Scottish Natural Heritage
Research Report No. 1108

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

Scottish Natural Heritage
Dualchas Nàdair na h-Alba
nature.scot

RESEARCH REPORT

Research Report No. 1108

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

For further information on this report please contact:

Deborah Spray
Scottish Natural Heritage
Strathallan Business Park
STIRLING
FK9 4TZ
Telephone: 01786 450362
E-mail: deborah.spray@nature.scot

This report should be quoted as:

Spencer, K.L. & Pitcher, A. 2019. An assessment of the results of soil and water samples from a range of wetland sites – Lochindores SSSI. *Scottish Natural Heritage Research Report No. 1108.*

RESEARCH REPORT

Summary

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

Research Report No. 1108
Contractor: OHES Environmental Ltd
Year of publication: 2019

Keywords

nutrients; Lochindores 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 Lochindores, in order to assess the trophic status of the designated wetland and identify any likely sources of nutrient input.

Main findings

- Lochindores SSSI has a relatively small surface water catchment and appears to be fed by lime rich groundwater which seeps to the surface in places.
- Groundwater samples taken at Lochindores have been compared with the nutrient level requirements of the vegetation types known on site. This indicates that the groundwater quality is consistent with the requirements of the vegetation currently found around the sample locations (and is consistent with the data recorded for Scotland (ER37) and for guideline/threshold levels for these habitats). There was no NVC data available for Lochindores SSSI.
- Using the 2012 surface water samples and the Scotland River Basin District Directions (SRBDD) 2014 standards, the loch exceeds standards for Total Ammonia and JNCC guidelines for Total Nitrogen. However it is emphasised that this is from a single within-loch sample. At the time of the survey, the loch was within Phosphate concentrations for Moderate Ecological Status.
- Lochindores has two distinct areas of trophic state, the majority of the site is Mesotrophic but with localised eutrophic areas.
- Assessment of vulnerability showed Lochindores SSSI was most at risk from agricultural practices and that stored nutrient within the loch sediments may also be an issue.

- Further investigations are recommended for the site (such as monthly water quality sampling, sediment sampling within the waterbody and seasonal water level recording). A range of remedial options are proposed for consideration, once additional data have been gathered.

For further information on this project contact:
Deborah Spray, Scottish Natural Heritage, Strathallan Business Park, Stirling, FK9 4TZ.
Tel: 01786 450362 or deborah.spray@nature.scot
For further information on the SNH Research & Technical Support Programme contact:
Research Coordinator, Scottish Natural Heritage, Great Glen House, Leachkin Road, Inverness, IV3 8NW.
Tel: 01463 725000 or research@nature.scot

Table of Contents **Page**

1. INTRODUCTION **1**
1.1 Project background and aims 1

2. METHODOLOGY **2**
2.1 Sampling methodology 2
2.2 Analysis of results 3

3. ASSESSMENT **5**
3.1 Site review 5
3.1.1 Site designation and specific targets 5
3.1.2 Site hydrology 8
3.1.3 Site soils / sediments 11
3.1.4 Site specific issues 11
3.2 Assessment of vegetation data 13
3.2.1 Historic evidence of community change 13
3.2.2 Community requirements and targets 13
3.3 Assessment of ground water samples 18
3.4 Assessment of surface water samples 20
3.4.1 Threshold levels 20
3.4.2 Current surface water quality status 20
3.4.3 Summary of trophic state and site vulnerability 23
3.5 Assessment of soil samples 25
3.6 Limitations 28
3.7 Recommendations on future measures and / or data requirements 28

4. REFERENCES **30**

ANNEX 1: WATER AND SOIL SAMPLES **31**

Acknowledgements

OHES Environmental wish to thank Deborah Spray, Andrew McBride and the team of SNH Operations staff for their assistance in providing information on each site. We would also like to thank SNH, SEPA and SNIFFER for the release of the ER37 draft report on proposed eco-hydrological guidelines for Scottish wetlands before publication, in order to inform this report.

1. INTRODUCTION

1.1 Project background and aims

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 Lochindores, 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 Lochindores.

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 45-60cm 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 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

Lochindores is located in the Sidlaw Hills, 6km southeast of Coupar Angus (Figure 1). This site (17.49 ha) sits at 229 m and is a continuous basin and valley mire system surrounded by unimproved grassland which is important for the range of mire habitats present. To the west is Laird's Loch SSSI and to the north east is Balshando Bog SSSI.

The site is also noted for its invertebrates, including some uncommon flies and water beetles.

Until 1982, the site was grazed irregularly and lightly as there was a constant problem of cattle getting stuck in the mire, which resulted in considerable poaching. Birch and willow carr are encroaching on the eastern end of the site, as well as gorse scrub around the drier northern and western boundaries. Grazing by cattle in autumn only occurs to keep rank vegetation in check and open up the sward. The mire surface becomes unstable towards Lochindores Loch, resulting in the site now being fenced off. Figure 2 shows the site in the 1800s.

3.1.1 Site designation and specific targets

Lochindores SSSI was notified in 1984. The sites designated features and their pressures are detailed in Table 1. The transition between the different mire types is one of the best examples of its kind in Tayside. The range of fen communities, which include basin mires and flushes, are species-rich with uncommon species. The eastern side of the site is dominated by open birch woodland with an extensive *Sphagnum* dominated moss layer. The feature is also noted as suffering from scrub encroachment and some signs of drying out.

Table 1. Lochindores SSSI notified features and their pressures.

SSSI features	Feature Category	Summary Condition / Latest Condition	Pressure
Hydromorphological mire range	Wetlands	Unfavourable Recovering (Aug 2011)	a) Invasive species b) Water quality

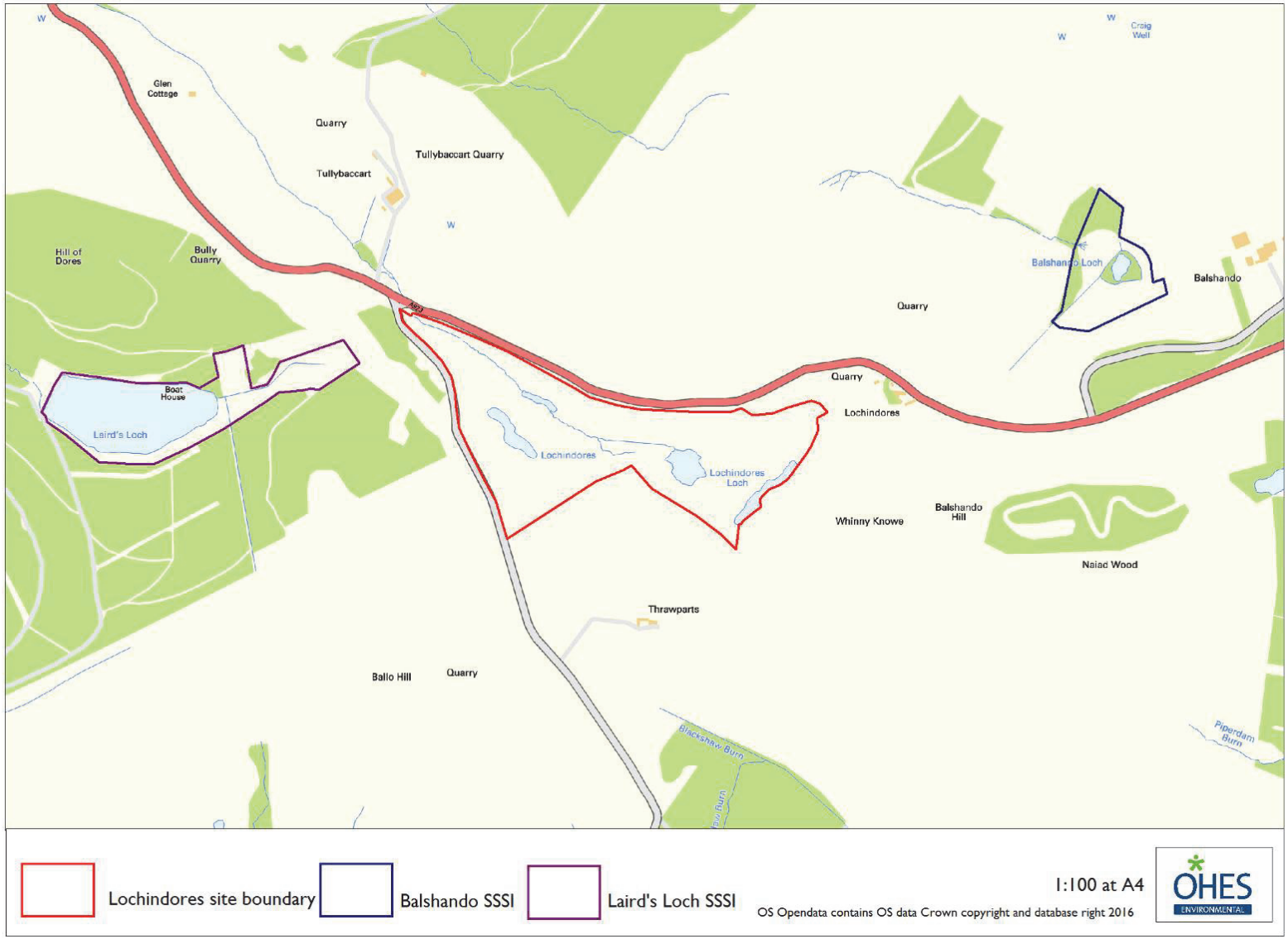

Figure 1. Site Boundary – Lochindores

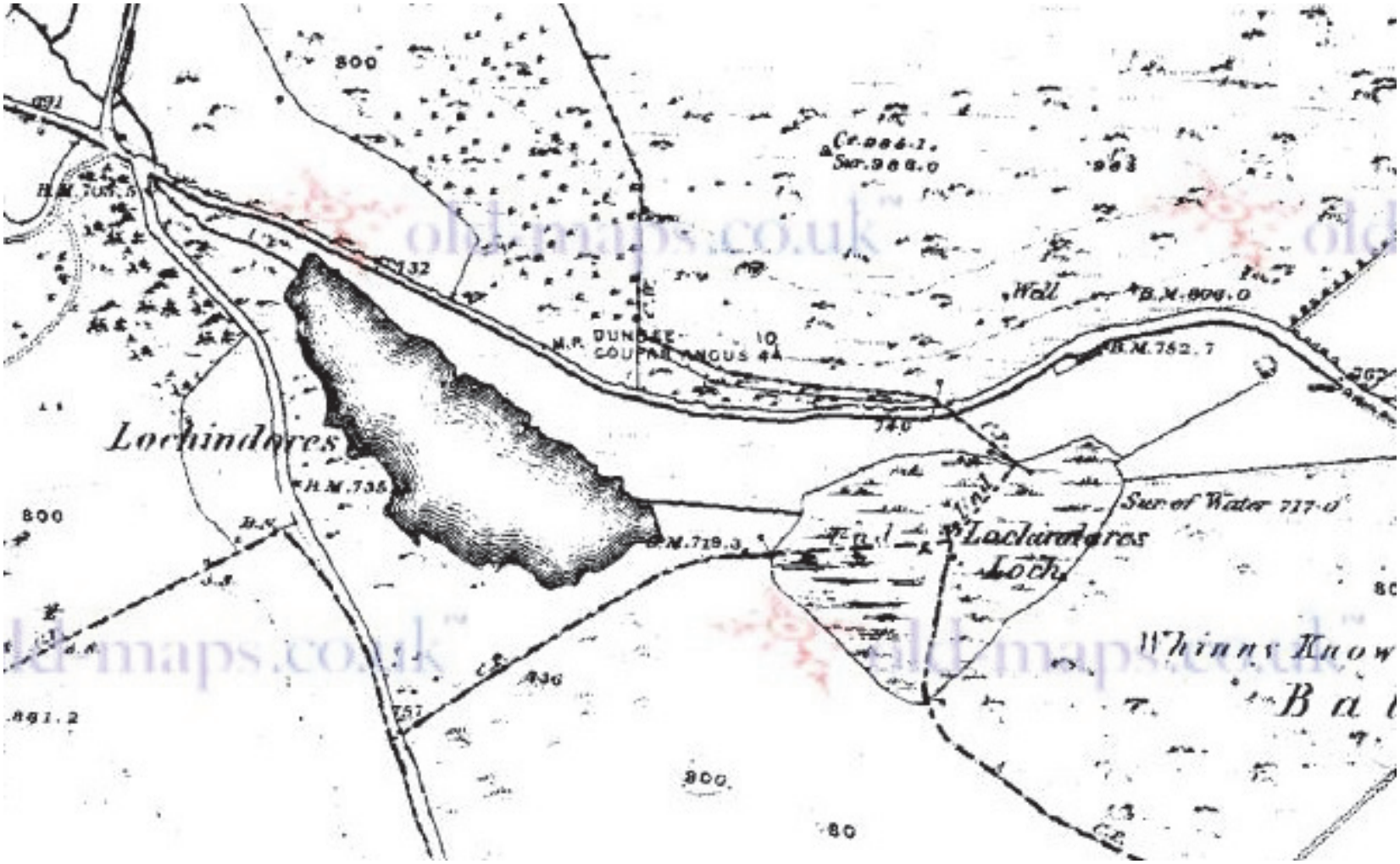

Figure 2. Ordnance Survey Six Inch 1843 – 1882 map (Source: National Library of Scotland)

3.1.2 Site hydrology

The site has a relatively small surface water catchment (Figure 3) and is known to be groundwater fed with lime rich waters that seep to the surface in places. The site is drained by a stream flowing from the site to the northwest (Figure 4). There is no inflow channel to the mire, but water seepage into the mire occurs below the road on the northern side. The site's two lochs are connected by an overgrown drain. The outflow stream has been artificially straightened and water levels have been altered in the past.

Lochindores is underlain by the Vale of Strathmore bedrock and extensive sand and gravel aquifers. In 2008 the groundwater was classified as 'Good' and the quantity as 'Poor' due to abstraction, and there was an upward trend in pollutants due to arable farming.

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 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 hydrologies composed of more than one WetMec type.

One of the limitations to this study is that little data were available to define detailed hydrological functioning for this site (such as dipwell data). Similarly, little information is available on the substrates present at Lochindores. However field notes recorded during the 2012 sampling generally showed peat underlain by sands and gravels (often super-saturated), sometimes with a layer of silt in between the two substrates. It can therefore be estimated that the site would be classified as WetMec 13: Seepage Percolation Basins (groundwater-fed basins typically with a transmissive surface layer and a buoyant surface), with combinations of WetMec 10: Permanent Seepage Slopes (summer wet surfaces usually on sloping, shallow peat) or WetMec 11: Intermittent Seepage Slopes (as 10 but seasonal spring presence) around the site margins. Internally, any areas marked out by ground slightly above the water table (so that precipitation is a more significant component of the water supply) would indicate WetMec 3: Buoyant, Weakly Minerotrophic Surfaces (transitional bogs). M4 *Carex rostrata – Sphagnum recurvum* mire is known to frequently occur within WetMec 3 and is believed to be present at Lochindores.

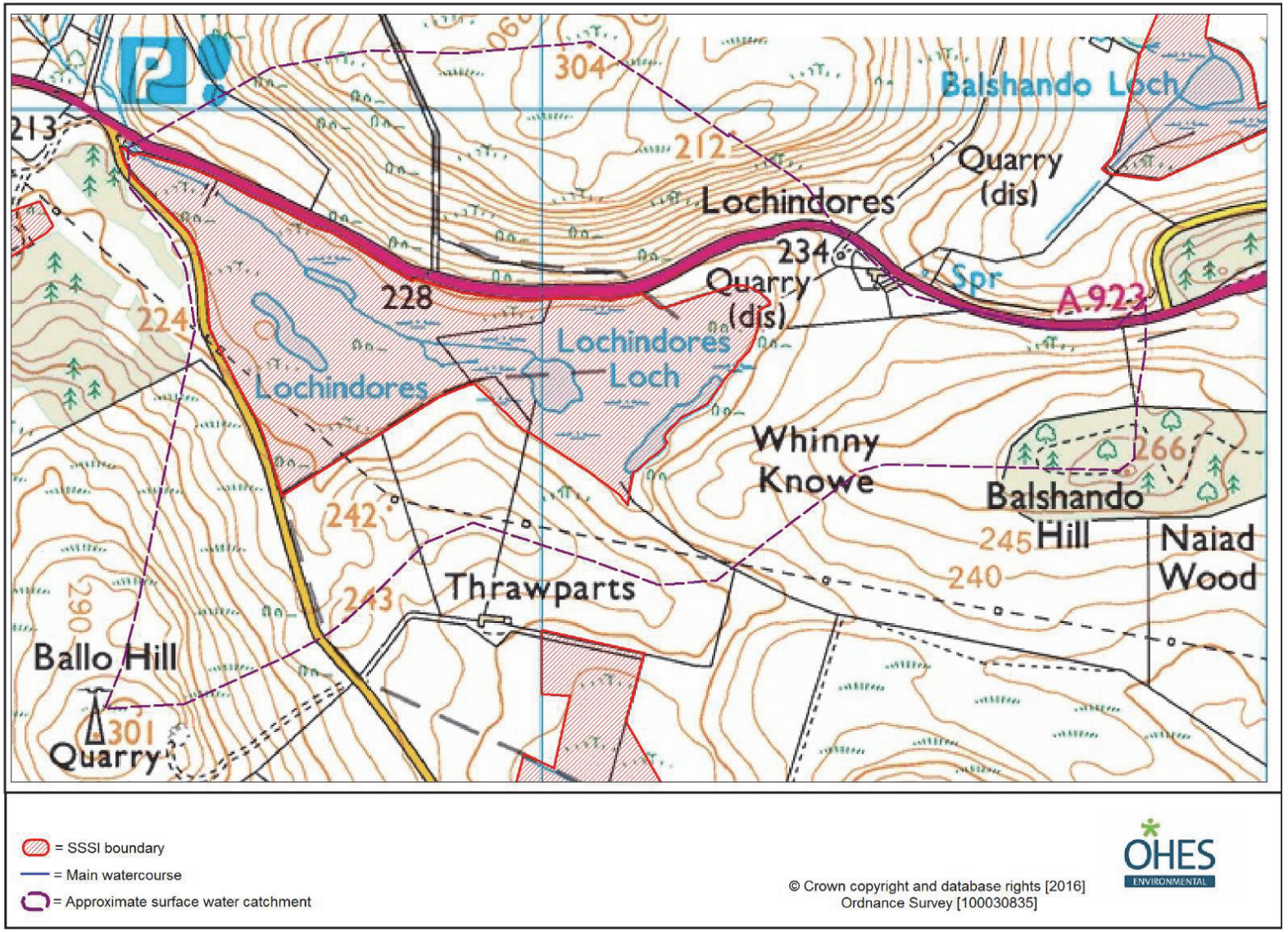

Figure 3. Lochindores – approximate surface water catchment

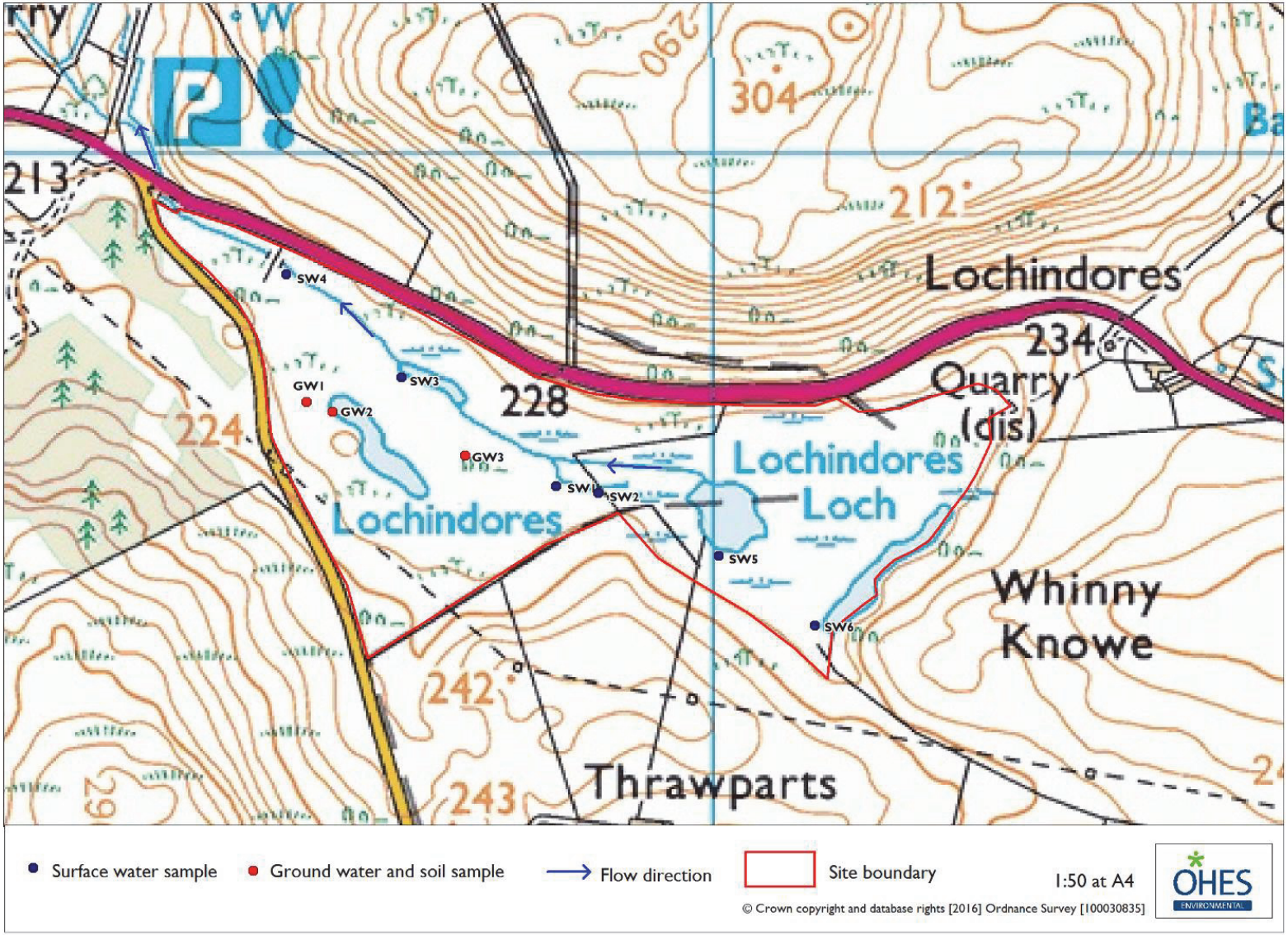

Figure 4. Lochindores – Hydrology and Sample Location

3.1.3 Site soils / sediments

Lochindores SSSI is marked as “Mixed Bottom Land” consisting of a wide range of soil types, including immature soils and alluvial soils. The Mountboy Association (shown in blue on Figure 5) occurs to the west and east, which is derived mainly from Old Red Sandstone lavas and sandstone. The imperfectly drained drifts vary in texture from loam to sandy clay loam. In some areas a coarse-textured drift derived largely from Old Red Sandstone sediments overlies lava rock. The remainder of the catchment is situated over the Darleith Association (shown in brown), derived from basaltic lavas and various basic intrusive rocks. The freely drained drifts are derived from a wide range of igneous rock, resulting in a range of textures. Figure 5 shows the distribution of soil types at Lochindores.

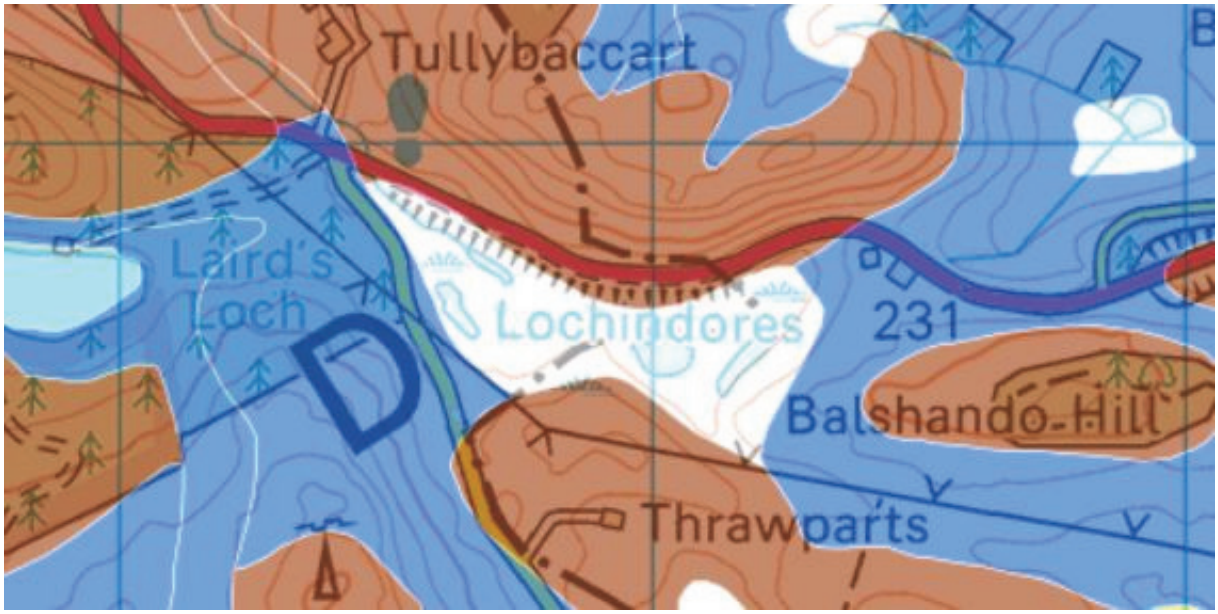

Figure 5. Lochindores – Soil types (source: Soil Survey of Scotland Staff, 1987)

3.1.4 Site specific issues

Diffuse pollution from agricultural activities in the catchment is believed to be increasing the nutrient load of the loch. A field abutting the far south-eastern side of the SSSI was identified during the 2013 SCM as possibly having caused some enrichment. This area has since been in a water margin under a Rural Development Contract to reduce nutrient runoff. Figure 6 identifies the possible nutrient sources at the site.

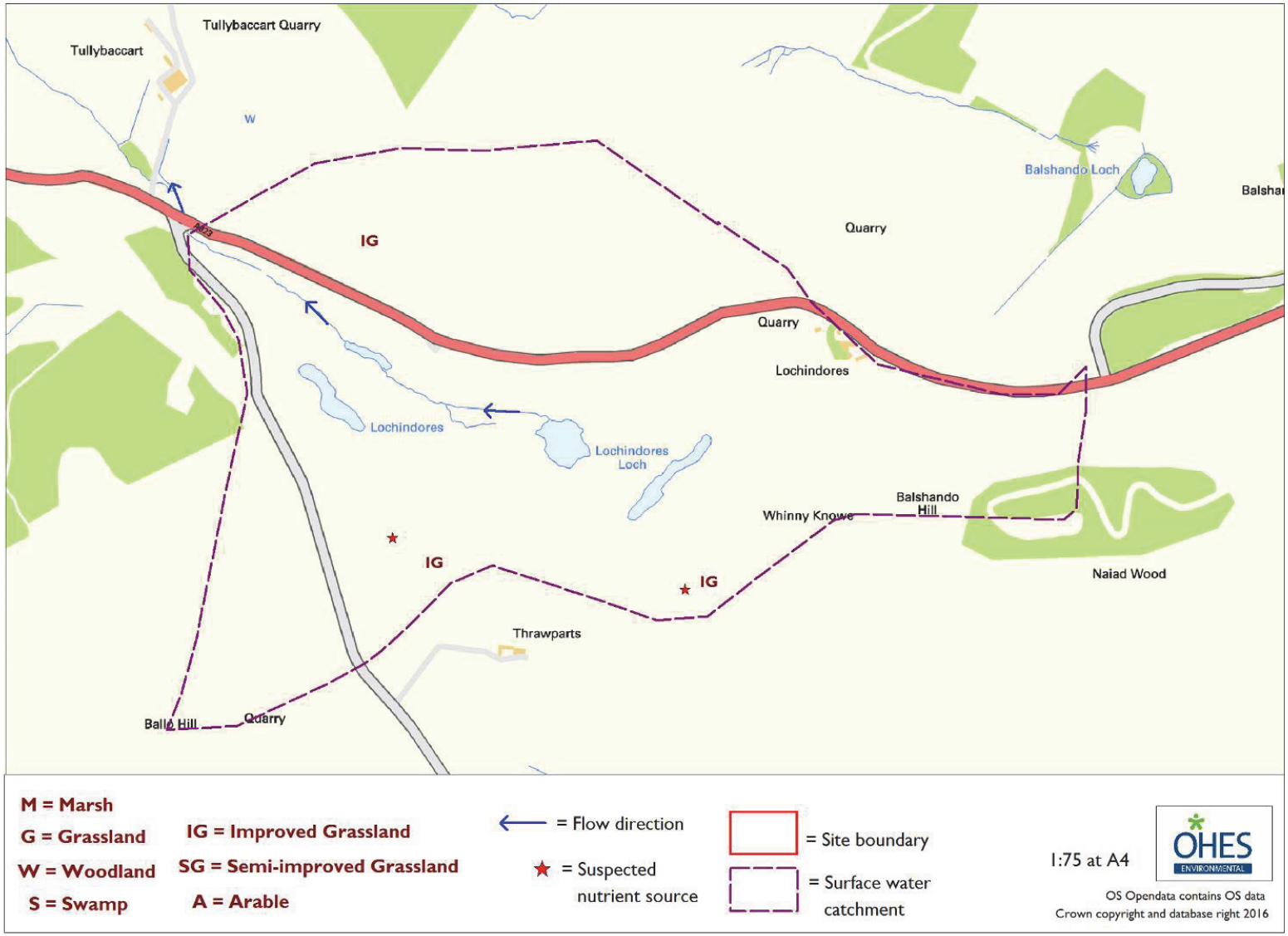

Figure 6. Land use and potential nutrient sources at Lochindores

3.2 Assessment of vegetation data

Lochindores SSSI contains a range of mire and swamp communities. Observations on the vegetation have been recorded in 2000, 2011 and 2013. However NVC data is not available for this site.

Observations of the vegetation communities at Lochindores (Site Condition Monitoring and site visit notes) record the presence of the following communities:

- M4 *Carex rostrata-Sphagnum recurvum* mire
- M5 *Carex rostrata-Sphagnum squarrosum* mire
- M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire
- M10 *Carex dioica-Pinguicula vulgaris* mire
- M23 *Juncus effusus/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 are unfortunately insufficient data to quantify changes in the total coverage of each community, however some key points are summarised below:

- *Juncus acutiflorus* cover during the 2011 Site Condition Monitoring was noted as being on average 20 % across the samples taken, resulting in the site target being met.
- The 2000 SCM categorised the site as Unfavourable - Declining due to scrub encroachment and drying out.
- In the 2011 and 2013 SCM there was no reduction in the area of the fen and all NVC communities were present, however M4, M5, M9 and M23 failed targets for floristic richness and / or scrub.
- During the 2013 SCM, the M4 lacked associates and the M5, M9 and S27 lacked characteristic species.
- The removal of scrub within the last two years appears to have already been beneficial to the condition of the open fen vegetation during the 2013 SCM. However significant amounts of grazing will need to occur to prevent re-establishment.

3.2.2 Community requirements and targets

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). The ER37 document presents guidelines on the eco-hydrological requirements of the different Scottish wetland types as described by WWF Consulting (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 potentially relevant to Lochindores SSSI are:

- Type 2a: Marshy grassland
- Type 3: Spring, flush and seepage
- Type 4: Fen
- Type 6: Reedbed

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)

The equivalent NVC types contained within these types are considerable, but those relevant to Lochindores 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 data and guidelines 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 0.045 mg/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 guidelines 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: 2 (or 9 mg/l as N-NO_3) for >175 m AOD

3.2.2.2 Type 3 Springs, flushes and seepages

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 Lochindores 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 have been recorded at Lochindores SSSI include:

- 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).

- M4 *Carex rostrata- Sphagnum recurvum* mire – occurs in pools and seepage areas across a range of mire situations, where waters are fairy acid and only slightly enriched (Rodwell, 1995). Calcium content in the source waters for M4 are believed to be less than those of M5 *C.rostrata-S.squarrosum* mire.

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 $N\text{-}NO_3$ for good condition and 6.4 mg/l $N\text{-}NO_3$ 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 $N\text{-}NO_3$. Phosphate levels are also typically below the detection limit of 0.2 mg/l PO_4 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 determinand.

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

	Springs/seepages			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Guidelines**
pH (-)				
Dissolved Oxygen (%)				
Electric Conductivity (mS/cm)				
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 NO_3)

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 Lochindores SSSI are:

- M4 *Carex rostrata–Sphagnum recurvum (S. fallax)* mire (see previous section)
- 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.
- M9 *Carex rostrata–Calliergon cuspidatum (Calliergonella cuspidata)/ Calliergon giganteum* mire – occurs on slope, stream-side, lochside and valley bottom/basin.
- M10 *Carex dioica-Pinguicula vulgaris* mire (see previous section)
- 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)

ER37 data and thresholds for Fens are presented in Table 4. UKTAG (2012 and 2014) states that 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 targets for Fen in Good Condition (Source: ER37)

	Fen			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Indicator**
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 = 2.04 (or 9 mg/l as NO_3) Olig = 0.91 (4 mg/l as NO_3)

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 UK TAG for groundwater are 22 mg/l but this value is significantly higher than was observed in Scottish reedbed. Thus ER37 state values between observed 1mg/l and UKTAG threshold of 22 mg/l should be viewed as an increasing risk.

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

	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	None set
Nitrogen (total) (mg/l)	1.1	3	6.9	
Nitrate (mg/l N-NO_3)	0.25	0.25	0.25	Threshold: 5 (or 22 mg/l as NO_3)

3.3 Assessment of ground water samples

Groundwater samples taken at Lochindores have been compared with the levels recorded in vegetation types as shown in section 3.2. Groundwater standards were used as opposed to surface water standards for several reasons. Firstly that almost all wetlands will have a component of groundwater influence, secondly that groundwater standards can often be more demanding than surface water standards and thirdly that the presence of a sandy base to the loch (as proved during the soil sampling) suggests some movement of water through the loch bed is possible.

Table 6 indicates that the vegetation currently found around the sample locations is consistent with the data recorded for Scotland (ER37) and is within guideline/threshold values for nutrient concentrations.

Table 6. Groundwater samples at Laird's Loch compared to Wetland Type for Scotland. Red text denotes sample exceeds 3rd quartile or guidelines/thresholds.

	Lochindore	Lochindore	Fen			Lochindore	Lochindore	Springs, flushes & seepages		
Sample	**GW1 (nr M5)**	**GW2 (in M9)**	**1st Quartile**	**3rd Quartile**	**Threshold**	**GW1 (in M10)**	**GW3 (in M4)**	**1st Quartile**	**3rd Quartile**	**Guideline**
pH (-)			6.4	7.4						
Dissolved Oxygen (%)			18	28						
Conductivity (mS/cm)			0.37	0.69						
Calcium (mg/l)	9.7	38	12	55		9.7	5.3	5.7	76	
Magnesium (mg/l)	1.5	3.6	3.4	14		1.5	<0.5	3.2	19	
Sodium (mg/l)	12	11	5.4	14		12	6.5	8.4	26	
Phosphate (mg/l)	0.059	0.056	0.064	0.1	None set	0.059	0.057	0.09	0.1	None set
Nitrogen (total) (mg/l)	1.5	5	1	5.1		1.5	7.5	0.5	4.2	
Nitrate (mg/l N-NO_3)	<0.5	<0.5	0.25	0.25	Threshold: >175m Meso = 2.04 (or 9 mg/l as NO_3) Olig = 0.91 (4 mg/l as NO_3)	<0.5	<0.5	0.25	0.25	Guideline: 2.05 (or 9 mg/l as NO_3)

3.4 Assessment of surface water samples

3.4.1 Threshold levels

There are currently several relevant documents providing guidance on water quality standards for surface waters in order to achieve Good Ecological Status (GES) or High Ecological Status (HES). The most up-to-date of these include the Scotland River Basin District (Standards) Directions 2014 (SRBDD, 2014) and JNCC Common Standards Monitoring for Freshwater Lakes (2015). However useful information is also available within the ECOFRAME report on implementation of the WFD by Brian Moss (2003).

For the purposes of this study, the primary standards used for variables are sourced from the SRBDD 2014 because they are the latest interpretation of the WFD for Scotland and are therefore highly relevant. The standards referred to in the other documents (such as JNCC standards) are referred to in some circumstances but it should be noted that, where they exist, the SRBDD standards are more stringent than CSM standards and therefore GES standards should be used for Favourable Condition targets of SSSI's. Where SRBDD standards are not provided a range of published documents are used to define those standards.

Under the SRBDD 2014, Lochindores is classified as very shallow (<3 m depth), freshwater, salmonid, high altitude (229 mAOD) lake of moderate alkalinity and >50 % calcareous bedrock. This equates to Ecotype 14 (small temperate lake, with a catchment geology of rock and a conductivity between 100 – 800 uScm) within the ECOFRAME document (Moss, 2003). Table 7 presents the SRBDD standards compared to those recorded from Lochindores, but owing to the fluid nature of the research and advice, represent a starting point.

Table 7. Water Quality standards for Lochindores

Variable	SRBDD (2014)		JNCC	ECOFRAME		Lochindores
	GES	HES		Good	High	
Total Ammonia as N	0.3 mg/l	0.2 mg/l	-	-	-	6.13 mg/l (Ammonium only)
Total Nitrogen	-	-	<1.5 mg/l	0.6 – 1.0 mg/l	<0.6 mg/l	3 mg/l
Acid Neutralising Capacity	>20 µeq/l	>40 µeq/l	>40 µeq/l	-	-	?
Dissolved oxygen	7 mg/l	9 mg/l	As SRBDD	-	-	?
Salinity/Conductivity	<1000 µScm		-	100 – 800µScm		?
Total Phosphorus	22 µg/l	15 µg/l	35 µg/l	30-50 µg/l	<30 µg/l	75 µg/l (Phosphate only)
pH	-	-	7 - 9	6 - 9		?

3.4.2 Current surface water quality status

Six surface water sampling points were monitored by SNH during the single sampling round (conducted in February 2012). These include: surface water immediately adjacent to three lochs (SW6, SW5 and SW3), an input channel (SW1 and SW2) and the outlet channel (SW4), see appendix 1 for raw data.

Figure 7 shows the results of Ammonium recorded at Lochindores against SRBDD standards for Total Ammonia. Results indicate that, at the time of survey, the two lochs at the top of the system were reasonably close to the specified level, but that the overgrown channel downstream was above specified concentrations. In particular, there appears to be

a high concentration of ammonia entering the system via the small inflow (SW1 and SW2), which is causing elevated concentrations in the surface water downstream of this point.

Total Nitrogen levels (as show in Figure 8) indicate that other forms of Nitrogen are also an issue. In this instance nitrogen appears to be entering the system at SW5 and SW6, which may be via the groundwater which feeds the site or via runoff from the catchment. Surface water at SW2 and SW1 were at Good and Moderate levels respectively, which may be helping to dilute the nitrogen concentrations for surface water sites downstream (SW3 and SW4).

Total Phosphorus levels were recorded at Lochindores but the levels of determination were below those useful in assessment against standards (i.e. all samples were marked as <0.2 mg/l). Instead, Phosphate Low Levels were recorded as being at Good Ecological Status at SW5 and SW6 and between Good Ecological Status and Moderate Ecological Status at SW2, SW3 and SW4 (Figure 9). Phosphate concentrations at SW1 were in excess of Poor, indicating that there is a possible source within the vicinity of this monitoring point, which has the potential to impact upon concentrations at downstream monitoring points (SW3 and SW4) although it does not appear to be impacting upon them currently.

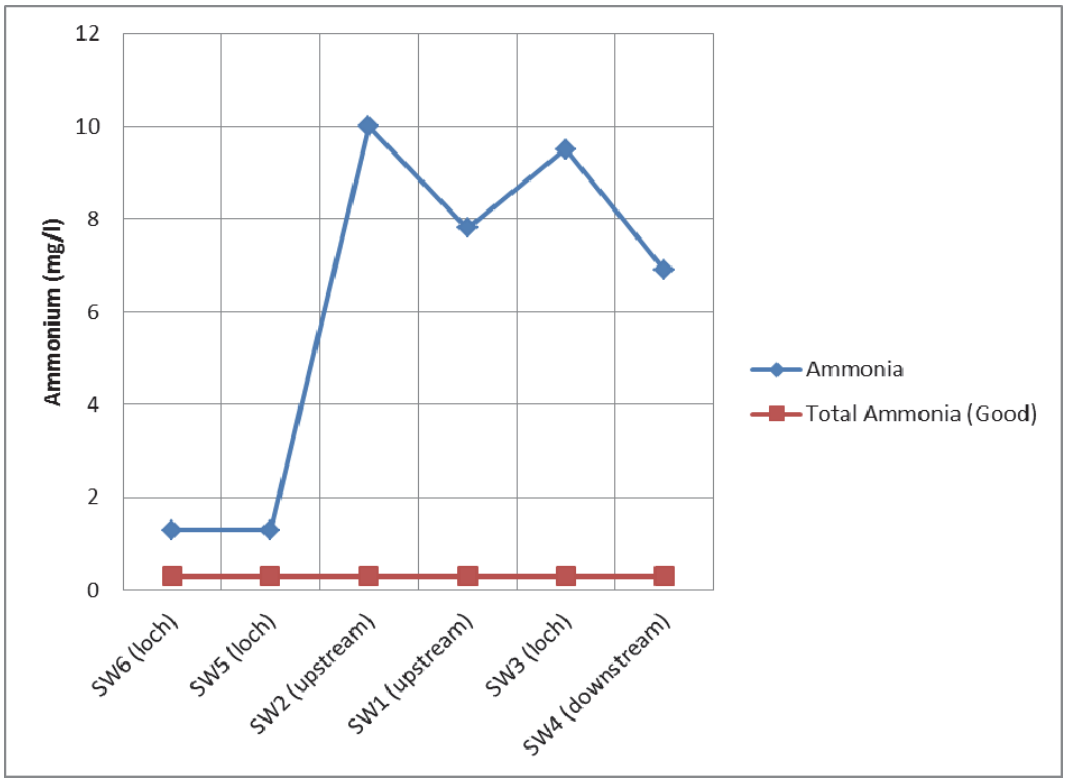

Figure 7. Ammonium recording at Lochindores (blue line) against SRBDD standards for Total Ammonia

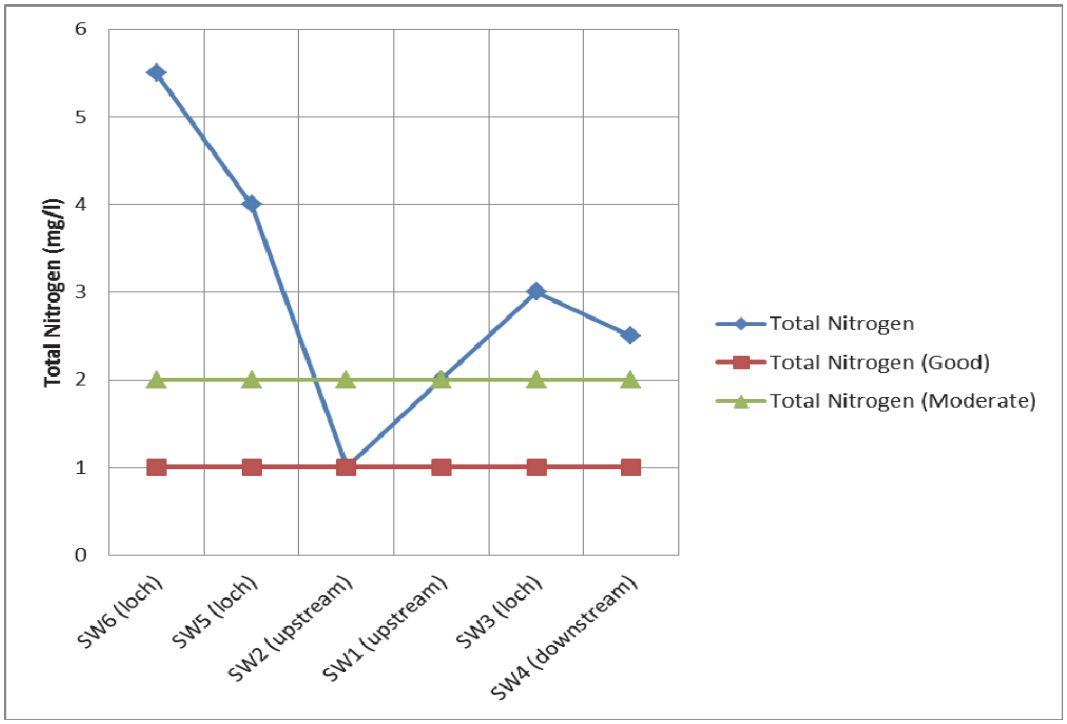

Figure 8. Total Nitrogen recording at Lochindores (blue line) against SRBDD standards

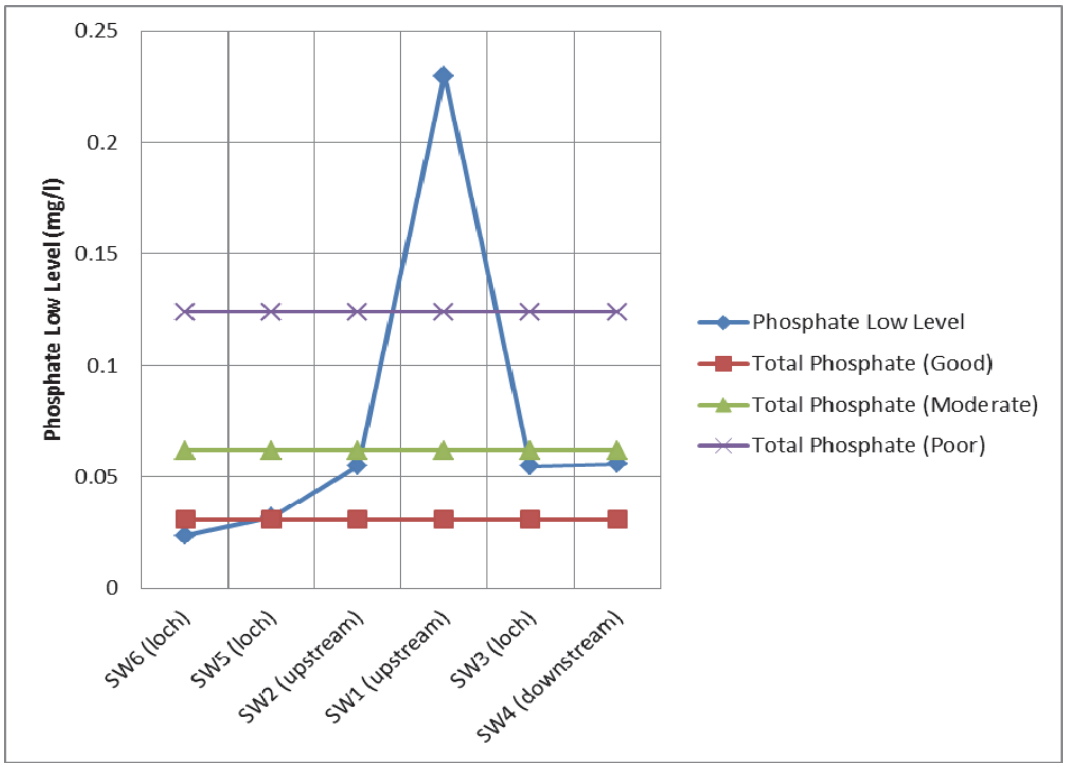

Figure 9. Total Phosphorus/Phosphate recording at Lochindores (blue line) against SRBDD standards.

3.4.3 Summary of trophic state and site vulnerability

Trophic state:

The categories of trophic state used within this report are as follows:

- **Dystrophic:** referring to those waterbodies with brownish waters as a result of high concentrations of humic substances and organic acids suspended in the water (also referred to as humic lakes). They are typically acidic and nutrient-poor (though this is not always the case).
- **Oligotrophic:** those waterbodies with low productivity as a result of low nutrient content. As a consequence, algal production is low and the waterbody retains very clear waters.
- **Mesotrophic:** namely lakes with an intermediate level of productivity, usually with clear waters and moderate cover of submerged plants.
- **Eutrophic:** referring to those waters with high biological productivity due to high levels of Nitrogen and Phosphorus. The water body may be dominated by either aquatic plants or algae.
- **Hypereutrophic:** those very nutrient-rich waterbodies which are characterised by frequent algal blooms and low visibility in the water column (less than 3 feet).

In addition to the definitions of trophic state provided in the JNCC CSM for freshwater lakes and the SRBDD 2014, the relationships between Trophic State/class and variables such as Phosphorus and Chlorophyll are shown in Table 8.

Lochindores appears to have two distinct areas of trophic state; the waterbodies at the head of the system (to the east) would both be classed as Mesotrophic based on the data available, however the waterbody further downstream shows increased phosphorus levels and therefore would fall into the Eutrophic category. Furthermore, the mire communities to the south-west of the site (which appear to be isolated from the inflow affecting SW1, SW2 and SW3) are all well within groundwater nutrient concentrations and guidelines for Scotland (ER37). Therefore this report concludes that the majority of the site is Mesotrophic, but with localised eutrophic areas.

Table 8. Nutrient status classification scheme (SEPA).

Description	Biological Factors	Chemical Factors
Oligotrophic (surrogate mean [TP] value; 8 $\mu g\ l^{-1}$)	High diversity, low biomass of biota. Phytoplankton blooms rare, macrophytes may be rare or adapted to low nutrient levels. Profundal benthos and plankton typical of nutrient poor lakes.	Mean total phosphorus ≤ 10 $\mu g\ l^{-1}$. Mean chlorophyll-*a* ≤ 2.5 $\mu g\ l^{-1}$. Max. chlorophyll-*a* ≤ 8.0 $\mu g\ l^{-1}$. Mean Secchi transparency ≥ 6.0 m. High oxygen concentration in hypolimnion.
Mesotrophic (surrogate mean [TP] value; 25 $\mu g\ l^{-1}$)	High diversity, variable biomass of biota. Phytoplankton blooms occur, macrophytes often diverse and abundant. Profundal benthos and plankton often intermediate between oligotrophic and eutrophic types.	Mean total phosphorus 10-35 $\mu g\ l^{-1}$. Mean chlorophyll-*a* 2.5-8 $\mu g\ l^{-1}$. Max. chlorophyll-*a* 8-25 $\mu g\ l^{-1}$. Mean Secchi transparency 6-3 m. Oxygen concentration may show some depletion in hypolimnion.
Eutrophic (surrogate mean [TP] value; 80 $\mu g\ l^{-1}$)	Lower diversity, high biomass of biota. Phytoplankton blooms occur regularly, macrophytes may be limited in diversity and abundance. Profundal benthos and plankton typical of nutrient rich lakes.	Mean total phosphorus 35-100 $\mu g\ l^{-1}$. Mean chlorophyll-*a* 8-25 $\mu g\ l^{-1}$. Max. chlorophyll-*a* 25-75 $\mu g\ l^{-1}$. Mean Secchi transparency 3-1.5 m. Oxygen concentration frequently depleted in hypolimnion.
Hypertrophic	Low diversity of tolerant biota, biomass may be very high. Severe phytoplankton blooms may be almost continuous, macrophytes may be limited to tolerant taxa or absent. Profundal benthos and plankton dominated by tolerant forms.	Mean total phosphorus ≥ 100 $\mu g\ l^{-1}$. Mean chlorophyll-*a* ≥ 25 $\mu g\ l^{-1}$. Max. chlorophyll-*a* ≥ 75 $\mu g\ l^{-1}$. Mean Secchi transparency ≤ 1.5 m. Severe oxygen concentration depletion in hypolimnion.

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

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

Source	Lochindores	
	Vulnerability	**Details of Factors**
EXTERNAL SOURCES		
1. Agriculture	Moderate - High	- Drainage of the catchment permits the flushing of fertiliser and nutrients into nearby watercourses which will eventually lead into parts of the wetland.
2. Human Population	Low	- Possible inputs from residential buildings at the east of the SSSI. - Possible runoff from the A923.
3. Aerial deposition	Low-Moderate	- Deposition rates within this part of the UK are lower than recorded in the south. Thus atmospheric Total Phosphorus input into the catchment is small, although Total Nitrogen remains a major contributor.
4. Regional Groundwater	Low	- The site is primarily groundwater fed and therefore regional groundwater may contribute to the water balance within the catchment. - The regional groundwater was recently classified as 'Good' quality.
INTERNAL SOURCES		
1. Wildlife	Low	- Species such as coots (which feed within the waterbody) will not represent an input of nutrients, whereas species such as geese (which often feed outside of a catchment but roost within it) can contribute significantly to Phosphorus and Nitrogen levels. - However, Total Phosphorus coefficients for individual birds are very small so that, even when occurring in large numbers, overall contribution to the nutrient budget is likely to be small.
2. Lake Sediment	Unknown	- A considerable store of nutrient may be present within the lochs in sediment form (both within the remaining open waterbodies and the historic parts of the loch which have terrestrialised). The seasonal release of stored nutrients within the sediments will occur naturally under certain conditions.

3.5 Assessment of soil samples

Soil chemistry was sampled at three locations within Lochindores (one was in M10 mire, one was in M4 mire and one was in M9 mire). Very little has been published about soil chemistry targets in terms of wetland types or NVC communities. However, the ER37 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
87 samples across 23 sites for Swamps

Table 10 presents the soil chemistry data for Lochindores samples against the ER37 data. The results show that for fen, the levels of nutrients recorded are generally within the inter-quartile range observed in Scottish samples. The exceptions are Soil samples 1 and 3 (GW1 and 3), where Phosphate levels were higher than typical below the root layer. However this could be the result of samples being taken from the historic loch bed (which has since terrestrialised).

All samples showed low levels of Nitrogen in all its forms, though it should be noted that all three soil samples were taken from the south-western part of the SSSI, which is an area seemingly less exposed to enrichment than the south-east.

Table 10. Soil samples at Lochindores and soil chemistry recorded by Wetland Type in Scotland (ER37)

	Lochindores		Lochindores		Lochindores		Fen	
Sample	**Soil 1 Root (in M10)**	**Soil 1 below (in M10)**	**Soil 2 Root (in M9)**	**Soil 2 below (in M9)**	**Soil 3 Root (in M4)**	**Soil 3 below (in M4)**	**1st Quartile**	**3rd Quartile**
Calcium (mg/kg)	2700	620	2800	1400	2500	1300	960	12,000
Magnesium (mg/kg)	460	2100	870	2200	700	1800	1,500	3,800
Sodium (mg/kg)	190	1500	190	380	150	75	74	280
Phosphate (available) (mg/l)	5.8	17	4.7	7	3.4	54	2.7	9.5
Nitrogen (total) (%)	0.08	0.86	0.02	0.27	0.15	0.16	0.25	1.4
Nitrogen (extractable) (mg/kg)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	1.4
Total organic carbon (%)	0.62	20	0.3	2.1	1.8	5.5	3.7	12
Potassium (total)	350	1400	330	200	180	170	-	-
Soil Moisture Content %	40	138	50	140	42	1760	-	-

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:

- NVC data was not available for Lochindores SSSI, therefore assumptions on vegetation types were based on field notes and the Site Condition Monitoring.
- 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 were 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.
- As stated in the ER37 report, insufficient numbers of samples within certain wetland types have limited the possibility of defining target thresholds, and therefore certain wetland types will need to be revisited once additional data have been gathered. In the short term, this means that wetland types such as fens, which currently contain 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). Both of these communities are currently placed within the same wetland type of "Fen" and are given the same threshold/guidance levels.

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 grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

The initial assessment of Lochindores SSSI, based on a single sampling round, suggests parts of the SSSI remain in good condition and groundwater quality should still support the wide range of mire communities found there. However, parts of the south-eastern portion of the site appear to be receiving enriched water, the most likely source being run-off or localised groundwater input from the adjacent improved grassland. Mention is made within the Site Management Statement that a field around this area is being managed to reduce enrichment to the SSSI, thus it is possible this issue is already being resolved since the 2012 sampling round.

This site would not appear to be a high priority for a full suite of additional monthly water quality monitoring. However, it is recommended that a full NVC is conducted in order to chart any loss of communities more effectively.

If the issue of localised enrichment has not already been addressed, possible remedial measures suited to the site could include:

- ***Reducing nutrient input*** - This is the most effective means of addressing eutrophication of the site. The primary exporters of nutrients appear to be agriculture to the south and east. Reduction of nutrient 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.

- ***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 30-40 m wide, with vegetation a few years old, on flat or gently sloping ground consisting of clay or humified organic material. Initial review of the available data would suggest that suitable substrate and topography is unlikely to be present at Lochindores, but this would need further investigation to be confirmed.

  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. Such ditch management is already likely to take place within the SSSI but could be extended into neighbouring agricultural land for additional benefit,

  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.

4. REFERENCES

Entec UK, 2009. A Functional Wetland Typology for Scotland. SNIFFER, Edinburgh.

Envirocentre, 2012. Wetland Soil and Water Samples: Summary report. SNH.

"ER37" EnviroCentre (draft February 2016).

Interagency Freshwater Group, 2015. Common Standards Monitoring Guidance for Freshwater Lakes. JNCC, Peterborough.

Moss, B. *et al*. 2003. The determination of ecological standards in shallow lakes – a tested system (ECOFRAME) for implementation of the European Water Framework Directive. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 13, 507-549.

Natural Scotland, 2009. The River Basin Management Plan for the Scotland River basin district 2009-2015.

Rodwell, J.S. 1995. British Plant Communities: Volume 4: Aquatic communities, swamps and tall-herb fens. Cambridge University Press: Cambridge.

Rodwell, J.S. 1991. British Plant Communities: Volume 2: Mires and heaths. Cambridge University Press: Cambridge.

The Water Framework Directive Directions (England and Wales) 2015.

UKTAG, 2008. UK Environmental Standards and Conditions (Phase 2).

UKTAG, 2014. Technical report on Groundwater Dependent Terrestrial Ecosystems (GWTDE) Threshold Values.

Wheeler, B.D., Gowing, D.J.G., Shaw, S.C., Mountford, J.O. & Money, R.P. 2004. Ecohydrological Guidelines for Lowland Wetland Plant Communities. Environment Agency, Anglian Region.

Wheeler, B.D., Shaw, S. & Tanner, K. 2009. A Wetland Framework for Impact Assessment at Statutory Sites in England and Wales. Environment Agency, Bristol.

WWT Consulting, 2007. Wetland Hydrogeomorphic Classification for Scotland. SNIFFER, Edinburgh.

ANNEX 1: WATER AND SOIL SAMPLES

Water samples

			Sample ID	GW1	GW2	GW3	SW1	SW2	SW3	SW4	SW5	SW6
Parameter	**Unit**	**Detection Limit**	**Sample Date**	21/02/2012	21/02/2012	21/02/2012	21/02/2012	21/02/2012	21/02/2012	21/02/2012	22/02/2012	22/02/2012
Phosphorus (total)	mg l^{-1}	0.2	Water	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ammonium	mg l^{-1}	0.01	Water	2.2	2.9	3.7	7.8	10	9.5	6.9	1.3	1.3
Nitrate	mg l^{-1}	0.5	Water	<0.5	<0.5	<0.5	0.8	<0.5	1.5	1.3	<0.5	6.1
Phosphate Low Level	mg l^{-1}	0.02	Water	0.059	0.056	0.057	0.23	0.055	0.055	0.056	0.032	0.024
Nitrogen (total)	mg l^{-1}	1	Water	1.5	5	7.5	2	1	3	2.5	4	5.5
Calcium	mg l^{-1}	5	Water	9.7	38	5.3	32	23	29	25	23	30
Magnesium	mg l^{-1}	0.5	Water	1.5	3.6	<0.5	5.6	4.7	5.5	4.7	5.7	6.6
Sodium	mg l^{-1}	0.5	Water	12	11	6.5	18	20	19	19	22	20
Iron (II)	µg l^{-1}	20	Water	<20	200	<20	<20	<20	<20	<20	<20	<20
Iron (III)	µg l^{-1}	20	Water	570	220	940	280	400	260	330	310	230
Iron (total)	µg l^{-1}	20	Water	590	420	940	280	400	260	330	310	230

Soil samples

			Sample ID	S1	S1	S2	S2	S3	S3
			Other ID	Below	Root	Below	Root	Below	Root
Parameter	**Unit**	**Detection Limit**	**Type**	21/02/2012	21/02/2012	21/02/2012	21/02/2012	21/02/2012	21/02/2012
Moisture	%	0.02	Soil	21.9	78.5	16.5	48.7	29.1	92.4
Stones content (>50mm)	%	0.02	Soil	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Phosphorus (available)	mg l-¹	10	Soil	5.8	17	4.7	7	3.4	54
Phosphorus (total)	mg kg-¹	-	Soil	3900	3300	4300	1600	4300	2900
Nitrogen (total)	%	0.02	Soil	0.08	0.86	0.02	0.27	0.15	0.16
Nitrite (extractable)	mg kg-¹	0.1	Soil	<0.10	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrate (extractable)	g l-¹	0	Soil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Calcium (total)	mg kg-¹	100	Soil	2700	620	2800	1400	2500	1300
Potassium (total)	mg kg-¹	0.2	Soil	350	1400	330	200	180	170
Sodium (total)	mg kg-¹	0.2	Soil	190	1500	190	380	150	75
Magnesium (total)	mg kg-¹	0.5	Soil	460	2100	870	2200	700	1800
Total Organic Carbon	%	0.2	Soil	0.62	20	0.30	2.1	1.8	5.5
Moisture content	%	-	Soil	40	138	50	140	42	1760
Bulk density	Mg/m3	-	Soil	1.71	1.32	1.61	1.33	1.62	0.99
Dry density	Mg/m3	-	Soil	1.22	0.56	1.08	0.55	1.14	0.05

www.nature.scot

ISBN: 978-1-78391-753-2

Great Glen House, Leachkin Road, Inverness, IV3 8NW
T: 01463 725000

You can download a copy of this publication from the SNH website.

recycle

Scottish Natural Heritage
Dualchas Nàdair na h-Alba
nature.scot