (BAP) Priority Habitat under the fen, marsh and swamp UK BAP broad habitat. S4 can occur across a wide range of wetland conditions, with hydrological inputs including surface water, ground water or often combinations of the two. Water levels are typically above the surface for several months of the year, and can reach significant depths. ER37 notes that "Although reedbed grows best in wet, eutrophic habitats (Rodwell, 1995), it also occurs in oligotrophic or hypertrophic conditions which are more frequently found in Scotland (Mountford, 2004)".

ER37 data and thresholds for Reedbed are presented in Table 5. Nitrate guidelines under UKTAG for groundwater are 4.9mg/l N-NO_3 for groundwater feeding mesotrophic swamp and reedbed in good condition and 5.1 mg/l N-NO_3 for poor conditions, but this value is significantly higher than was observed in Scottish reedbed. ER37 reports that "site specific investigations indicate mean concentrations of Welsh and Scottish swamp and reedbed of 0.3 and 0.5 mg/l N-NO_3 (16 wetlands in good condition) and 6.2 and 5.6 mg/l N-NO_3 (9 wetlands poor condition). On this basis a threshold value of 5.0 mg/l N-NO_3 has been adopted by UKTAG (2012)". However, ER37 concludes values between observed 1mg/l and UKTAG threshold of 22 mg/l should be viewed as an increasing risk.

No threshold value is given in UKTAG (2012) or the ER37 report for Phosphate concentrations.

Table 5. Groundwater thresholds for Reedbed in Good Condition (Source: ER37 Draft)

	Reedbed			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Threshold:**
pH (-)	5.7	6.1	6.5	
Dissolved Oxygen (%)	18	20	22	
Electric Conductivity (mS/cm)	0.13	0.2	0.28	
Calcium (mg/l)	36	48	59	
Magnesium (mg/l)	5.8	12	18	
Sodium (mg/l)	12	13	19	
Phosphate (mg/l)	0.043	0.1	0.1	
Nitrogen (total) (mg/l)	1.1	3	6.9	
Nitrate (mg/l N-NO_3)	0.25	0.25	0.25	Threshold: 5 mg/l N-NO_3 (or 22 mg/l as NO_3)

3.3 Assessment of ground water samples

Groundwater samples taken at Bailliewhirr have been compared with the levels recorded in vegetation types as shown in section 3.2. Groundwater concentrations were used as opposed to surface water concentrations for several reasons; firstly that almost all wetlands will have a component of groundwater influence and secondly that groundwater thresholds can often be more demanding than surface water thresholds.

Table 6 indicates that the vegetation currently found around the sample locations is not consistent with the data recorded for Scotland (ER37) or for guideline/threshold values. High Total Nitrogen and Nitrate levels recorded in the north-west of the site (GW3 and GW4) suggest the groundwater quality is below guidelines for Type 3 Springs and seepages, Type 2a Marshy grassland and Type 4 Fens. Phosphate levels also appear to be high when compared to the UKTAG mean phosphate levels for Fen communities.

The initial sampling would suggest the eutrophic waters are entering the SSSI on the western and northern sides, and through the issues in the north-west corner, which are penetrating into the wetland communities of the site. Water supply from the south-eastern ditch (which originates within the plantation) appears to be less eutrophic.

High nitrogen levels in the fen communities are likely to result in deterioration of this habitat over time if the quality of groundwater that it receives does not improve. In contrast, the more tolerant requirements within reedbed suggest this habitat is within acceptable water quality levels on the SSSI.

It is noted that no Dissolved Oxygen levels were recorded for the sample points at Bailliewhirr. This determinant can be very useful in assessing suitability for certain NVC communities as it reflects the subsurface movement of water which some of the more ecologically value communities require.

Table 6. Groundwater samples at Bailliewhirr compared to Wetland Type for Scotland. Red text denotes sample exceeds 3rd quartile.

	Bailliewhirr	Bailliewhirr	Springs & seepages			Bailliewhirr	Bailliewhirr	Bailliewhirr	Bailliewhirr	Fen		
Sample	**GW1**	**GW3**	**1st Quartile**	**3rd Quartile**	**Guideline**	**GW1**	**GW2**	**GW3**	**GW4**	**1st Quartile**	**3rd Quartile**	**Threshold**
pH (-)										6.4	7.4	
Dissolved Oxygen (%)										18	28	
Conductivity (mS/cm)										0.37	0.69	
Calcium (mg/l)	56	51	5.7	76		56	26	51	44	12	55	
Magnesium (mg/l)	13	11	3.2	19		13	5.8	11	11	3.4	14	
Sodium (mg/l)	16	14	8.4	26		16	15	14	14	5.4	14	
Phosphate (mg/l)	0.07	0.061	0.09	0.1	None set	0.07	0.069	0.061	0.065	0.064	0.1	None set
Nitrogen (total) (mg/l)	5.02	10.1	0.5	4.2		5.02	4.91	10.1	6.98	1	5.1	
Nitrate (mg/l N-NO_3)	<0.5	8.4	0.25	0.25	Guideline: 2.05 (or 9 mg/l as NO3)	<0.5	<0.5	8.4	12	0.25	0.25	Threshold: <175 m Meso = 5 (or 22 mg/l as NO3) Olig = 4.5 (or 20 mg/l as NO3)

Table 6 continued. Groundwater samples at Bailliewhirr compared to Wetland Type for Scotland. Red text denotes sample exceeds target.

	Bailliewhirr	Bailliewhirr	Bailliewhirr	Bailliewhirr	Marshy grassland			Bailliewhirr	Bailliewhirr	Reedbed		
Sample	**GW1 (in M23)**	**GW2 (in M23)**	**GW3**	**GW4**	**1st Quartile**	**3rd Quartile**	**Indicator/ Guideline:**	**GW1**	**GW2**	**1st Quartile**	**3rd Quartile**	**Threshold**
pH (-)					6.3	7.1	5 to 8			5.7	6.5	
Dissolved Oxygen (%)					32	40				18	22	
Conductivity (mS/cm)					0.093	0.18				0.13	0.28	
Calcium (mg/l)	56	26	51	44	8	24		56	26	36	59	
Magnesium (mg/l)	13	5.8	11	11	2.5	8.7		13	5.8	5.8	18	
Sodium (mg/l)	16	15	14	14	6.2	12		16	15	12	19	
Phosphate (mg/l)	0.07	0.069	0.061	0.065	0.041	0.065	Indicator: 0.065	0.07	0.069	0.043	0.1	None set
Nitrogen (total) (mg/l)	5.02	4.91	10.1	6.98	2.5	7		5.02	4.91	1.1	6.9	
Nitrate (mg/l N-NO_3)	<0.5	<0.5	8.4	12	0.25	0.25	Guideline<175 m 5.9 (or 26 mg/l as N-NO3)	<0.5	<0.5	0.25	0.25	Threshold: 5 (or 22 mg/l as NO3)

3.4 Assessment of surface water samples

3.4.1 Current surface water quality status

Three surface water samples were taken from Bailliewhirr; one within the outflow of the site (SW1) and two within inflows from issues/drains (SW2 and 3). Due to the likely interaction of groundwater and surface water samples, the two sets of results were compared to assess their similarities. The surface and groundwater results can be found in Table 7.

As is to be expected, the surface water results from the watercourses are higher than groundwater results from within the wetland for a number of parameters (such as Calcium, Phosphate and Nitrogen). This will in part be due to the vegetation utilising some of these resources, but also suggests that at least some of the wetland vegetation is receiving fresh supplies of nutrient from the ditch to the north-west. SW2 (which was not supplied with grid references but is assumed to be taken from the main issues in the central wetland and therefore representing the purest groundwater input) showed the lowest levels of Nitrogen and Nitrate, but also Calcium and Magnesium. This implies the groundwater input into the site (from this spring at least) is not as base-rich as was first suspected.

Table 7. A comparison of groundwater and surface water parameters

	Bailliewhirr	Bailliewhirr	Bailliewhirr	Bailliewhirr	Bailliewhirr	Bailliewhirr
Sample	**SW1 - outflow**	**GW2**	**SW3 - inflow**	**GW4**	**SW2 - inflow**	**GW1**
Calcium (mg/l)	50	26	91	44	36	56
Magnesium (mg/l)	11	5.8	16	11	8.7	13
Sodium (mg/l)	17	15	16	14	15	16
Phosphate (mg/l)	0.16	0.069	0.061	0.065	0.062	0.07
Nitrogen (total) (mg/l)	8.11	4.91	19	6.98	7.04	5.02
Nitrate (mg/l $N\text{-}NO_3$)	19	<0.5	31	12	8.30	<0.5

Surface water results were compared to SNIFFER data (ER37 report) for the various vegetation communities at Bailliewhirr. Water chemistry guidelines generally refer to groundwater rather than surface water and therefore comparison can only typically be made between Bailliewhirr and the SNIFFER dataset for wetlands in Scotland. Table 8 indicates that the surface water within the ditches is not always consistent with the vegetation recorded by the SNIFFER dataset. High readings for parameters such as nitrogen and phosphate were recorded in the outflow (SW1) and the north-west inflow (SW3), beyond the levels typically found in reedbed, marshy grassland and fen.

Table 8. Surface water samples at Bailliewhirr compared with Wetland Type for Scotland (ER37 Draft). Red text denotes sample exceeds 3rd quartile.

	Bailliewhirr	Reedbed		Bailliewhirr	Bailliewhirr	Marshy grassland	
Parameter	**SW1 (near S4)**	**1st Quartile**	**3rd Quartile**	**SW2**	**SW3**	**1st Quartile**	**3rd Quartile**
pH (-)		6.6	6.8			6.5	7.5
Dissolved Oxygen (%)		63	81			61	70
Electric Conductivity (mS/cm)		0.23	0.26			0.2	0.71
Calcium (mg/l)	50	24	44	36	91	8.5	44
Magnesium (mg/l)	11	4	5.6	8.7	16	3.2	9
Sodium (mg/l)	17	6	20	15	16	6	14
Phosphate (mg/l)	0.16	0.01	0.055	0.062	0.061	0.005	0.058
Nitrogen (total) (mg/l)	8.11	1.8	6	7.04	19	1.5	6
Nitrate (mg/l N-NO_3)	19	0.21	4.6	8.3	31	0.4	8.6

Table 8 continued. Surface water samples at Bailliewhirr compared with Wetland Type for Scotland. Red text denotes sample exceeds 3rd quartile (except where low numbers of samples were available to establish the interquartile range).

	Bailliewhirr	Bailliewhirr	Springs and seepages		Bailliewhirr	Bailliewhirr	Fens	
Parameter	**SW2**	**SW3**	**1st Quartile**	**3rd Quartile**	**SW2**	**SW3**	**1st Quartile**	**3rd Quartile**
pH (-)			6.5	7.5			6.7	7.4
Dissolved Oxygen (%)			61	70			53	57
Electric Conductivity (mS/cm)			0.2	0.71			0.25	0.62
Calcium (mg/l)	36	91	29	29	36	91	13	38
Magnesium (mg/l)	8.7	16	3.6	3.6	8.7	16	5	8
Sodium (mg/l)	15	16	5.7	5.7	15	16	7	12
Phosphate (mg/l)	0.062	0.061	0.01	0.01	0.062	0.061	0.02	0.084
Nitrogen (total) (mg/l)	7.04	19	5	5	7.04	19	1.8	5
Nitrate (mg/l N-NO_3)	8.3	31	1.3	1.3	8.3	31	0.25	5.2

3.4.2 Summary of site vulnerability

Groundwater is considered to be the primary source of water feeding Bailliewhirr wetland and as such, the condition of the groundwater will define the health of the vegetation communities present here. Groundwater assessment provided in the previous sections shows that high Total Nitrogen and Nitrate levels were recorded in the north-west of the site, which exceed guidelines/thresholds for several wetland types (Springs and seepages, Marshy grassland and Fens). Phosphate levels also appear to be high when compared to the UKTAG mean phosphate levels for Fen communities, though they are consistent with the range observed in ER37 for Scotland. Surface water assessment also shows the best water quality is located in the ditch supplied by the main springs, but enriched water is present within the north-western ditch.

An assessment of vulnerability of the site to enrichment is given in Table 9 below.

Table 9. Assessment of the vulnerability of Bailliewhirr to eutrophication from catchment sources and their relative importance. Negative factors are shown in black, positive factors in blue.

Source	Bailliewhirr	
	Vulnerability	**Details of Factors**
EXTERNAL SOURCES		
1. Agriculture	Moderate	- A significant proportion of the land surrounding the SSSI is used as improved grassland, some of which appears to be providing enriched waters into the site. - The effect of eutrophication is somewhat ameliorated by the presence of good water quality from springs and seepages, which appears to be protecting the eastern side of the wetland.
2. Human population	Low	- Very few residential properties are present within the surface water catchment.
3. Aerial deposition	Low-Moderate	- Deposition rates within this part of the UK are lower than recorded in England. Thus atmospheric Total Phosphorus input into the catchment is small, although Total Nitrogen remains a contributor.
4.Regional Groundwater	Low	- Regional groundwater may be contributing to the site's water balance but is understood to be of good water quality.
INTERNAL SOURCES		
1. Wildlife	Low	- The site does not contain large numbers of bird species which would significantly contribute to the nutrient balance.
2. Site management	Moderate	- Some parts of the site that are grazed are understood to have small amounts of fertiliser added. No data was available on exact quantities.

3.5 Assessment of soil samples

Soil chemistry was sampled at four locations within Bailliewhirr (2 samples were in M23 *Juncus effusus/acutiflorus-Galium palustre* rush-pasture, with the potential for S4 *Phragmites australis* swamp and S27 Carex *rostrata-Potentilla palustris* fen) and 2 were in mire communities of unconfirmed NVC type (but possibly consisting of M10 *Carex dioica–Pinguicula vulgaris* mire, M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire and M23 *Juncus effusus/acutiflorus-Galium palustre* rush-pasture). Very little has been published about soil chemistry targets in terms of wetland types or NVC communities. However, the ER37 draft report presents summaries of the soil chemistry recorded across a number of sample locations in Scotland, which are used here as an indicator of any site abnormalities.

The ER37 data is based on: 20 samples across 8 sites for Reedbeds
49 samples across 13 sites for Marshy Grassland
60 samples across 19 sites for Fens
12 samples across 5 sites for Springs, seepages and flushes

Table 10 presents the soil chemistry data for Bailliewhirr samples against the ER37 data. It shows that levels of Magnesium, Sodium, extractable Phosphorus and extractable Nitrogen are all below the levels observed within the SNIFFER dataset. Total Nitrogen levels in all four samples from Bailliewhirr were above those typically recorded in marshy grassland, reedbed, springs and fen. Phosphate was also elevated in Soil sample 1 (GW1) across all four of the aforementioned vegetation types.

Soil sample 1 (GW1) was taken from the centre of the site in moderately humified peat overlaying soil rock c50 cm below the root zone, with the root zone having lower moisture content than below.

Soil sample 2 (GW2) was taken towards the outflow of the site in moderately humified peat, underlain by rock at c70 cm. This sample location had lower soil moisture content than at Soil sample 1, presumably due to the proximity of the outflow drain.

Soil samples 3 and 4 (GW3 and 4) were taken towards the western edge of the site in fibrous peat, again underlain by rock at c 40 cm. The soil moisture content was higher at the root layer than below, with soil sample 4 (at the top of the system) showing the lowest soil moisture content

Table 10. Soil samples at Bailliewhirr and soil chemistry recorded by Wetland Type in Scotland (ER37). Red text denotes sample exceeds typical range.

	Bailliewhirr		Bailliewhirr		Bailliewhirr		Bailliewhirr		Marshy Grassland		Bailliewhirr		Bailliewhirr		Reedbed	
Sample	**Soil1 Root (in M23)**	**Soil1 below (in M23)**	**Soil 2 Root (in M23)**	**Soil 2 below (in M23)**	**Soil 3 Root**	**Soil 3 below**	**Soil 4 Root**	**Soil 4 below**	**1st Quartile**	**3rd Quartile**	**Soil1 Root**	**Soil1 below**	**Soil 2 Root**	**Soil 2 below**	**1st Quartile**	**3rd Quartile**
Calcium (mg/kg)	780	1,300	750	1,800	1,400	2,100	2,800	2,400	160	4,200	780	1,300	750	1,800	1,700	13,000
Magnesium (mg/kg)	80	130	85	170	120	160	300	260	1,100	2,700	80	130	85	170	200	2,700
Sodium (mg/kg)	18	20	24	21	18	39	26	22	43	200	18	20	24	21	32	44
Phosphorus (available) (mg/l)	9.7	9.3	4.1	2.8	5.4	4.1	2.1	2.5	3.4	9.5	9.7	9.3	4.1	2.8	1.1	6
Nitrogen (total) (%)	2.2	2.1	2.5	2	2.6	2.2	2.2	2.2	0.05	0.78	2.2	2.1	2.5	2	0.99	1.7
Nitrogen (extractable) (mg/kg)	<0.1	0.21	<0.1	0.16	0.18	0.19	0.13	0.13	0.35	0.93	<0.1	0.21	<0.1	0.16	0.39	0.56
Total organic carbon (%)	3.7	4.7	3	6.2	4.7	7.6	11	9.3	2.1	20	3.7	4.7	3	6.2	5.5	22
Potassium (total)	<5.0	<5.0	26	<5.0	<5.0	<5.0	<5.0	<5.0	-	-	<5.0	<5.0	26	<5.0	-	-
Soil Moisture Content %	971	1,087	758	616	854	561	499	357	-	-	971	1,087	758	616	-	-

Table 10 continued. Soil samples at Bailliewhirr and soil chemistry recorded by Wetland Type in Scotland (ER37). Red text denotes sample exceeds typical range.

	Bailliewhirr		Bailliewhirr		Bailliewhirr		Bailliewhirr		Fen		Bailliewhirr		Springs & seepages	
Sample	**Soil 1 Root**	**Soil 1 below**	**Soil 2 Root**	**Soil 2 below**	**Soil 3 Root**	**Soil 3 below**	**Soil 4 Root**	**Soil 4 below**	**1st Quartile**	**3rd Quartile**	**Soil 3 Root**	**Soil 3 below**	**1st Quartile**	**3rd Quartile**
Calcium (mg/kg)	780	1,300	750	1,800	1,400	2,100	2,800	2,400	960	12,000	1,400	2,100	3300	18000
Magnesium (mg/kg)	80	130	85	170	120	160	300	260	1,500	3,800	120	160	1600	2100
Sodium (mg/kg)	18	20	24	21	18	39	26	22	74	280	18	39	250	650
Phosphate (available) (mg/l)	9.7	9.3	4.1	2.8	5.4	4.1	2.1	2.5	2.7	9.5	5.4	4.1	2.7	4.9
Nitrogen (total) (%)	2.2	2.1	2.5	2	2.6	2.2	2.2	2.2	0.25	1.4	2.6	2.2	0.2	1.4
Nitrogen (extractable) (mg/kg)	<0.1	0.21	<0.1	0.16	0.18	0.19	0.13	0.13	0.4	1.4	0.18	0.19	No data	No data
Total organic carbon (%)	3.7	4.7	3	6.2	4.7	7.6	11	9.3	3.7	12	4.7	7.6	3	44
Potassium (total)	<5.0	<5.0	26	<5.0	<5.0	<5.0	<5.0	<5.0	-	-	<5.0	<5.0	-	-
Soil Moisture Content %	971	1,087	758	616	854	561	499	357	-	-	854	561	-	-

3.6 Limitations

A number of factors will limit the possibility of drawing reliable conclusions relating to the potential eutrophication of this site. They include:

- No site visit was possible as part of the analysis within this report and therefore there has been no opportunity to gain first-hand knowledge of the site.
- Data was collected from a single sampling round which, though providing consistency of timing could be very misleading if for example weather conditions were atypical. Clearly a single sample round will also not reflect conditions experienced through the various seasons (such as those times of the year when fertiliser may be added or heavy rain may increase the amount of suspended solids and therefore nutrient loadings).
- The relationship between wetland types and Phosphorus targets is still under review and therefore levels which may appear to be acceptable now may change status if Phosphorus targets are more clearly defined.
- There were insufficient data for any statistical analysis.
- NVC survey data was not available; therefore very broad estimations were made based on vegetation descriptions from the Site Condition Monitoring and other available reports.
- As stated in the ER37 report, insufficient numbers of samples within certain wetland types have limited the possibility of defining thresholds, and therefore certain wetland types will need to be revisited once additional data has been gathered. In the short term, this means that wetland types such as Fens, which currently contains a wide range of NVC communities, may appear to be more tolerant of nutrient-rich situations than is actually the case. For example, assessment of lowland wetland communities across England and Wales (by Wheeler, Shaw and Tanner, 2009), states that M5 has a mean substrate fertility[3] (mg phytometer) of 13.8 (and a range of 4 to 29), whereas M10 has a mean substrate fertility of 6.5 (and a range of 3 to 18). Grouping these communities together will therefore inevitably blur any relationship to nutrient tolerance.

3.7 Recommendations on future measures and / or data requirements

There are a wide range of options for remedial measures within wetland systems. Some, such as the implementation of buffer zones, represent very little risk of negative impact and therefore can be implemented without the need for more detailed study. The risk with such early implementation is mainly that the measures may be placed in sub-optimal locations and therefore may result in an ineffective use of resources.

Other remedial measures, such as re-routing water supplies, de-silting or addition of water control structures, require a minimum level of supporting data in order to accurately assess their potential impact and effectiveness. These measures are not advisable without further investigation.

The recommendations for further investigation presented below are based on ensuring sufficient understanding exists so that any remedial measures focus on the area of greatest concern and can undergo risk/benefit assessment prior to implementation. The remedial options identified below are merely put forward for further consideration based on the characteristics of each site.

[3] Wheeler, Shaw and Tanner state that “Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

The initial assessment for Bailliewhirr, based on a single sampling round, suggests enriched water is entering the SSSI from the north and west (where improved grassland is present). This indication would need to be confirmed by the following data requirements:

- Ideally, monthly surface water sampling within existing points SW1, SW2 and SW3 for a full year to ascertain the patterns of enriched water movement across the site and whether it is acting as a sink for nutrients generated off-site.
- Rainfall data in the region for the period when surface water sampling takes place.
- A full NVC survey of the wetland communities present and their distribution.
- Further detail on the seasonal water levels present on the site (either through discussion with the site manager or, ideally, through collection of water level data by means of a gauge board or dipwell).

Once these data have been gathered and analysed it will be possible to assess the best means of protecting the ecological value of the site. Such measures could include:

- ***Reducing nutrient input*** - This is the most effective means of addressing eutrophication of the site. As the primary exporters of nutrients are improved grassland to the north and west it would require the support of neighbouring landowners prepared to reduce the application of fertiliser and slurry to their land, or to change their land use to semi-improved grassland in addition to reducing their livestock units per hectare. The advantage of this approach is the long-term sustainability of the wetland interest in the catchment. There are also likely to be benefits to other habitats such as dry grassland through reduction in nutrients.

- ***Redirecting problematic water sources*** – It may be possible to redirect the north-western ditch so that it bypasses the main area of wetland. The existing data would suggest the spring sources feeding the site are of better water quality than surface run-off. However, this method requires careful consideration of the water balance for the site to ensure sufficient water will still be available to supply the wetland. It is possible such a scheme could be detrimental to the site.

- ***Soft engineering options*** - There are several generally accepted soft engineering options available, all of which work on the principle of protecting wetland through a combination of chemical, physical and biological processes. These might include:

  Buffer Zones; Buffer zones of various kinds can be used to remove nutrients before they can enter the wetland (such as reedbeds, grass strips and woodland buffers). Nitrate in particular is removed both by bacterial processes (such as denitrification) and plant uptake. However the effectiveness of the buffer zone will depend on its size, condition of the vegetation, flow rate of water through the buffer and the underlying substrate. Hence buffer strips are generally more effective when they are 30-40m wide, with vegetation a few years old, on flat or gently sloping ground consisting of clay or humified organic material. Consequently, use of buffer zones would not be effective within fields containing steeply sloping land, which appears to be the case in certain parts of Bailliewhirr. Furthermore, the effectiveness of the buffer zone will be dependent on management, to ensure nutrients are removed via, for example, cutting and removal of vegetation.

  Ditch management; Ditches can be profiled to permit marginal wetland vegetation to establish, thus acting as a buffer strip. In addition, ditch clearance is only undertaken over short sections at a time and only when absolutely necessary, in order to maximise plant uptake, reduce velocity and increase residence time.

Vegetated filter strips and earth banks; Filter strips are thin lines of vegetation (often only 2 m wide) which are located within field or at field edges and are generally used to reduce run-off and soil erosion (e.g. “contour grass strips”). Earth banks provide a similar role but both methods are ineffective when on free-draining soils and so are not recommended within this catchment.

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ANNEX 1: WATER AND SOIL SAMPLES

Water samples

		Sample ID	GW1	GW2	GW3	GW4	SW1 (outflow)	SW2 inflow	SW3 inflow
Parameter	**Unit**	**Sample Date**	09/02/2012	09/02/2012	09/02/2012	09/02/2012	09/02/2012	09/02/2012	09/02/2012
Phosphorus (total)	mg l-¹	Water	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ammonium	mg l-¹	Water	0.23	0.4	0.17	0.15	0.06	0.12	0.06
Nitrate	mg l-¹	Water	<0.5	<0.5	8.4	12	19	8.3	31
Phosphate Low Level	mg l-¹	Water	0.07	0.069	0.061	0.065	0.16	0.062	0.061
Nitrogen (total)	mg l-¹	Water	5.02	4.91	10.1	6.98	8.11	7.04	19
Calcium	mg l-¹	Water	56	26	51	44	50	36	91
Magnesium	mg l-¹	Water	13	5.8	11	11	11	8.7	16
Sodium	mg l-¹	Water	16	15	14	14	17	15	16
Iron (II)	µg l-¹	Water	310	340	130	20	40	20	<20
Iron (III)	µg l-¹	Water	140	700	770	880	200	200	340
Iron (total)	µg l-¹	Water	450	1000	900	900	240	220	340

Soil samples

			Sample ID	S1	S1	S2	S2	S3	S3	S4	S4
			Other ID	Root	Below	Root	Below	Root	Below	Root	Below
			Sample Date	09/02/2012	09/02/2012	09/02/2012	09/02/2012	09/02/2012	09/02/2012	09/02/2012	09/02/2012
Parameter	**Unit**	**Detection Limit**	**Type**								
Moisture	%	0.02	Soil	91	91.5	89	84.7	88.8	80.6	79.9	74.8
Stones content (>50mm)	%	0.02	Soil	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Phosphorus (available)	mg l^{-1}	10	Soil	9.7	9.3	4.1	2.8	5.4	4.1	2.1	2.5
Phosphorus (total)	mg kg^{-1}	-	Soil	520	73	330	270	420	85	220	98
Nitrogen (total)	%	0.02	Soil	2.2	2.1	2.5	2	2.6	2.2	2.2	2.2
Nitrite (extractable)	mg kg^{-1}	0.1	Soil	<0.1	0.21	<0.1	0.16	0.18	0.19	0.13	0.13
Nitrate (extractable)	g l^{-1}	0	Soil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Calcium (total)	mg kg^{-1}	100	Soil	780	1300	750	1800	1400	2100	2800	2400
Potassium (total)	mg kg^{-1}	0.2	Soil	<5.0	<5.0	26	<5.0	<5.0	<5.0	<5.0	<5.0
Sodium (total)	mg kg^{-1}	0.2	Soil	18	20	24	21	18	39	26	22
Magnesium (total)	mg kg^{-1}	0.5	Soil	80	130	85	170	120	160	300	260
Total Organic Carbon	%	0.2	Soil	3.7	4.7	3	6.2	4.7	7.6	11	9.3
Moisture content	%	-	Soil	971	1087	758	616	854	561	499	357
Bulk density	Mg/m3	-	Soil	0.95	1	0.87	1.02	0.94	0.9	1.01	0.8
Dry density	Mg/m3	-	Soil	0.09	0.08	0.1	0.14	0.1	0.14	0.17	0.18

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