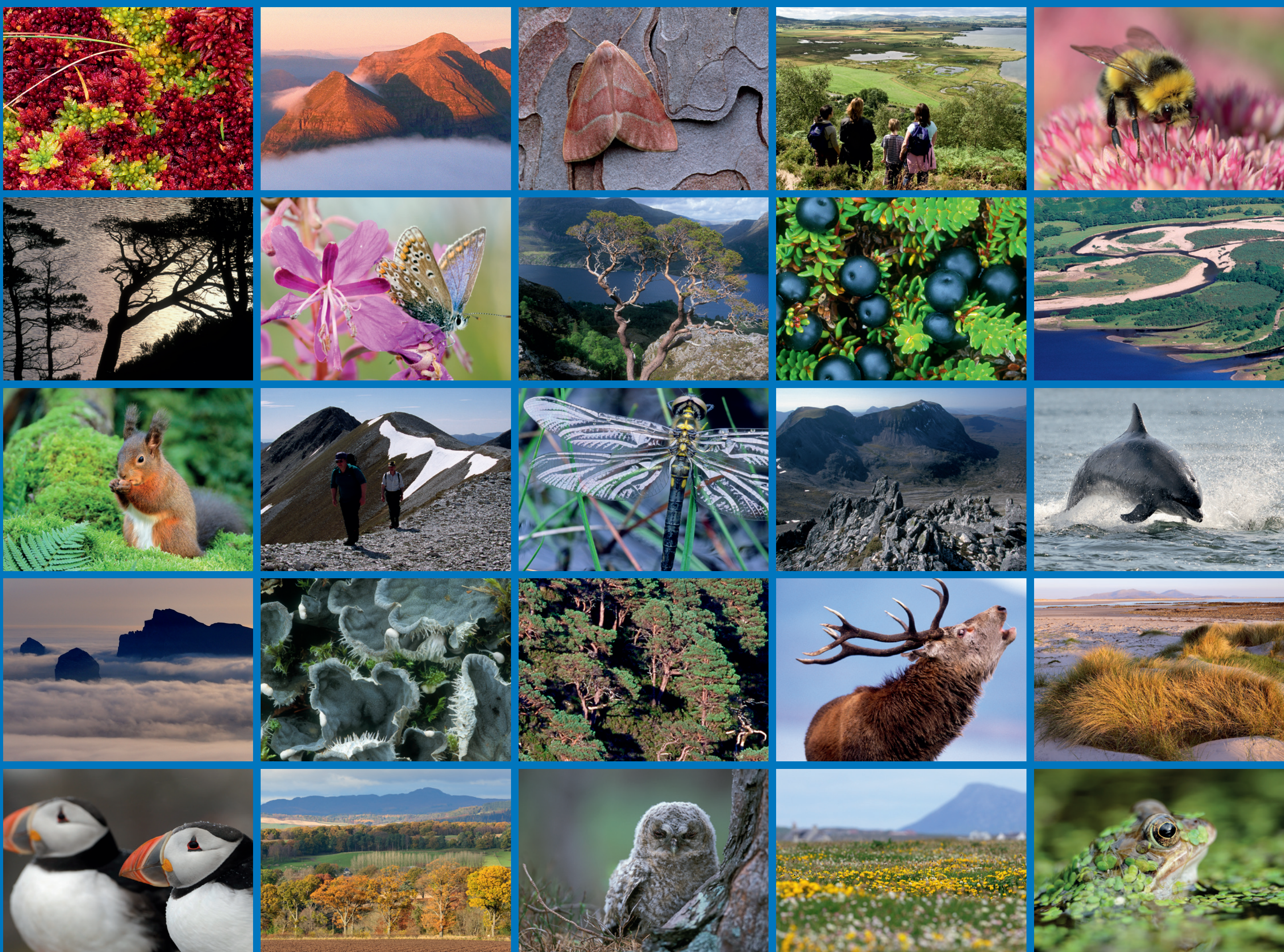
Scottish Natural Heritage
Research Report No. 1107

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



# RESEARCH REPORT

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RESEARCH REPORT

# Summary

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

**Research Report No. 1107**
**Contractor: OHES Environmental Ltd**
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**Keywords**

nutrients; diffuse pollution; wetland; Lindores Loch 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 Lindores loch, in order to assess the trophic status of the designated wetland and identify any likely sources of nutrient input.

**Main findings**

- Lindores Loch SSSI is fed by groundwater seepage into the loch and a small number of groundwater-fed ditches. The groundwater quality will therefore have a strong influence on the quality of the loch. Lindores Loch has a small surface water catchment and a low flushing rate (with a turnover rate of approximately 8 months).
- A total phosphorus level of 217.3 $mg^{-1}$ was recorded in 2004, which is well in excess of the expected range for a mesotrophic loch. There have been persistent problems with increased nutrient inputs to the loch, resulting in changes in the composition of vegetation communities.
- Groundwater samples taken at Lindores Loch SSSI 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). However, both of these vegetation types are able to tolerate eutrophic situations and therefore are no indication of a low trophic status. In fact, the higher than typical Total Nitrogen levels recorded in the reedbed samples are some cause for concern.
- Using the 2012 surface water sample and the Scottish River Basin District Directive (SRBDD) 2014 standards, the loch appears to exceed standards for Total Ammonia and Total Phosphorus, as well as JNCC guidelines for Total Nitrogen. However it is emphasised that this is from a single sample.
- The results suggest that the loch may be acting as a sink for nutrients, with water quality improving downstream when compared to samples near the loch. The elevated reading at SW3 suggests that there is a source of Phosphate local to this sampling point. A

possible source could be pig slurry which has historically been spread on the surrounding fields and may be a cause of the high Phosphate concentrations at this location.

- Given that both Nitrogen and Phosphorus levels are significantly above targets for GES, this report concludes that the trophic state of Lindores Loch surface water is Eutrophic.
- Assessment of vulnerability showed Lindores Loch SSSI was most at risk from agricultural practices, historic input of sewage, historic site management practices and possibly release of stored nutrient from loch sediments.
- Further investigations are recommended for the site (such as monthly water quality sampling on all inflows, sediment sampling within the loch and seasonal water level monitoring). A range of remedial options are proposed for consideration, once additional data have been gathered.

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**Acknowledgements**

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# 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 Lindores Loch, 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 but 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 Lindores Loch.

### 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 6$^{th}$ February 2012 and the 20$^{th}$ 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 condition 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).

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[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

Lindores Loch SSSI is located immediately south of the village of Lindores in north-west Fife. The 53.93 ha site lies between the railway, A913 to Coupar and B937 and is comprised of two parts (separated by a railway line). It is a relatively large open loch with associated areas of fen, alder / willow carr and extensive freshwater transition mire (Figure 1). The loch is at an altitude of 68 m AOD, has a surface area of 40.5 ha, a mean depth of 1.5 m and a maximum depth of 3 m.

The non-native species Canadian pondweed has become established at the loch since the mid-1980s. Lindores Loch is one of two sites in Scotland to have a particular flightless water beetle species. In Britain the beetle is not normally found north of York and Anglesey.

The loch was used as a fishery of perch and pike until 1966 when poisoning of the coarse fish was carried out (using Rotanone) to clear the loch for the introduction of brown and rainbow trout. In subsequent years, the loch has operated as a trout fishery.

Shooting has been carried out by the landowner. There are piers and a mooring area, a car park and an office, which have modified the natural shore profile on the south-eastern perimeter.

Previous studies suggest the loch is naturally alkaline and has experienced increased eutrophication. Consequently, it has undergone increased planktonic production, increased diatoms associated with nutrient-rich water, a reduction in diversity of zooplankton communities and a decline in the diversity and conservation interest of the aquatic plant communities. Cyanobacteria algal blooms and foam occur at Lindores loch. Experimental treatment of algal blooms were carried out in 1995 using bales of barley straw, which retard algal growth. There has been a marked shift towards more nutrient tolerant plant species. Since 1900, four aquatic species have died out: autumnal water-starwort, common water-starwort, needle spike rush and alternate water-milfoil. The most marked changes appear to coincide with fish stocking in the 1960s, however there is evidence of progressive enrichment over 100 years ago. Figure 2 shows Lindores Loch in the 1800s.

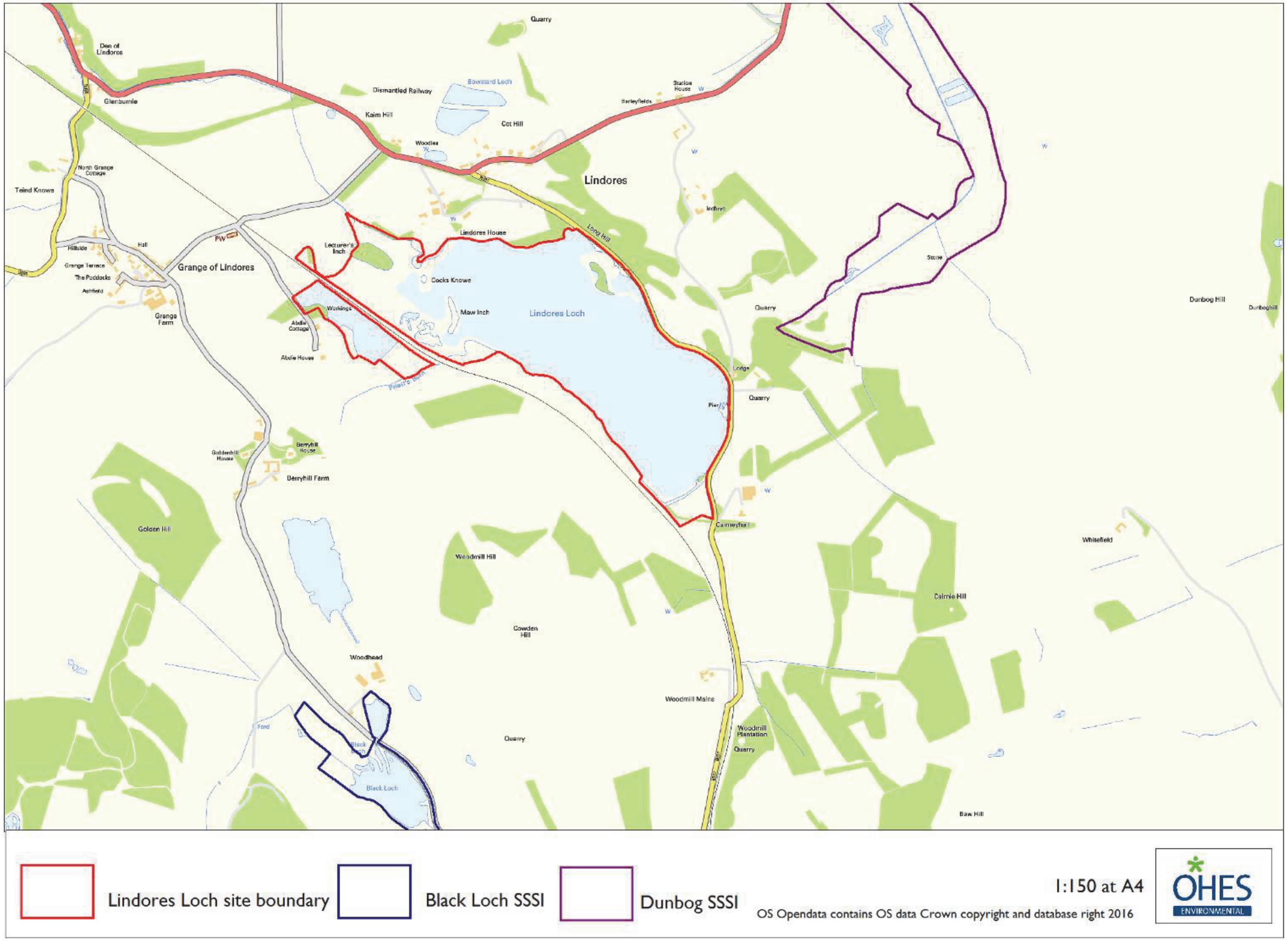


*Figure 1. Site Boundary – Lindores Loch*


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

### 3.1.1 Site designations and specific targets

The SSSI was first designated in 1972 and was re-notified in 1986 with a slight decrease in area. The features for which the site is notified can be found in Table 1, along with their pressures. The standing water habitat consists of a relatively large, hard mesotrophic loch with extensive stonewort beds and at least six species of pondweed. The freshwater transition mire is the most extensive and least disturbed example of this habitat type in the area and supports a diverse vascular plant flora, along with the adjoining rich-fen and alder-willow carr.

There is a diverse breeding bird community present including several regionally uncommon waterfowl species such as great crested grebe and water rail. The site has historically held up to 25% of the UK black-necked grebe population with breeding pairs between the 1940s to mid-1980s; however no breeding records have been noted since 1990.

*Table 1. Lindores Loch SSSI and its notified features and pressures*

| SSSI features | Feature Category | Summary Condition / Latest Condition | Pressure |
|---|---|---|---|
| Breeding bird assemblage | Birds | Unfavourable Recovering (Jun 2008) | a) Game/fisheries management<br>b) Water quality |
| Mesotrophic loch | Freshwater habitats | Unfavourable No Change (Jul 2004) | a) Game/fisheries management<br>b) Invasive species |

### 3.1.2 Site hydrology

The site is fed by groundwater seepage into the loch and a small number of groundwater-fed ditches. The spring-fed ditch to the east has been provisionally included within the surface water catchment as it is possible (but currently unclear) if this channel feeds into Lindores Loch or Dunbog Bog. Three other springs are located within the catchment which presumably feed into Lindores Loch. The groundwater quality will therefore have a strong influence on the quality of the loch.

Water is presumed to exit the site to the north-west, with one inflow from the south-west (Figure 3). Lindores Loch has a small surface water catchment (see Figure 4) and a low flushing rate (with a turnover rate of approximately 8 months).

Lindores Loch is underlain by the Glenfarg bedrock and localised sand and gravel aquifers. In 2008, the groundwater quality was classed as 'Poor' with the quantity classed as 'Good'. An upward pollutant trend was identified with diffuse source pollution from mixed farming and non-urban land management measures as a pressure.

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. Similarly, very little information is available on the substrates present at Lindores Loch (other than the presence of peat over sands and silts, with freedraining surrounding upland). Application of systems such as the WetMecs scheme requires detailed information on both these factors before it can be accurately applied. As a consequence, it can only be postulated that the site would probably be classified as WetMec 13: Seepage Percolation Basins (groundwater-fed basins where the summer water table is near the surface, springs and seepages are often visible around the periphery and the basal substrate is sands or gravels).


*Figure 3. Lindores Loch – Hydrology and Sample Locations*

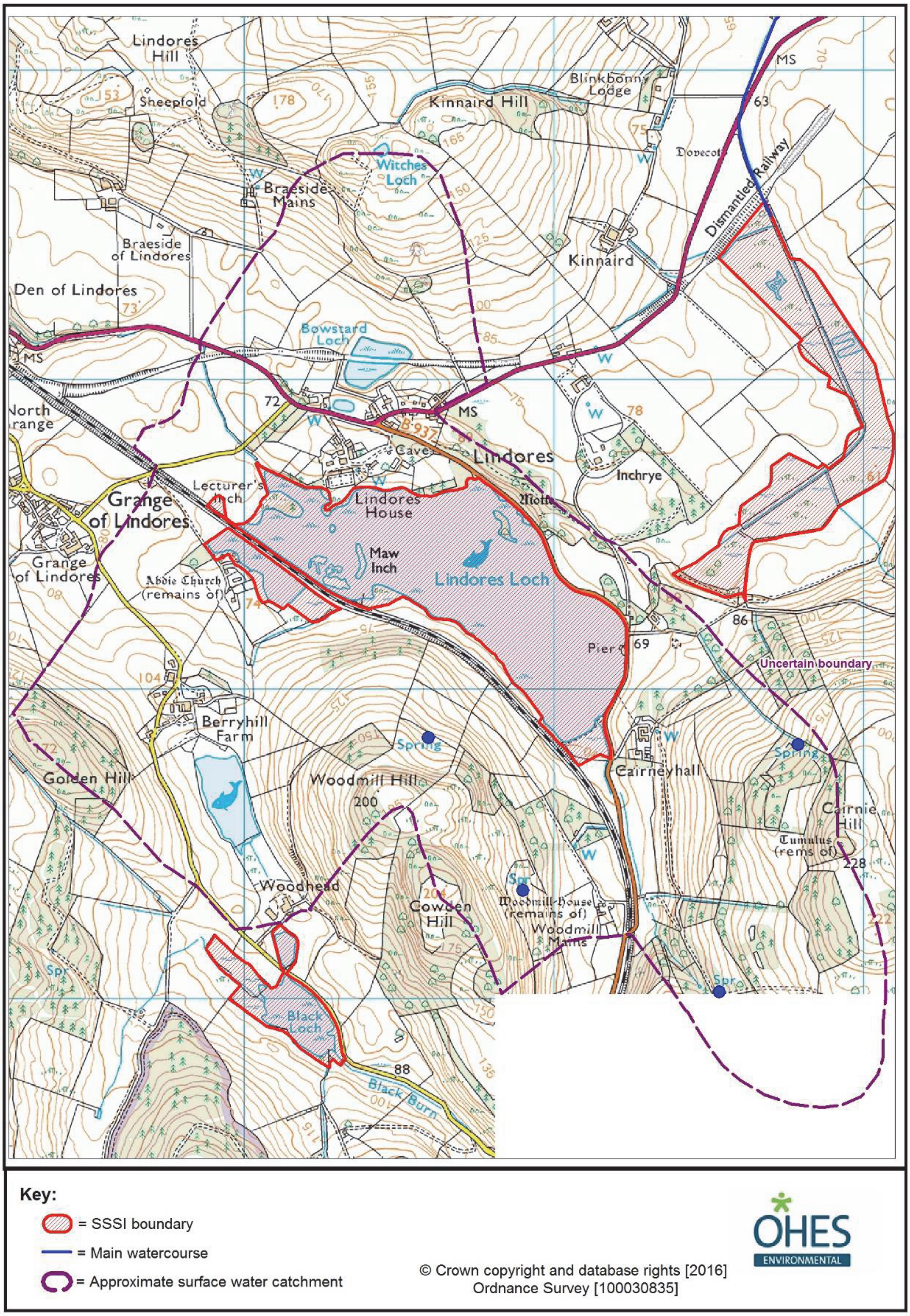


*Figure 4. Lindores Loch – approximate surface water catchment*

### 3.1.3 Site soil / sediments

To the north and east of Lindores Loch lies the freely drained Gleneagles Association, derived from Glacio-fluvial deposits of sands and gravels, derived mainly from sediments and lavas of Lower Old Red Sandstone age with some acid schists. To the west lie Alluvial soils, derived from recent riverine and lacustrine peaty alluvial deposits. To the south of Lindores Loch is the Southope Association. These freely drained drifts are derived from andesitic and intermediate lavas of Lower Old Red Sandstone age. Figure 5 shows the distribution of soil types at Lindores Loch.

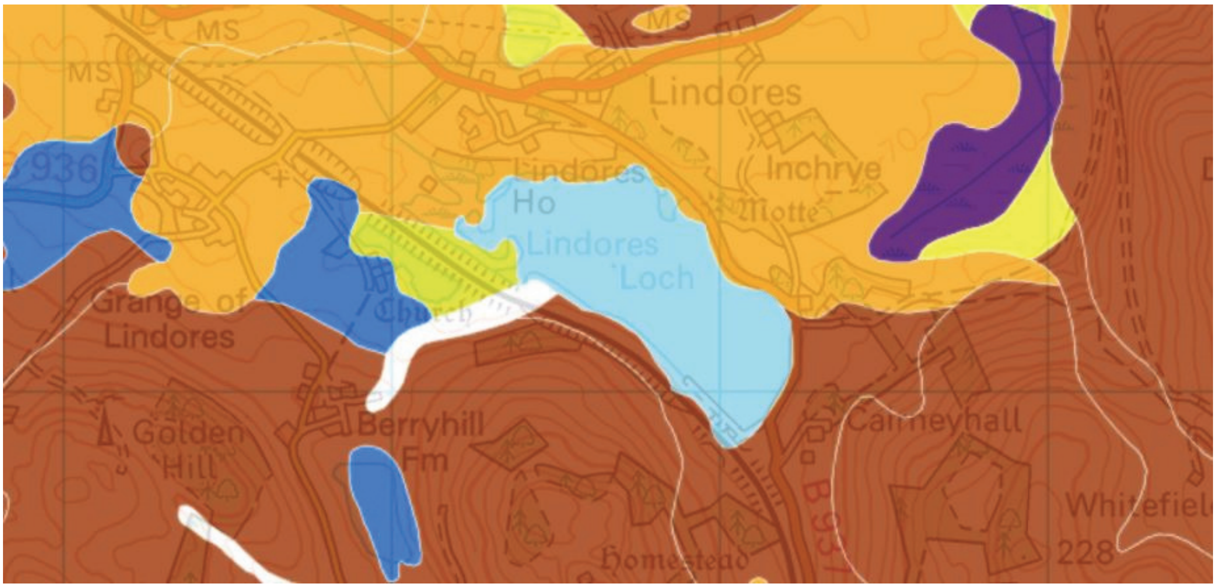


*Figure 5. Lindores Loch – Soil types (source: Soil Survey of Scotland Staff, 1987).*

### 3.1.4 Site specific issues

A total Phosphorus level of 217.3 $mg^{-1}$ was recorded in 2004, which is well in excess of the expected range for a mesotrophic loch. There have been persistent problems with increased nutrient inputs to the loch, resulting in changes in the composition of vegetation communities. Spreading of pig slurry from the nearby piggery on adjacent fields was common until 1982 and raw sewage from Lindores House was noted discharging into the loch by the fisheries manager in 1992. A number of point sources of diffuse pollution have been identified and could be improved through the creation of buffer strips next to arable fields within the loch catchment area. A trough for watering stock could be installed to prevent drinking from a burn that feeds directly into the loch and thus disturbing sediment. There is also believed to be an accumulation of Phosphorus in the loch itself, within the sediments. Areas of rainfall runoff associated with high nutrient loads were identified and mapped by SEPA, as well as land use as part of a nutrient budget study (see figure 6). Livestock was found to be the major contributor to the Phosphorus budget of the catchment. Figure 7 shows the locations of these possible sources of nutrients.

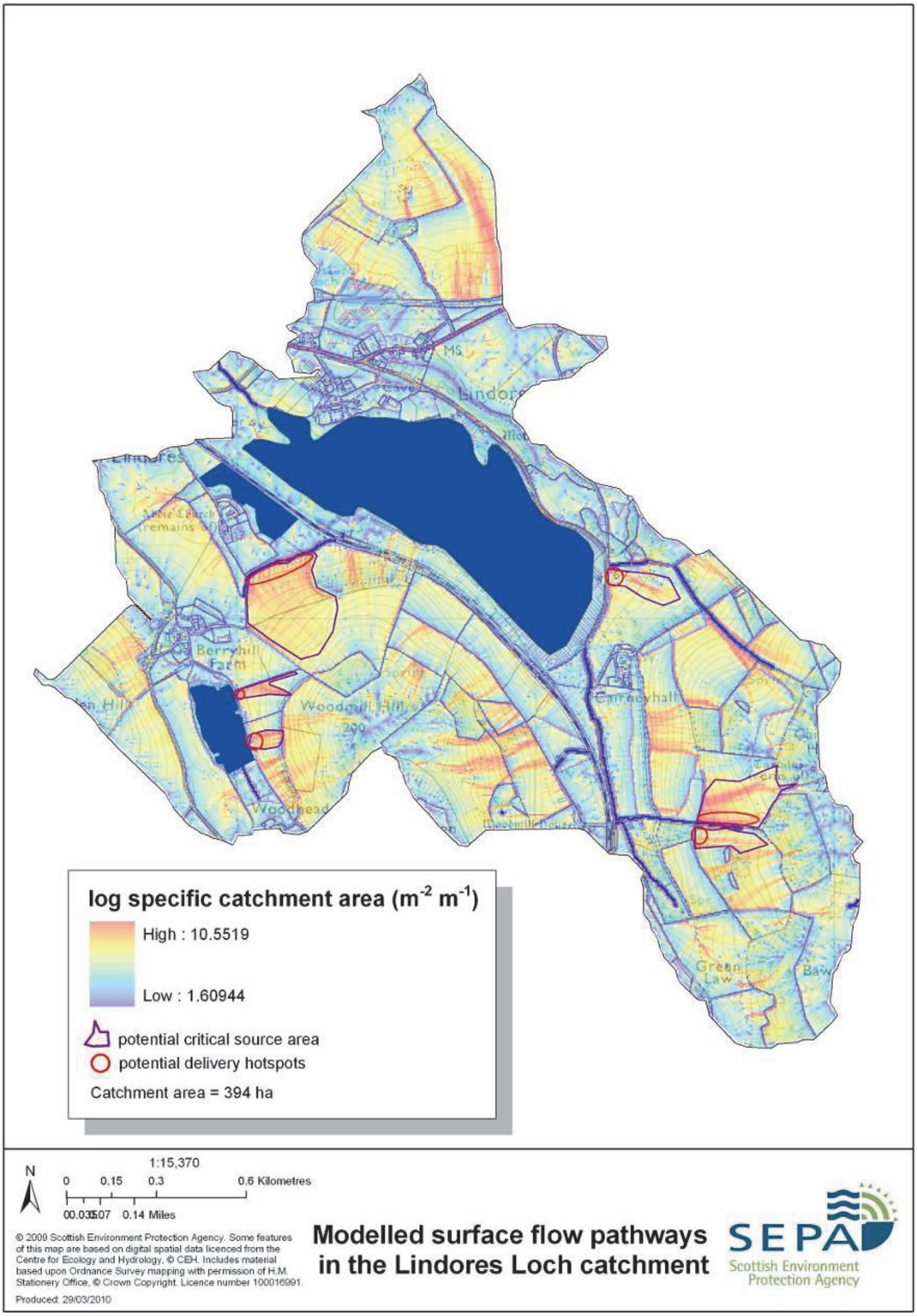


*Figure 6. Nutrient budget study at Lindores Loch*

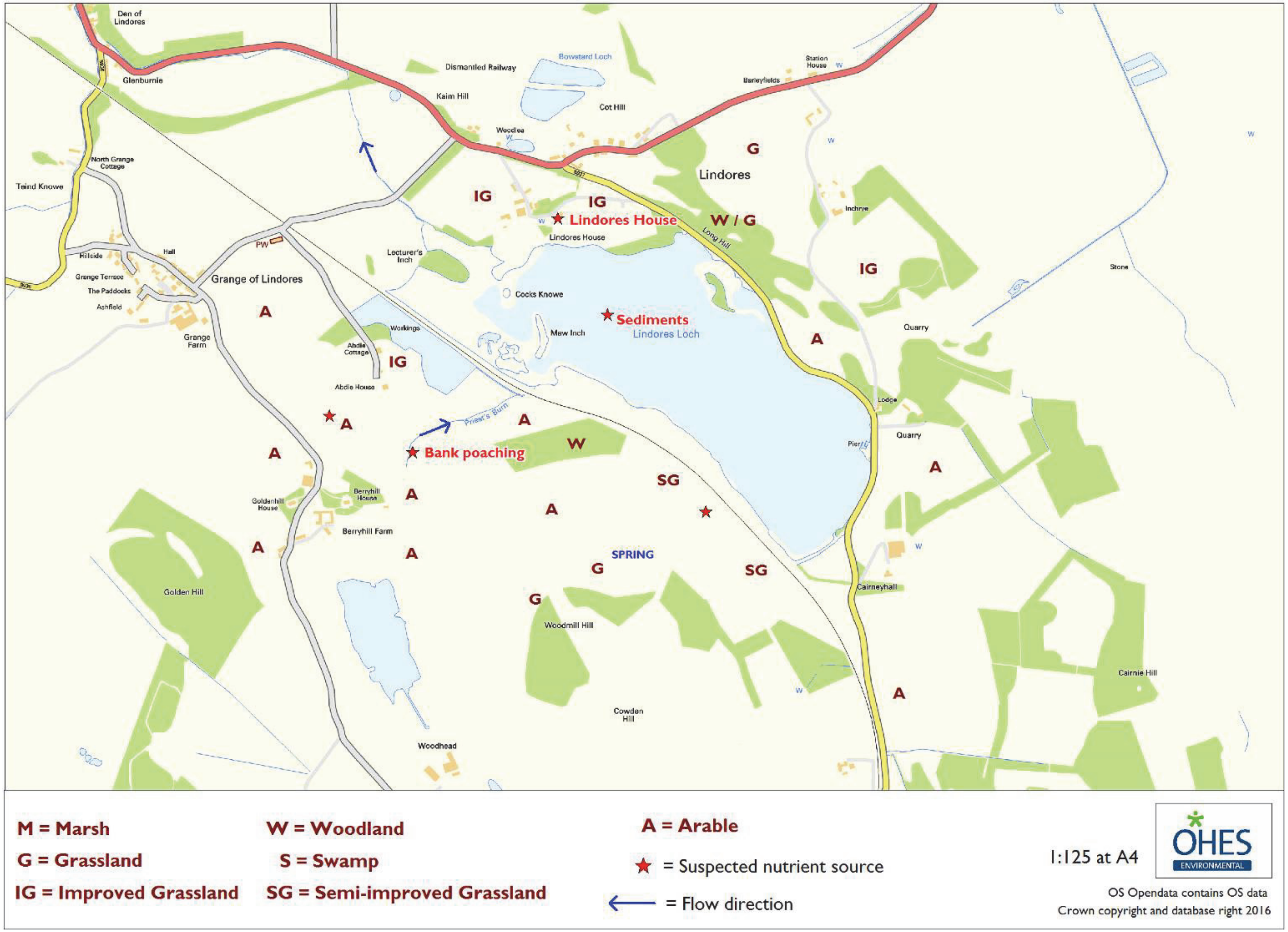


*Figure 7. Land use and potential nutrient sources at Lindores Loch*

## 3.2 Assessment of vegetation data

Lindores Loch SSSI contains a range of open water transitional fen and swamp communities, principally located around the margins of the loch and the terrestrialised western ends of the historic loch boundary. Observations on the vegetation have been recorded in 2009 and 2010. NVC communities are mapped for the whole site in an SNH dataset. Figure 8 shows the NVC communities recorded at that time.

The NVC data suggests the presence of the following communities:

- S4 *Phragmites australis* swamp and reed-beds
- S5 *Glyceria maxima* swamp
- S13 *Typha angustifolia* swamp
- S19 *Eleocharis palustris* swamp
- M27 *Filipendula ulmaria-Angelica sylvestris* mire
- M28 *Iris pseudacorus-Filipendula ulmaria* mire
- MG1 *Arrhenatherum elatius* grassland
- A5 *Ceratophyllum demersum* community
- A8 *Nuphar lutea* community
- A10 *Polygonum amphibium* community
- W2 *Salix cinerea-Betula pubescens-Phragmites australis* woodland
- W7 *Alnus glutinosa-Fraxinus excelsior-Lysimachia nemorum* woodland
- W21 *Crataegus monogyna-Hedera helix* scrub
- OV27 *Epilobium angustifolium* community

### *3.2.1 Historic evidence of community change*

There are insufficient data to quantify changes in the total coverage of each community. However, some key points are summarised below;

- The 2009 SCM states that there was no reduction in the total combined extent of wetland in relation to the baseline, however there may have been a possible increase of *Phragmites* in centre of loch which was not present on the original NVC map.
- The range and extent of key NVC open water fen communities (S4, S5, S13, and S19) was noted as ‘no change’ during the 2009 SCM; however there was a possible increase in S5 at the expense of the S4 community.
- The *Phragmites australis* sub-community was maintained at >90 % cover throughout the site, as noted during the 2009 SCM.
- Marsh pennywort *Hydrocotyle vulgaris* and fen bedstraw *Galium palustre* were prominent throughout the S4 community during a 2010 site visit.
- *Solanum dulcamara* was not noted on the west of the railway line where the majority of the S5 is located and neither was *Lemna minor,* which resulted in a target failure during a site visit in 2010.


*Figure 8. NVC communities recorded at Lindores Loch – unknown date (Source: SNH)*

### *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 Lindores Loch SSSI are:

- Type 1: Wet woodland
- Type 3:Spring flush and seepage
- Type 4: Fen
- Type 5: Swamp
- Type 6: Reedbed

#### 3.2.2.1 Type 1b Other wet woodland

Wet woodland occurs on poorly drained or seasonally wet soils, with alder, ash, birch and willows as the predominant tree species. It is often found on floodplains, as successional habitat from (or to) fen, bog or swamp, alongside or within streams and rivers, within hill-side flushes and seepages, and in peaty hollows (ER37). The characteristic tree species are adapted to waterlogged conditions and can cope with periods of inundation. Alluvial forests with alder *Alnus* glutinosa and ash *Fraxinus excelsior* (*Alno-padion, Alnion incanae, Salicion albae*) are an Annex 1 habitat type covered by the EC Habitats Directive. Wet woodlands are also priority habitats under the UK BAP.

Of the wet woodland communities listed within the SNIFFER (2009) report, the following have been considered as potentially present at Lindores Loch SSSI:

- W2 *Salix cinerea-Betula pubescens-Phragmites australis* woodland – typically occurring on floodplain mires over fen peats, but also can be found on terraces in valley mires (Rodwell, 1991). The distribution of W2 is primarily one of lowland wetlands, but can be found in a northern context occurring in transition with swamp communities such as S4 *Phragmites* reedbed, S5 *Glyceria maxima* swamp and S26 *Phragmites-Urtica* tall-herb fen.

- W7 *Alnus glutinosa-Fraxinus excelsior-Lysimachia nemorum* woodland – characteristic of moist to very wet mineral soils of a mesotrophic nature. Usually the soil pH is between 5 and 6, and only moderately base-rich. The community occurs widely within the north and west of Britain.

ER37 data and thresholds for Wet Woodland are presented in Table 2. UKTAG (2012) Nitrate results for the UK indicate mean values for wet woodland in good condition of 3.9 mg/l N-$NO_3$ and third quartile values of 5.1 mg/l N-$NO_3$ (ER37). UKTAG (2012) has set Nitrate threshold values for wet woodlands of 5 mg/l N-$NO_3$ at low altitude (<175 m AOD) and 2 mg/l N-$NO_3$ at medium altitude (>175 m AOD). Nitrate levels at Scottish sites (groundwater median: 0.25 mg/l N-$NO_3$) are much lower than those recorded for wet woodland in both good and poor conditions by UKTAG (2012) and below the aforementioned thresholds.

UKTAG (2012) Phosphate results for the UK indicate mean values for wet woodland in good condition 0.041 mg/l P-$PO_4$ and third quartile values of 0.057 mg/l P-$PO_4$. Phosphate levels recorded by UKTAG (2012) are comparable with Scottish observations with a median value of 0.080 mg/l P-$PO_4$ for groundwater. No guideline value has been set for Phosphate.

*Table 2. Groundwater thresholds for Wet Woodland*

| | Wet Woodland | | | |
|---|---|---|---|---|
| **Parameter** | **1st Quartile** | **Median** | **3rd Quartile** | **Threshold** |
| pH (-) | 6.8 | 6.9 | 7.0 | |
| Dissolved Oxygen (%) | 20 | 22 | 25 | |
| Electric Conductivity (mS/cm) | 0.23 | 0.26 | 0.46 | |
| Calcium (mg/l) | 7 | 29 | 60 | |
| Magnesium (mg/l) | 1.7 | 6 | 8.8 | |
| Sodium (mg/l) | 6.6 | 9.2 | 12 | |
| Phosphate (mg/l) | 0.012 | 0.08 | 0.1 | None set |
| Nitrogen (total) (mg/l) | 1.2 | 3.0 | 5.0 | |
| Nitrate (mg/l N-$NO_3$) | 0.1 | 0.25 | 0.25 | Threshold:<br>Low altitude = 5 mg/l N-$NO_3$ |

### 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 Lindores 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 Lindores Loch include:

- M28 *Iris pseudacorus-Filipendula ulmaria* mire – typically occurring on nutrient rich soils (mesotrophic to eutrophic) within seepage zones where conditions are kept moist through most of the year. It is the western counterpart of M27 *Filipendula-Angelica* mire, as it requires specific and mild climatic conditions. The community can be fairly species-rich and is particularly well developed in Scotland (Rodwell, 1991).

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-$NO_3$ for good condition and 6.4mg/l N-$NO_3$ for poor condition. Clearly the data from wetlands in Scotland of this type is very low compared to these levels, and below the detection limit of 0.5 mg/l N-$NO_3$. 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 determinand.

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

| | Springs/seepages | | | |
|---|---|---|---|---|
| **Parameter** | **1st Quartile** | **Median** | **3rd Quartile** | **Guidelines** |
| 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 Lindores Loch SSSI are:

- M27 *Filipendula ulmaria-Angelica sylvestris* mire - occurs on slopes, floodplains, stream-sides, loch sides and valley bottoms and is associated with high water level fluctuation (ER37). It is generally associated with moderate to high fertility.

ER37 data and thresholds for Fens are presented in Table 4. UKTAG (2012) 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 3$^{rd}$ 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 tests for some of the samples".

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

| | 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<br>Meso = 5 (or 22 mg/l as $NO_3$)<br>Olig = 4.5 (or 20 mg/l as $NO_3$) |

#### 3.2.2.4 Type 5 Swamp

Swamps occupy the transition between open water and dry land across a range of different trophic states. They typically occur where water levels are above the ground for most of the year, with the main water supply from surface waters (such as in floodplains and around loch shores). However, groundwater can be important in the absence of a surface water supply. They usually consist of species-poor, emergent vegetation but are still important as a UK BAP priority habitat.

The main NVC communities listed in WWF Consulting (2009) and which are found at Lindores Loch are:

- S13 *Typha angustifolia* swamp – occurring in still to slow moving lowland waters with silty substrates, around the margins of lakes and ponds (Rodwell, 1995). Water supply is typically neutral to basic, mesotrophic to eutrophic, and can be of variable depth. Its distribution is rarer in the north but generally scattered across the UK. S13 is generally a species-poor community, with floating stands being less vigorous than those rooted in surface sediments.

- S19 *Eleocharis palustris* swamp – characteristic of waters up to 50cm deep, occurring around large lakes, small ponds and streamsides (Rodwell, 1995). It can tolerate still or running waters, with nutrient preferences differing between sub-communities. The *Eleocharis palustris* sub-community found at Lindores loch occurs in mesotrophic situations.

ER37 data and guidelines for Swamps are presented in Table 5. Mean nitrate levels for groundwater-fed swamp in good condition are reported in UKTAG 2012 as 4.9 and 3.5 mg/l

$N\text{-}NO_3$ for mesotrophic and oligotrophic swamp respectively (ER37). Swamp groundwater sampled in Scotland was significantly lower than this (third quartile value of <0.25 mg/l $N\text{-}NO_3$). This suggests that all sampled Scottish swamps are in good condition.

Phosphate samples reported in the UKTAG (2012) show mean values for swamp in good condition of 0.050 and 0.034 mg/l $P\text{-}PO_4$ for mesotrophic and oligotrophic swamp respectively (ER37). However the results for poor condition suggest condition is not strongly related to groundwater phosphate levels in swamps. The UKTAG values for good condition are comparable with Scottish samples. However a threshold value has not been set at this stage due to inconclusive results.

*Table 5. Groundwater guidelines for Swamp in Good Condition (Source: ER37)*

| | Swamp | | | |
|---|---|---|---|---|
| **Parameter** | **1st Quartile** | **Median** | **3rd Quartile** | **Guideline** |
| pH (-) | 5.7 | 6.3 | 7.1 | |
| Dissolved Oxygen (%) | 15 | 24 | 36 | |
| Electric Conductivity (mS/cm) | 0.24 | 0.26 | 0.43 | |
| Calcium (mg/l) | 10 | 26 | 44 | |
| Magnesium (mg/l) | 3.6 | 5.4 | 16 | |
| Sodium (mg/l) | 5.5 | 9 | 18 | |
| Phosphate (mg/l) | 0.024 | 0.062 | 0.1 | None set |
| Nitrogen (total) (mg/l) | 2 | 3 | 7 | |
| Nitrate (mg/l $N\text{-}NO_3$) | 0.25 | 0.25 | 0.25 | Guideline:<br>Meso = 5 (or 22 mg/l as $NO_3$)<br>Olig = 4.1 (or 18 mg/l as $NO_3$) |

3.2.2.5 Type 6 Reedbed

Equivalent NVC types covered:

- S4a *Phragmites australis* sub-community (present at Lindores Loch)
- 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 6. Nitrate guidelines under UKTAG 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 6. Groundwater thresholds 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 Lindores Loch have been compared with the levels given for 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 7 indicates that the vegetation currently found around the sample locations is typically consistent with the data recorded for Scotland (ER37) and for guideline/threshold levels. However, both of these vegetation types are able to tolerate eutrophic situations and therefore are no indication of a low trophic status. In fact, the higher than typical Total Nitrogen levels recorded in the reedbed samples are some cause for concern.

No groundwater samples were taken within/near to the marshy grassland or fen habitat present on site and therefore no comparison could be made with published levels for this wetland type.

*Table 7. Groundwater samples at Lindores Loch compared to Wetland Type for Scotland. Red text denotes sample exceeds 3rd quartile.*

| | Lindores Loch | Swamp | | | Lindores Loch | Lindores Loch | Reedbed | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample** | **GW1 (in S5)** | **1st Quartile** | **3rd Quartile** | **Guideline** | **GW2 (in S4)** | **GW4 (in S4)** | **1st Quartile** | **3rd Quartile** | **Threshold** |
| pH (-) | | 5.7 | 7.1 | | | | 5.7 | 6.5 | |
| Dissolved Oxygen (%) | | 15 | 36 | | | | 18 | 22 | |
| Conductivity (mS/cm) | | 0.24 | 0.43 | | | | 0.13 | 0.28 | |
| Calcium (mg/l) | 219 | 10 | 44 | | 22 | 26 | 36 | 59 | |
| Magnesium (mg/l) | 50 | 3.6 | 16 | | 8.5 | 10 | 5.8 | 18 | |
| Sodium (mg/l) | 5.5 | 5.5 | 18 | | 13 | 16 | 12 | 19 | |
| Phosphate (mg/l) | 0.064 | 0.024 | 0.1 | None set | 0.06 | 0.058 | 0.043 | 0.1 | None set |
| Nitrogen (total) (mg/l) | 5 | 2 | 7 | | 10 | 8.5 | 1.1 | 6.9 | |
| Nitrate (mg/l N-$NO_3$) | <0.5 | 0.25 | 0.25 | Guideline:<br>Meso = 5 (or 22 mg/l as NO3)<br>Olig = 4.1 (or 18 mg/l as NO3) | <0.5 | <0.5 | 0.25 | 0.25 | Threshold:<br>5 mg/l (or 22 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 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 targets) are referred to in some circumstances but it should be noted that, where they exist, the SRBDD standards are more stringent than CSM targets 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, Lindores Loch is classified as a very shallow (<3 m depth), freshwater, salmonid, low altitude (<80 mAOD) lake of high alkalinity (> 50 mg/l) and >50 % siliceous and ≤90 % siliceous 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 8 presents the SRBDD standards compared to those recorded from Lindores Loch, but owing to the fluid nature of the research and advice, represent a starting point. It clearly shows that the loch fails the standards related to nutrient concentrations.

*Table 8. In-loch water quality standards for Lindores Loch*

| Variable | WFD (2015) | | JNCC | ECOFRAME | | Lindores Loch |
|---|---|---|---|---|---|---|
| | GES | HES | | Good | High | |
| Total Ammonia as N | 0.6 mg/l | 0.3 mg/l | - | - | - | 2.3 mg/l (Ammonium only) |
| Total Nitrogen | - | - | <1.5 mg/l | 0.6 – 1.0 mg/l | <0.6 mg/l | 5 mg/l |
| Acid Neutralising Capacity | >20 µeq/l | >40 µeq/l | >40 µeq/l | - | - | ? |
| Dissolved oxygen | 7 mg/l | 9 mg/l | As WFD | - | - | ? |
| Salinity/Conductivity | <1000 µScm | | - | 100 – 800 µScm | | ? |
| Total Phosphorus | 31 µg/l | 23 µg/l | 35 µg/l | 30-50 µg/l | <30 µg/l | 71 µg/l (Phosphate only) |
| pH | - | - | 7 - 9 | 6 - 9 | | ? |

### *3.4.2 Current surface water quality status*

Four surface water sampling points were monitored by SNH during the single sampling round (conducted in February 2012). These include: three surface water points immediately adjacent to the loch (SW1, SW3 and SW4) and the outlet channel (SW2). See appendix 1 for the raw data.

Figure 9 shows the results of Ammonium recorded at Lindores Loch against SRBDD standards for Total Ammonia. It indicates that, at the time of survey, the loch exceeded standard concentrations, particularly at SW4. This suggests that the residential buildings nearby (Abdie cottage and house) could be a source of nutrients to the loch.

Total Nitrogen levels (as shown in Figure 10) indicate that other forms of nitrogen are also an issue, with all surface water samples exceeding the JNCC threshold levels. Again, SW4 readings were elevated in comparison to the other surface water samples, suggesting a nitrogen source is located within the vicinity of this sampling point. The results suggest that the loch may be acting as a sink, with water quality improving downstream (SW2) when compared to samples near the loch.

Total Phosphorus levels were recorded at Lindores Loch but the levels of determination were below those useful in assessment against threshold values (i.e. all samples were marked as <0.2 mg/l). Instead, Phosphate low levels were recorded between Moderate Ecological Status (MES) and Poor Ecological Status (PES), apart from SW3 which was well in excess of PES (Figure 11). Given that these values do not take into account the full Phosphorus concentration it can therefore be assumed that Total Phosphorus levels are in excess of SRBDD standards. The elevated reading at SW3 suggests that there is a source of Phosphate local to this sampling point. A possible source could be pig slurry which has historically been spread on the surrounding fields and may be a cause of the high Phosphate concentrations at this location.

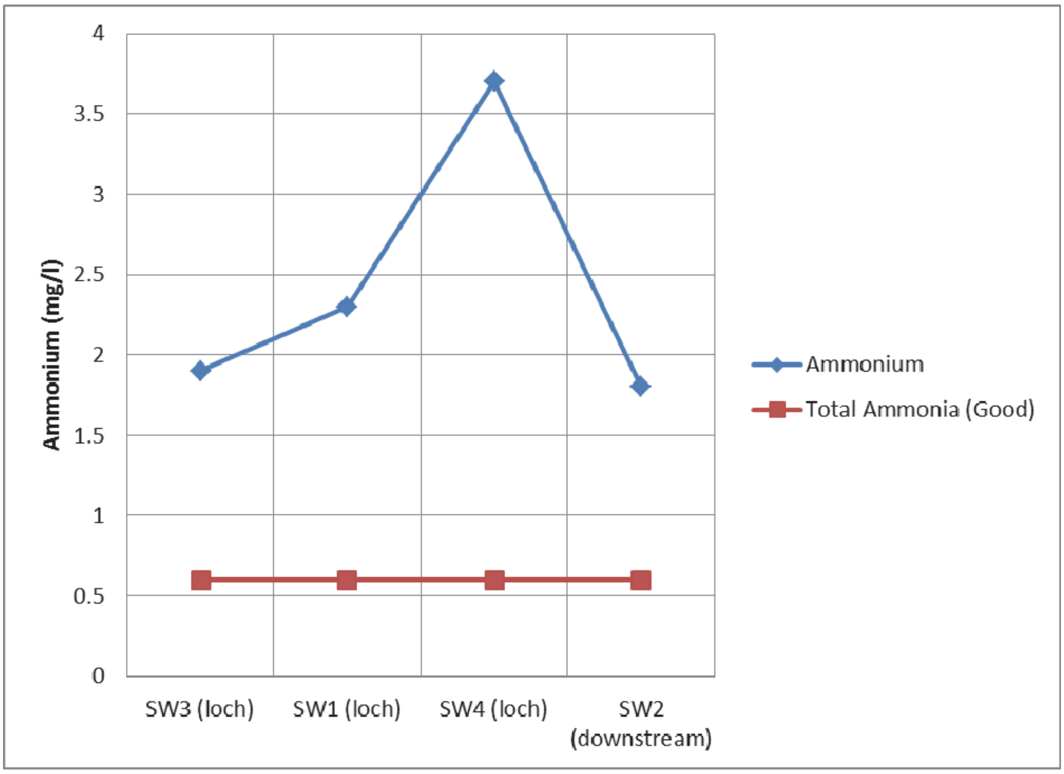


*Figure 9. Ammonium recording at Lindores Loch (blue line) against SRBDD 2014 standards for Total Ammonia*

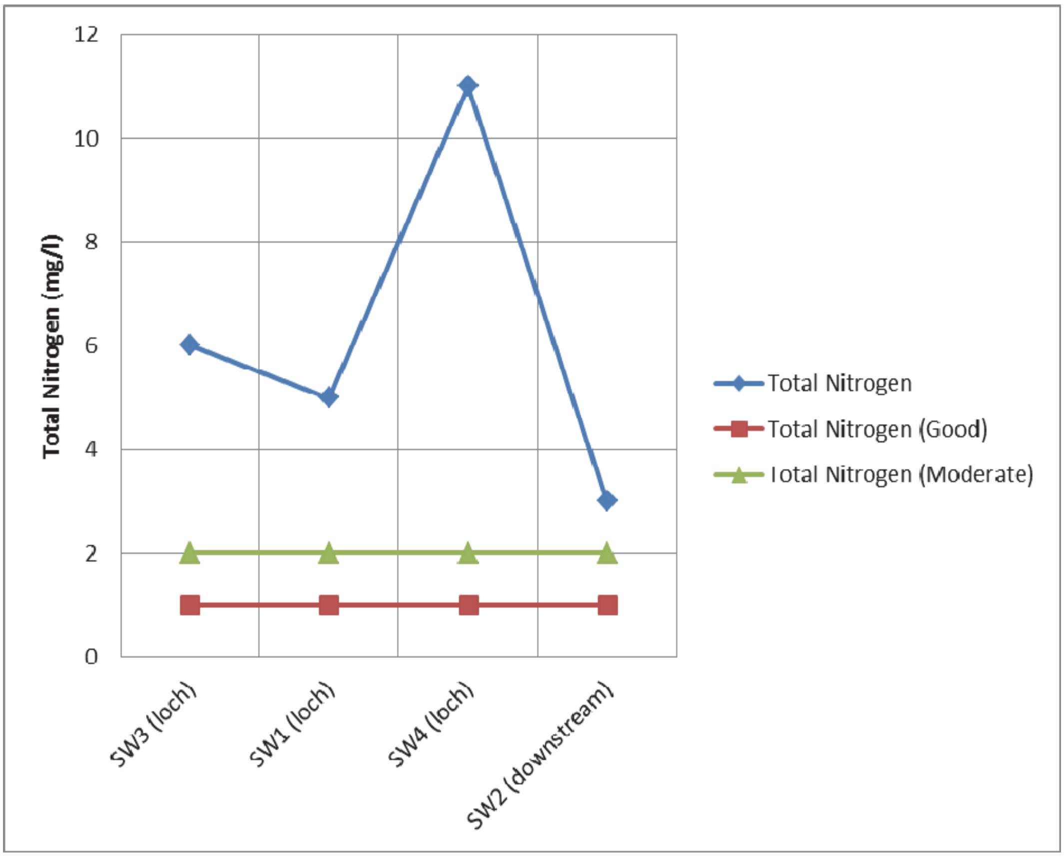


*Figure 10. Total Nitrogen recording at Lindores Loch (blue line) against JNCC standards*

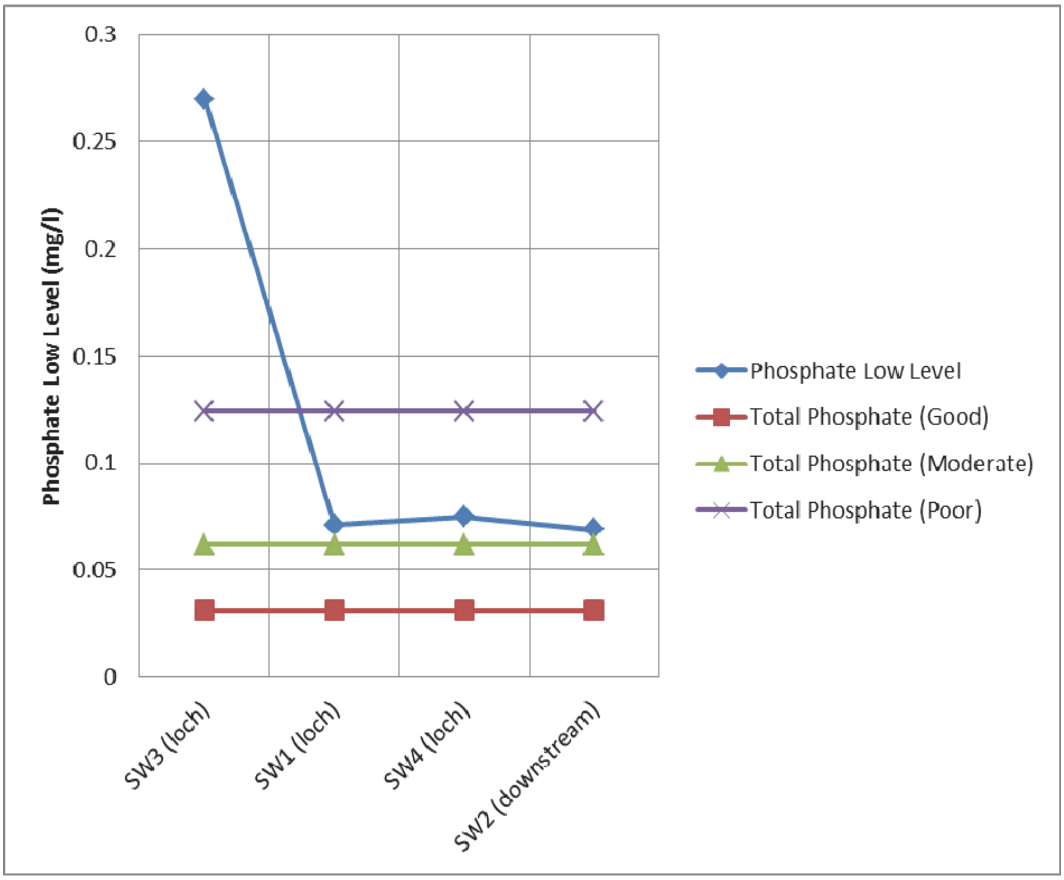


*Figure 11. Total Phosphorus/Phosphate recording at Lindores Loch (blue line) against SRBDD standards*

### *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 9.

*Table 9. Nutrient status classification scheme (SEPA).*

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

Given that both Nitrogen and Phosphorus levels are significantly above targets for GES, this report concludes that <u>the trophic state of Lindores Loch is Eutrophic.</u>

An assessment of vulnerability of the site to enrichment is given in Table 10 below.

*Table 10. Assessment of the vulnerability of Lindores Loch to eutrophication from catchment sources, and their relative importance. Negative factors are shown in black, positive factors in blue.*

| Source | Lindores Loch | |
|---|---|---|
| | **Vulnerability** | **Details of Factors** |
| **EXTERNAL SOURCES** | | |
| **1. Agriculture** | High | - Pig slurry has historically been spread within the catchment, which would allow nutrients to be flushed into the loch.<br>- Livestock have direct access to inflows to the loch.<br>- Drainage of the catchment permits the flushing of fertiliser and nutrients applied to arable fields into nearby watercourses, which will eventually feed into the loch. |
| **2. Human population** | Moderate - High | - Historic input of raw sewage from Lindores House has been recorded.<br>-There is potential run-off from other residential properties in the area and their septic tanks. |
| **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** | Moderate | - Regional groundwater significantly contributes to the water balance within the catchment, which was classified as 'Poor' quality. |
| **INTERNAL SOURCES** | | |
| **1. Wildlife** | Low – Moderate | - Several bird species are recorded in large numbers on the reserve, which may represent a significant source of nutrient input, depending on the species. For example, 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.<br>- 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 loch in sediment form. The seasonal release of stored nutrients within the loch sediments will occur naturally under certain conditions.<br>- If excess nutrients continue to be generated from other practises within the catchment, the subsequent store of nutrients available for release within the reserve will continue to build up. |
| **3. Site management** | Moderate | - Issues with nutrients in the past have historically coincided with fish stocking practices. This could be due to inputs to the system via artificial food or through the stirring up of the potentially nutrient rich sediment during benthic foraging. |

### 3.5 Assessment of soil samples

Soil chemistry was sampled at three locations within Lindores Loch (2 of which were in S4 Reedbed 1 within S5 *Glyceria maxima* swamp). 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 11 presents the soil chemistry data for Lindores Loch samples against the ER37 data. It shows that levels of Magnesium and Calcium are at the lower end of the range observed in Scottish samples. Sodium, Phosphate, Nitrogen and Total Organic Carbon were elevated in some but not all of the samples. Sodium and Phosphate were particularly elevated in the below root sample of Soil sample 2 (GW2) but the reasons for this are unclear. Soil sample 2 was taken in the north west of the site in fibrous peat overlaying gleyed stony sand from c80 cm. The soil moisture content was very similar in the root layer and below.

Soil sample 1 (GW1) was taken in the east of the site in fibrous peat underlain by course sand in gleyed silt. Here the root layer had much higher water content than below. Soil samples 3 and 4 (GW3 and 4) were taken in the west of the site within fairly close proximity to each other. Both were in fibrous peat underlain by humified peat from c 35 cm. Both root layers had higher moisture content than below, with soil sample 4 being slightly more moist.

*Table 11. Soil samples at Lindores Loch and soil chemistry recorded by Wetland Type in Scotland (ER37). Red text denotes sample exceeds typical range.*

| | Lindores Loch | | Lindores Loch | | Swamp | | Lindores Loch | | Lindores Loch | | Reedbed | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample** | **Soil1 Root (in S5)** | **Soil1 below (in S5)** | **Soil 3 Root (in S5)** | **Soil 3 below (in S5)** | **1st Quartile** | **3rd Quartile** | **Soil2 Root (in S4)** | **Soil2 below (in S4)** | **Soil 4 Root (in S4)** | **Soil 4 below (in S4)** | **1st Quartile** | **3rd Quartile** |
| Calcium (mg/kg) | <100 | 3,900 | <100 | <100 | 140 | 5,800 | <100 | <100 | <100 | 3,400 | 1,700 | 13,000 |
| Magnesium (mg/kg) | 3,400 | 240 | 3,100 | 2,200 | 410 | 3,400 | 2,800 | 2,300 | 3,400 | 2,300 | 200 | 2,700 |
| Sodium (mg/kg) | 75 | 25 | 85 | 40 | 17 | 140 | 45 | 190 | 85 | 95 | 32 | 44 |
| Phosphate (available) (mg/l) | 15 | 7.2 | 8.8 | 6.8 | 2.9 | 12 | 26 | 20 | 5 | 3.5 | 1.1 | 6 |
| Nitrogen (total) (%) | 1.3 | 0.16 | 0.66 | 0.09 | 0.17 | 1.2 | 0.29 | 0.45 | 0.91 | 0.17 | 0.99 | 1.7 |
| Nitrogen (extractable) (mg/kg) | <0.1 | <0.1 | <0.1 | 0.11 | 0.43 | 0.9 | <0.1 | <0.1 | <0.1 | <0.1 | 0.39 | 0.56 |
| Total organic carbon (%) | 38 | 1.2 | 7.4 | 0.67 | 4.1 | 25 | 3.4 | 4.7 | 9 | 0.91 | 5.5 | 22 |
| Potassium (total) | 150 | 90 | 90 | 150 | - | - | 150 | 520 | 140 | 120 | - | - |
| Soil Moisture Content % | 871 | 36 | 177 | 39 | - | - | 80 | 98 | 213 | 22 | - | - |

### 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.

### 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 the site.

The initial assessment of Lindores Loch SSSI, based on a single sampling round, suggests enriched water is present within the SSSI, seemingly through several different sources. As a nutrient model has already been conducted, some of the data stated below may already exist but has been included here for completeness. Further data should ideally be collected in the following areas:

- Ideally, monthly surface water sampling within all inflow and outflow channels 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. This should include a central surface water sampling point from the loch and a sampling point near one of the springs (to test the quality of the groundwater directly). This would equate to 5 sampling points.
- Rainfall data in the region for the period when surface water sampling takes place.
- At least four sediment samples within the waterbody (3 within the main loch and 1 within the section west of the railway line) to identify the extent of the internal store of nutrients. This should be combined with a sediment depth survey and sample of macrophytes presence (although the latter may already exist under the previous nutrient modelling exercise).

- Ideally, the installation of a simple dipwell or gauge board in order to build up a series of monthly water levels from this point forward. It is presumed that no water control structure is present at the outlet of the loch and therefore water levels will be controlled directly by the groundwater feed.
- A basic hydrological walkover of the catchment to confirm whether the SSSI is connected to neighbouring waterbodies, the extent of silt within the ditches and the condition of the peat.

Once this data has 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. The primary exporters of nutrients appear to be a combination of agriculture around the loch, as well as localised enrichment from livestock near key watercourses. 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.

- ***Redirecting problematic water sources*** – It may be possible to redirect one of the feeder ditches away from the loch if it represents a particular problem to water quality. However, as there are other SSSI's both to the north and south of Lindores Loch, the possibility of redirecting water without affecting other important areas may be small.

- ***Removing nutrient-rich sediments from the loch*** – This would be an expensive option and would need careful consideration to ensure such action did not risk damage to the bed of the loch, any geological or archaeological features or alter the water level regime. Consideration would also need to be given to suitable receiver sites and to whether long term measures (such as a change in landuse upstream of the SSSI) may also be required to prevent future build-up of sediment.

- ***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 only partially present at Lindores Loch SSSI.

  *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 and so are not recommended within this catchment.

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## ANNEX 1: WATER AND SOIL SAMPLES

Water samples

| | | | **Sample ID** | GW1 | GW2 | GW4 | SW1 | SW2 | SW3 | SW4 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Unit** | **Detection Limit** | **Sample Date** | 20/02/2012 | 20/02/2012 | 20/02/2012 | 20/02/2012 | 20/02/2012 | 20/02/2012 | 20/02/2012 |
| Phosphorus (total) | mg $l^{-1}$ | 0.2 | Water | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 |
| Ammonium | mg $l^{-1}$ | 0.01 | Water | 14 | 9.5 | 7 | 2.3 | 1.8 | 1.9 | 3.7 |
| Nitrate | mg $l^{-1}$ | 0.5 | Water | <0.5 | <0.5 | <0.5 | 12 | 2.3 | 20 | 39 |
| Phosphate Low Level | mg $l^{-1}$ | 0.02 | Water | 0.064 | 0.06 | 0.058 | 0.071 | 0.069 | 0.27 | 0.075 |
| Nitrogen (total) | mg $l^{-1}$ | 1 | Water | 5 | 10 | 8.5 | 5 | 3 | 6 | 11 |
| Calcium | mg $l^{-1}$ | 5 | Water | 219 | 22 | 26 | 36 | 27 | 25 | 47 |
| Magnesium | mg $l^{-1}$ | 0.5 | Water | 50 | 8.5 | 10 | 16 | 10 | 9.1 | 16 |
| Sodium | mg $l^{-1}$ | 0.5 | Water | 5.5 | 13 | 16 | 13 | 14 | 12 | 12 |
| Iron (II) | µg $l^{-1}$ | 20 | Water | 20 | 20 | 20 | <20 | <20 | <20 | <20 |
| Iron (III) | µg $l^{-1}$ | 20 | Water | 260 | 520 | 290 | 270 | 410 | 300 | 180 |
| Iron (total) | µg $l^{-1}$ | 20 | Water | 280 | 540 | 310 | 270 | 410 | 300 | 180 |

Soil samples

| Parameter | Unit | Detection Limit | Sample ID | S1 | S1 | S2 | S2 | S3 | S3 | S4 | S4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Other ID** | Below | Root | Below | Root | Below | Root | Below | Root |
| | | | **Sample Date** | 20/02/2012 | 20/02/2012 | 20/02/2012 | 20/02/2012 | 20/02/2012 | 20/02/2012 | 20/02/2012 | 20/02/2012 |
| Moisture | % | 0.02 | Soil | 23.6 | 89.2 | 48.2 | 92.2 | 89.3 | 90 | 73.2 | 84.9 |
| 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 | 4.8 | 59 | 4.3 | 9.6 | 30 | 62 | 12 | 32 |
| Phosphorus (total) | mg $kg^{-1}$ | - | Soil | 2200 | 2600 | 1900 | 1300 | 1700 | 1400 | 1900 | 1000 |
| Nitrogen (total) | % | 0.02 | Soil | 0.12 | 0.34 | 0.31 | 0.41 | 1.9 | 2.2 | 1.4 | 1.3 |
| Nitrite (extractable) | mg $kg^{-1}$ | 0.1 | Soil | <0.1 | 2.2 | <0.1 | <1.0 | <0.1 | <1.0 | <1.0 | <1.0 |
| Nitrate (extractable) | g $l^{-1}$ | 0 | Soil | <0.01 | <0.1 | <0.01 | <0.1 | <0.01 | <0.1 | <0.01 | <0.1 |
| Calcium (total) | mg $kg^{-1}$ | 100 | Soil | 1600 | 1700 | 1700 | 2800 | 3200 | 920 | 1900 | <100 |
| Potassium (total) | mg $kg^{-1}$ | 0.2 | Soil | 120 | 12000 | 130 | 120 | 110 | 70 | 13000 | 31000 |
| Sodium (total) | mg $kg^{-1}$ | 0.2 | Soil | 40 | 350 | 80 | 55 | 65 | 85 | 260 | 500 |
| Magnesium (total) | mg $kg^{-1}$ | 0.5 | Soil | 1700 | 1300 | 1100 | 1500 | 610 | 910 | 520 | 170 |
| Total Organic Carbon | % | 0.2 | Soil | 0.76 | 21 | 1.80 | 46 | 44 | 51 | 19 | 37 |
| Moisture content | % | - | Soil | 40 | 580 | 84 | 1173 | 812 | 1067 | 252 | 782 |
| Bulk density | Mg/m3 | - | Soil | 1.78 | 1.11 | 1.51 | 1.03 | 0.98 | 0.97 | 1.04 | 0.88 |
| Dry density | Mg/m3 | - | Soil | 1.27 | 0.16 | 0.82 | 0.08 | 0.11 | 0.08 | 0.3 | 0.1 |

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