Scottish Natural Heritage
Research Report No. 1113

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

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RESEARCH REPORT

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

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RESEARCH REPORT

Summary

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

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Keywords

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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 Redmyre SSSI, in order to assess the trophic status of the designated wetland and identify any likely sources of nutrient input.

Main findings

- Redmyre SSSI is a basin fen with a permanently high water table, contained by the local landform. It is fed by a very small surface water catchment, mainly consisting of the SSSI boundary, with some immediately adjacent woodland. A narrow burn drains out of the fen and into Redmyre Loch to the west. The site is freely draining in the east and poorly drained in the west. It is therefore likely that a considerable proportion of the water balance is sourced from groundwater input, possibly through broad seepage zones in the east.
- Groundwater samples taken at Redmyre have been compared with the nutrient level requirements of the vegetation types known on site. They indicate that Phosphate levels recorded within marshy grassland exceed the target range for Springs or Fens. GW4 had marginally higher Phosphate levels than the other samples, possibly as a result of its proximity to the loch and the nature of the substrate at this point (unconsolidated loose peat likely to be in hydraulic conductivity with the loch itself).
- Nitrate was not analysed at a level of determination sufficient to compare with the ER37 figures, but Total Nitrogen levels in all Redmyre samples either exceeded or were at the upper limits of those recorded in the ER37 dataset. Levels of Total Nitrogen were lowest in the groundwater sample nearest an observed spring source.
- Surface water and groundwater results at Redmyre are fairly similar, with marginally higher Phosphate and Total nitrogen levels in the groundwater samples. This would appear to support the theory that enrichment is not coming from the surrounding land but is instead the result of mineral flushing of the substrate, generally within the centre of the site.

- Assessment of vulnerability showed Redmyre SSSI was at low risk from sources such as agricultural practices. Instead complex interactions between substrates and groundwater may be resulting in release of nutrients such as Phosphate previously bound up in the substrate. However, not enough is known about the groundwater source or its movement through the site to accurately gauge its significance.
- The key recommendation proposed for this site is therefore to conduct further investigation on the nature and extent of the substrate types, together with more detailed water sample analysis, so that the necessity for any remedial measures can be better defined. In particular, a peat survey of the site, regular surface water sampling and further examination of the vegetation.

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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 Redmyre SSSI 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 Redmyre SSSI.

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 15cm 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 the SNH office near Perth for dispatch to the project laboratory. Samples were packed in cool boxes with ice to ensure that the samples remained cool in transit to minimise sample deterioration. Unfortunately some samples from some sites were misplaced by the laboratory and could therefore not be processed. All samples were tested using accredited methods or where accreditation was not available, using in-house procedures with routine QA / QC checks in place to ensure data quality.

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

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

Water samples were analysed for the following suite:

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

2.2 Analysis of results

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

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

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

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

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

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

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

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

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

3. ASSESSMENT

3.1 Site review

Redmyre SSSI is 1 km to the south-east of Little Ballo, off the A923 at an altitude of 200-210 m (Figure 1). The 6.43 ha site is one of the largest and least disturbed areas of poor to mid fen in Perth and Kinross. The fen is a topogenous or basin fen with a permanently high water table, contained by the local landform. Redmyre SSSI supports several different types of characteristic vegetation as well as a number of plant species of restricted distribution and isolated rain-fed hummocks. The fen is surrounded by unimproved acid grassland and dwarf shrub heath, which is increasingly scarce in this area.

The surrounding land comprises of conifer plantation, some new broadleaf plantation, grazing pasture and rough scrub. Redmyre was grazed until the mid-1990s. A 5 year Natural Care Scheme was entered into in 2006 which included the reinstatement of grazing with permanent and temporary fencing. Figure 2 shows the site in the 1800s.

3.1.1 Site designation and scientific targets

Redmyre SSSI was designated in 1984 for its nutrient-poor fen vegetation. The features for which it is designated along with their pressures are detailed in Table 1. The mire itself is a floating raft of vegetation and supports a number of rarer plant species, including a nationally rare orchid and several locally rare species. The site is less disturbed than other mires, resulting in a high number of characteristic plant species.

Table 1. Redmyre SSSI designated features and their pressures.

SSSI features	Feature Category	Summary Condition / Latest Condition	Pressure
Basin fen	Wetlands	Favourable Maintained (Jul 2013)	a)Invasive species

Figure 1. Site Boundary – Redmyre

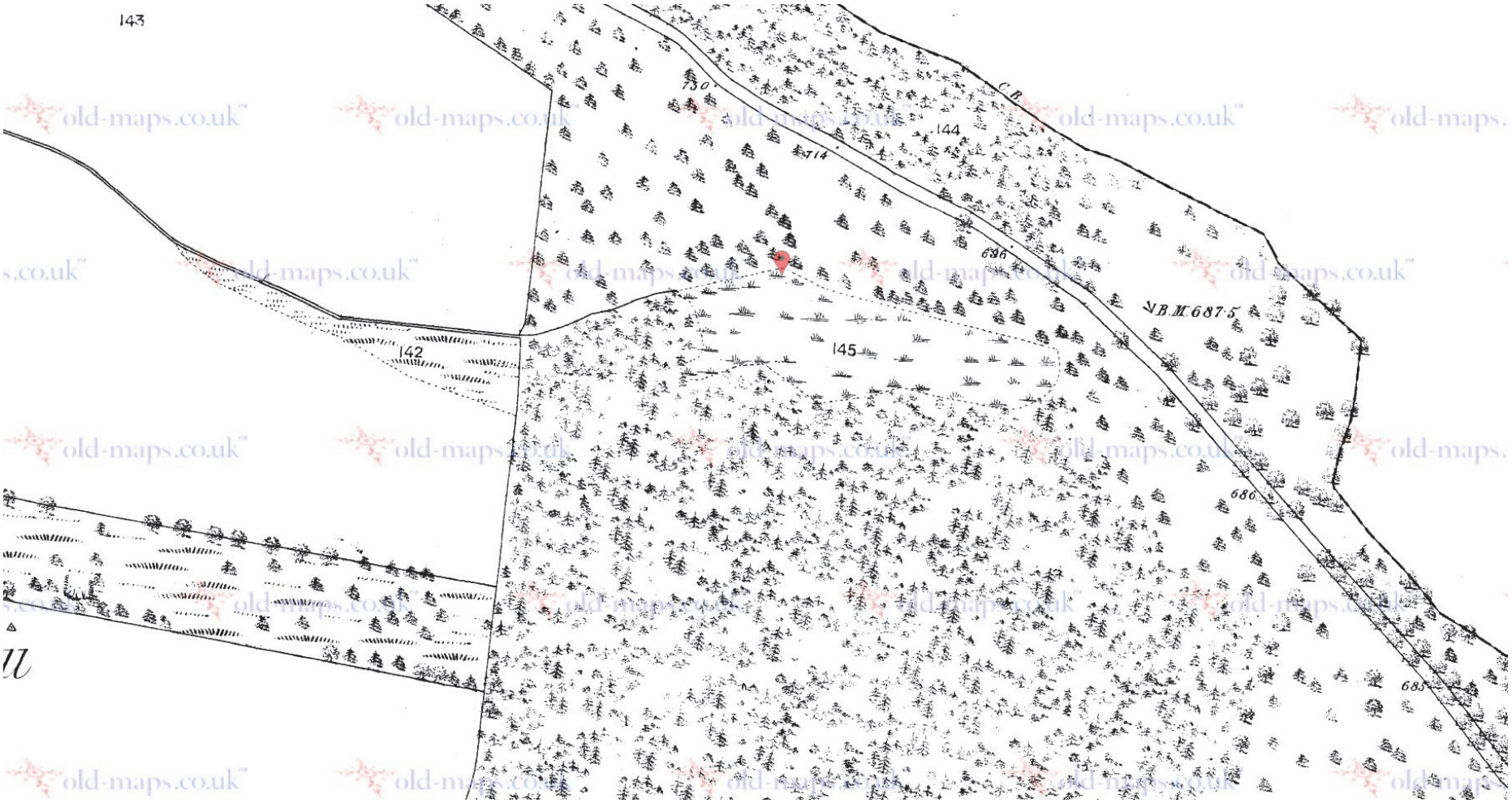

Figure 2. Ordnance Survey 1862 map (Source: www.old-maps.co.uk)

3.1.2 Site hydrology

Redmyre SSSI is fed by a very small surface water catchment, mainly consisting of the SSSI boundary, with some immediately adjacent woodland (Figure 3). A narrow burn drains out of the fen and into Redmyre Loch to the west (Figure 4). The site is freely draining in the east and poorly drained in the west. It is therefore likely that a considerable proportion of the water balance is sourced from groundwater input, possibly through broad seepage zones in the east. During the collection of water samples in 2012, spring input was observed around the centre of the site (at GW2).

Redmyre SSSI is underlain by the Sidlaw Hills bedrock and localised sand and gravel aquifers. In 2008, the quality of the groundwater was classified as 'Poor', while the quantity was classified as 'Good'. An upward trend in pollutants in the form of diffuse source pollution from mixed farming and non-urban land management was identified for this waterbody. There is no historic rainfall data available for Redmyre Loch.

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. The occurrence of vegetation communities such as *Carex rostrata – Calliergon cuspidate/giganteum* mire (M9) and *Carex rostrate - Sphagnum squarrosum* mire (M5) suggest the presence of several seepage driven WetMec types, but further classification is dependent on the underlying substrate. For example if, as seems likely, the site retains some direct connectivity with the underlying groundwater aquifer, it would most likely fall under combinations of WetMec 13 (Seepage Percolation Basin) or WetMec 14 (Seepage Percolation Trough) at the western end of the SSSI, flanked by slopes of WetMec 10 (Permanent Seepage Slopes) or WetMec 15 (Seepage Flow Tracks). All of these WetMec types are known to support M5, M9 and M10 mire. Alternatively, if the western end of the SSSI is marked by low permeability material, so that the groundwater is sourced from seepage to the east flowing over the surface aquitard, a classification of WetMec 16 (Groundwater-Flushed Bottom) with WetMec 17 (Groundwater-Flushed Slopes) would be more appropriate.

In addition to the above, reference is made to the site having raised rain-fed hummocks, which would most likely fall under the classification of WetMec 2 Buoyant Ombrogenous Surfaces (more or less buoyant surfaces fed exclusive by precipitation). As a result, Redmyre SSSI is likely to contain multiple WetMec types, the boundaries of which may be very difficult to define accurately without considerable site investigation.

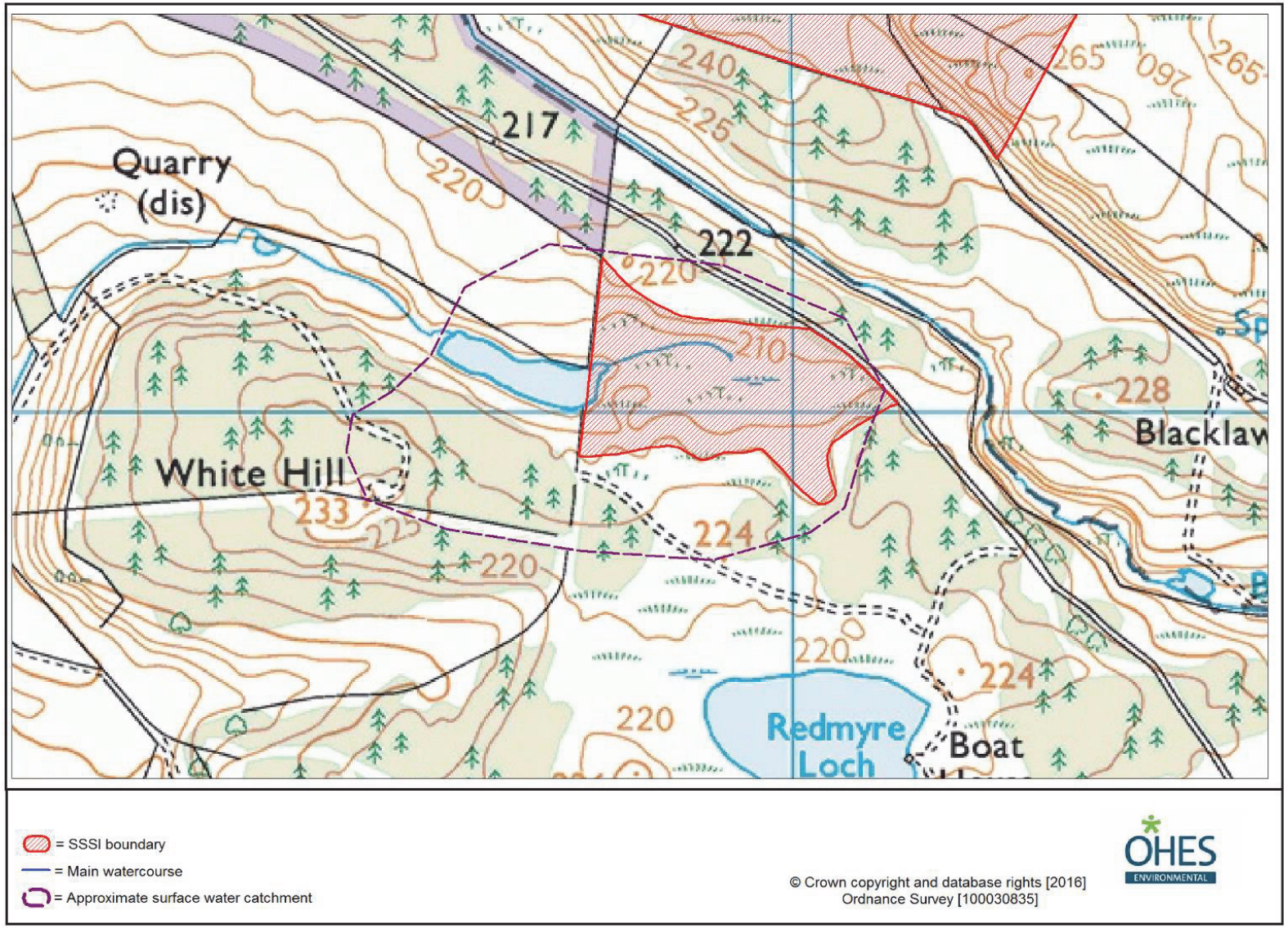

Figure 3. Redmyre – approximate surface water catchment

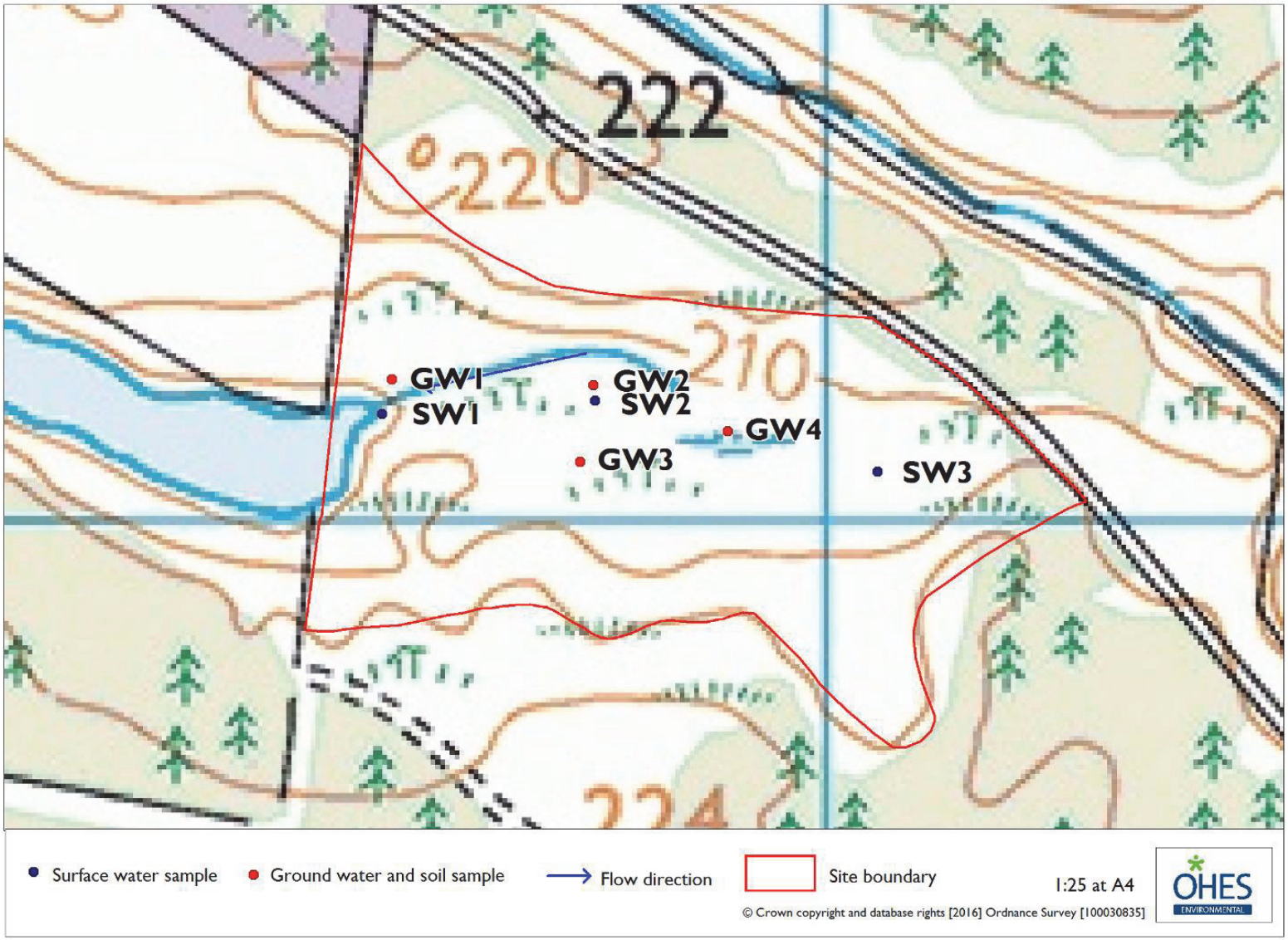

Figure 4. Redmyre – Hydrology and Sample Locations

3.1.3 Site soils / sediments

Redmyre SSSI is underlain by the Darleith Association, which was developed on drifts derived from basaltic rocks, including extrusive lavas, intrusive sills and dykes and rocks plugging volcanic vents. The drifts are generally thin, brown or reddish brown loamy tills with a high content of basic igneous stones. Figure 5 shows the distribution of soil types at Redmyre SSSI.

The site itself is reported to consist of approximately 0.75 m of peat on the surface, underlain by sand or sandy silt. In the centre of the site, immediately upstream of the ditch, a layer of "gyttia-like material" was recorded during collection of the water samples in 2012. The formation of gyttia soils takes place in former lakes, predominantly under aeration. This phenomenon of now terrestrial, but former subhydric, soils is mainly due to artificial drainage. The original meaning of the term gyttia, as defined by Troëls-Smith (1955) refers to a ''….mudlike, homogeneous, non-plastic deposit consisting of particles or colloids < 0.1 mm …. '' composed of decayed and decomposed microorganisms and higher plants. In recent years, the term has become more of a synonym for organic lake sediments generally (Schnurrenberger, Russell and Kelts, 2003). At Redmyre SSSI, its presence coincided with reports of Chara at the surface and indicates lacustrine deposits of a calcareous nature.

Figure 5. Redmyre – Soil types (Source: Soil Survey of Scotland Staff, 1981).

3.1.4 Site specific issues

It is believed that mineral rich flushing in the eastern end of the site is leading to the presence of higher nutrient levels. The site itself is not thought to have been treated with agricultural chemicals but rather enrichment is occurring from within the catchment. Figure 6 shows the land use within the surface water catchment.

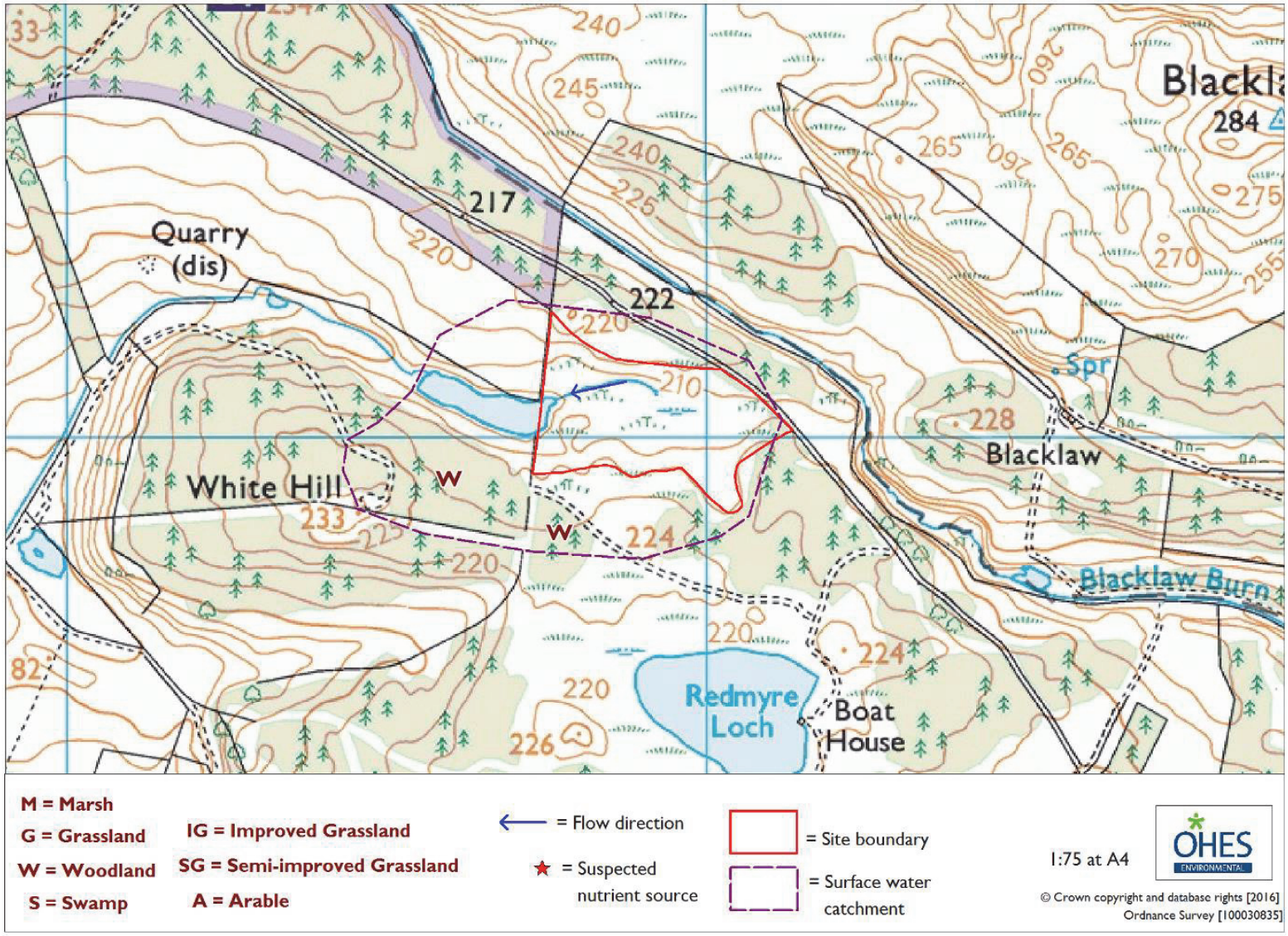

Figure 6. Land use and potential nutrient sources at Redmyre

3.2 Assessment of vegetation data

Redmyre SSSI contains a range of basin fen communities. Observations on the vegetation have been recorded in 2000 and 2013, however NVC communities are only mapped for the whole site in 2000, with no available quadrat data. Figure 7 shows the NVC communities recorded in 2000.

The historic data suggests the continued presence of the following communities:

- W3 *Salix pentandra-Carex rostrata* woodland
- W23 *Ulex europaeus-Rubus fruticosus* scrub
- U4 *Festuca ovina-Agrostis capillaris-Galium saxatile* grassland
- MG1 *Arrhenatherum elatius* grassland
- MG9 *Holcus lanatus-Deschampsia cespitosa* grassland
- M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire
- M15 *Scirpus cespitosus-Erica tetralix* wet heath
- M23 *Juncus effusus/acutiflorus-Galium palustre* rush-pasture
- H12 *Calluna vulgaris-Vaccinium myrtillus* heath

It is noted that the 2000 NVC survey does not show communities such as M10 *Carex dioica-Pinguicula vulgaris* mire. Though more typical of soligenous situations, M10 is known to occur in isolated zones of calcareous spring input around communities such as M9. Notes taken during the collection of water samples in 2012 suggest the presence of M10, M4 *Carex rostrata-Sphagnum recurvum* mire and M5 *Carex rostrate - Sphagnum squarrosum* mire within the centre of the site. Therefore, for the purposes of analysis, the following communities have also been considered:

- M10 *Carex dioica-Pinguicula vulgaris* mire
- M5 *Carex rostrata- Sphagnum squarrosum* (in terms of water source, this community seems more likely to occur at Redmyre than M4. However the presence of *S.recurvum* recorded here indicates M4 may also be present).

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:

- Comparison of the 2013 SCM with the 2000 NVC shows that the extent of M9 community has been retained, as well as the areas of M23 rush pasture, resulting in a Favourable Maintained condition classification of the site.
- Three notable species, *Carex diandra* (RDB Near-Threatened), *Carex limosa* and *Eleocharis quinqueflora* were noted on the 2013 visit.
- Field notes gathered during the collection of water samples in 2012 suggest the presence of other mire communities (such as M4/5/10). Such communities were not recorded in the SCM survey of 2013, but this may be due to the very localised nature of these communities.

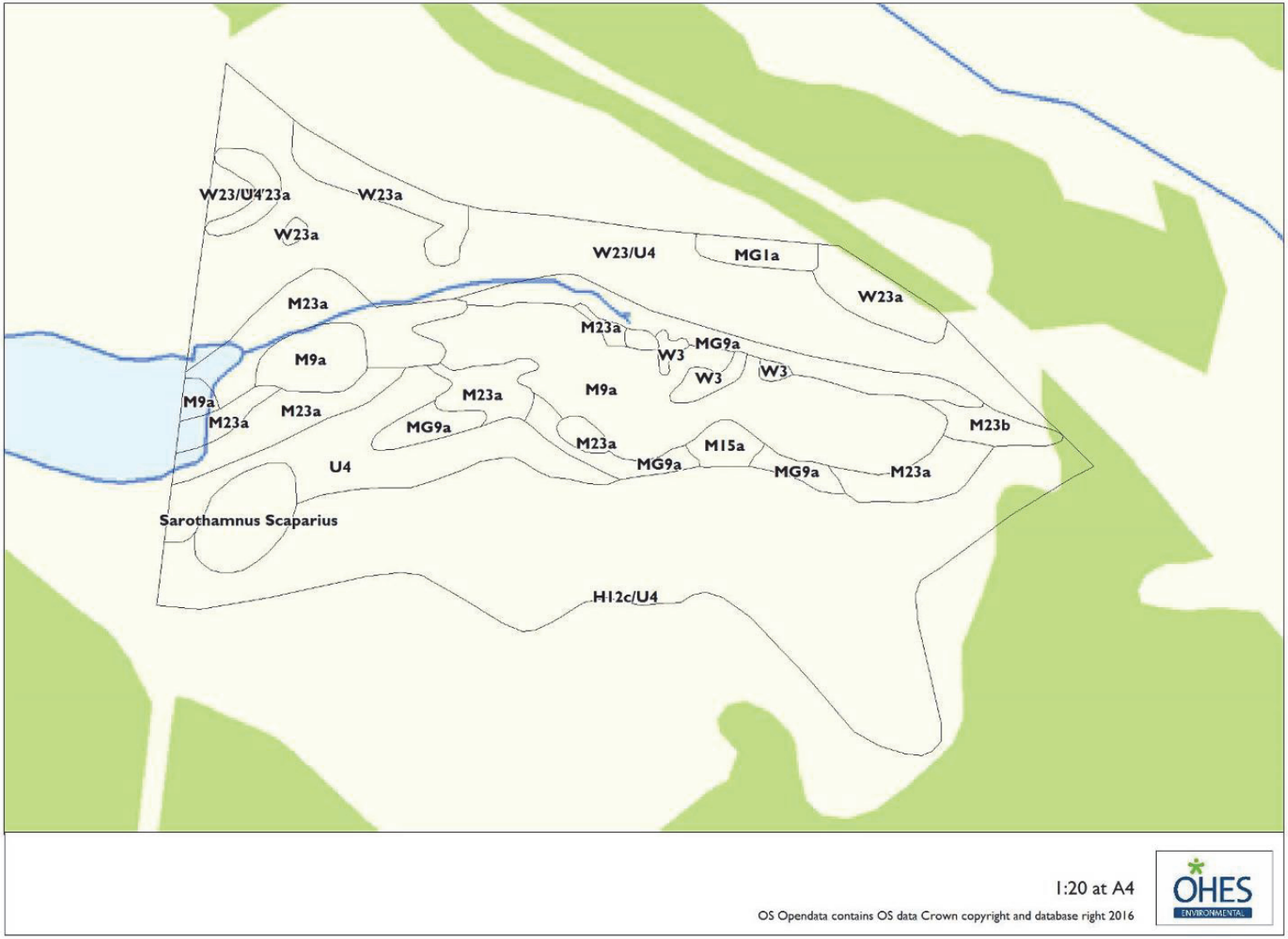

Figure 7. NVC communities recorded in 2000 (Source: SNH)

3.2.2 Community requirements

The requirements of wetland communities have been discussed in several publications over the past decade, some of which are specifically aimed at providing guidance on the implementation of WFD regulations. Considerable advances have also 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 Redmyre SSSI are:

- Type 2a: Marshy grassland
- Type 3c: Springs, seepages and flushes
- Type 4: Fen
- Type 7: Wet heath

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

3.2.2.1 Type 2a Marshy grassland

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

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

The equivalent NVC types contained within these types are considerable, but those relevant to Redmyre include:

- M23 *Juncus effuses/acutiflorus – Galium palustre* rush-pasture
- MG9 *Holcus lanatus - Deschampsia cespitosa* grassland

These communities range from relatively species-poor communities whose distribution is widespread across Scotland (such as MG9), to those which can contain considerable plant diversity (such as M23). The hydrology is typically one of a high water table close to the surface for most of the year (ER37), with periodic flooding.

ER37 data for marshy grassland is 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 guidelines 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 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 Redmyre 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 Redmyre include:

- M5 *Carex rostrata–Sphagnum squarrosum* mire – occurring on soft, spongy peats or as a floating raft within topogenous and soligenous sites. This community is typically supplied by mildly acidic to moderately calcareous waters, which can be oligotrophic to moderately fertile in nature. It can be found in base-poor catchments where slates and shales predominate, but is also sometimes associated with more calcareous rocks.

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

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

ER37 data and guidelines for springs and seepages are presented in Table 3. Under the UKTAG report (2012), mean Nitrate levels in springs and seepages (excluding tufa-forming springs) is 1.8 mg/l $N\text{-}NO_3$ 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 standards, 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)

	Springs/seepages			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Indicator/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 $N\text{-}NO_3$)	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 Redmyre SSSI are:

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

- M10 *Carex dioica-Pinguicula vulgaris* mire – see characteristics listed under previous section.

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

Mean Phosphate values for the UK (UKTAG, 2012) for fens in good condition are 0.033 and 0.021 mg/l P-PO_4 for mesotrophic and oligotrophic fen respectively (ER37). Mean values for fen in poor conditions are 0.034 mg/l P-PO_4 and 0.064 mg/l P-PO_4 for mesotrophic and oligotrophic groups. ER37 reports that median Phosphate concentrations in Scottish fens are 0.10 mg/l P-PO_4 (for groundwater) and 0.046 mg/l P-PO_4 (for surface water). These figures exceed mean values given for good condition under UKTAG, 2012. No guideline value has currently been set for Phosphate. ER37 reports however that "groundwater results are skewed by the analytical level of detection of 0.20 mg/l used in laboratory 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 Meso = 2.04 (or 9 mg/l as NO_3) Olig = 0.91 (4 mg/l as NO_3)

3.2.2.4 Type 7 Wet heath

Wet heaths are found in acidic soil conditions, where species such as *Erica tetralix*, moisture-loving grasses, sedges and sphagnum moss occur. It is characteristic of both moderately sloping ground with impeded drainage and high rainfall or small depressions /

basins. Wet heath falls under H4010 Northern Atlantic wet heaths with *Erica tetralix* which is listed in Annex 1 of the EU Habitats Directive (ER37).

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

- M15 *Scirpus cespitosus-Erica tetralix* wet heath – characteristic of acidic and oligotrophic, moist peats and peaty mineral soils (Rodwell, 1995). Distributed mainly across the north and west of Britain, it can be moderately species-rich depending on management such as burning and grazing history.

However, as none of the sampling points appear to be located near this type of vegetation, and the water quality is likely to show considerable variation, it was not felt appropriate to compare the requirements for wet heath with any of the water samples taken in 2012.

3.3 Assessment of ground water samples

Groundwater samples taken at Redmyre SSSI have been compared with the nutrient level requirements of the vegetation types known on site.as shown in section 3.2. Groundwater thresholds were used as opposed to surface water thresholds for two reasons: firstly that almost all wetlands will have a component of groundwater influence, and secondly that groundwater thresholds can often be more demanding than surface water thresholds.

Table 5 indicates that Phosphate levels recorded within marshy grassland exceed the indicator level (note no levels are given for Springs or Fens but it is likely these would be no higher than Marsh indicator levels). GW4 had marginally higher Phosphate levels than the other samples, possibly as a result of its proximity to the loch and the nature of the substrate at this point (unconsolidated loose peat likely to be in hydraulic conductivity with the loch itself).

Nitrate was not analysed at a level of determination sufficient to compare with the ER37 figures, but Total Nitrogen levels in all Redmyre samples either exceeded or were at the upper limits of those recorded in the ER37 dataset. Levels of Total Nitrogen were lowest in the groundwater sample nearest an observed spring source (GW2). In this sample, Calcium was also recorded at higher levels than surrounding fen samples, consistent with a groundwater source.

Table 5. Groundwater samples at Redmyre compared to Wetland Type for Scotland. Red text denotes sample exceeds 3rd quartile.

	Redmyre	Marshy Grassland			Redmyre	Springs/seepages			Redmyre	Redmyre	Fen		
Sample	**GW3 (in M23)**	**1st Quartile**	**3rd Quartile**	**Guideline**	**GW2 (in M9 or M10)**	**1st Quartile**	**3rd Quartile**	**Guideline**	**GW1 (in M5 or M9)**	**GW4 (in M9)**	**1st Quartile**	**3rd Quartile**	**Threshold**
pH (-)		6.3	7.1	5 to 8							6.4	7.4	
Dissolved Oxygen (%)		32	40								18	28	
Conductivity (mS/cm)		0.093	0.18								0.37	0.69	
Calcium (mg/l)	6.6	8	24		25	5.7	76		16	11	12	55	
Magnesium (mg/l)	3.3	2.5	8.7		2.9	3.2	19		2.4	1.7	3.4	14	
Sodium (mg/l)	6.8	6.2	12		9.7	8.4	26		9.7	8.3	5.4	14	
Phosphate (mg/l)	0.066	0.041	0.065	Indicator: 0.065	0.062	0.09	0.1	None set	0.074	0.06	0.064	0.1	None set
Nitrogen (total) (mg/l)	7	2.5	7		4	0.5	4.2		7	6	1	5.1	
Nitrate (mg/l N-NO_3)	<0.5	0.25	0.25	Guideline: 2 (or 9 mg/l as NO_3) for >175 m AOD	<0.5	0.25	0.25	Guideline: 2.05 (or 9 mg/l as NO_3)	<0.5	<0.5	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)

3.4 Assessment of surface water samples

3.4.1 Current surface water quality status

Three surface water samples were taken from Redmyre. Due to the likely interaction of groundwater and surface water samples the two sets of results were compared to assess their similarities. The surface and groundwater results can be found in Table 6.

Table 6. Comparison of Surface water and Groundwater at Redmyre

Sample	GW1	SW1	GW2	SW2	GW3	GW4	SW3
Calcium (mg/l)	16	9.8	25	8.3	6.6	11	7.8
Magnesium (mg/l)	2.4	1.9	2.9	1.5	3.3	1.7	1.6
Sodium (mg/l)	9.7	8	9.7	7.4	6.8	8.3	7.1
Phosphate (mg/l)	0.074	0.056	0.062	0.058	0.066	0.06	0.053
Nitrogen (total) (mg/l)	7	2	4	1.5	7	6	4
Nitrate (mg/l N-NO_3)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	4.3

The results in Table 6 show that the surface water and groundwater results at Redmyre SSSI are fairly similar, with higher Phosphate and Total Nitrogen levels in the groundwater samples. This would appear to support the theory that enrichment is not coming from the surrounding land uses but is instead the result of mineral flushing of the substrate, generally within the centre of the site. SW3, located in the far east of the site, received a particularly high Nitrate reading, which may either be the result of very localised enrichment from non-spring sources or is an anomalous reading.

Surface water results were compared to SNIFFER data (ER37 report) for the various vegetation communities at Redmyre SSSI. Water chemistry guidelines generally refer to groundwater rather than surface water and therefore comparison can only typically be made between Redmyre SSSI and the SNIFFER dataset for wetlands in Scotland. Table 7 indicates that the surface water within the site is generally consistent with the vegetation requirements indicated by the SNIFFER dataset, but that Nitrate levels in the east of the site approach UKTAG guidelines for oligotrophic situations.

Table 7. Surface water samples at Redmyre compared with Wetland Type for Scotland (ER37 Draft). Red text denotes sample exceeds 3rd quartile.

	Redmyre	Springs and seepages		Redmyre	Redmyre	Fens	
Parameter	**SW2 (near M9 or M10)**	**1st Quartile**	**3rd Quartile**	**SW1 (near M9)**	**SW3 (near M9)**	**1st Quartile**	**3rd Quartile**
pH (-)		6.5	7.5			6.7	7.4
Dissolved Oxygen (%)		61	70			53	57
Electric Conductivity (mS/cm)		0.2	0.71			0.25	0.62
Calcium (mg/l)	8.3	29	29	9.8	7.8	13	38
Magnesium (mg/l)	1.5	3.6	3.6	7.9	1.6	5	8
Sodium (mg/l)	7.4	5.7	5.7	8	7.1	7	12
Phosphate (mg/l)	0.058	0.01	0.01	0.056	0.053	0.02	0.084
Nitrogen (total) (mg/l)	1.5	5	5	2	4	1.8	5
Nitrate (mg/l $N\text{-}NO_3$)	<0.5	1.3	1.3	<0.5	4.3	0.25	5.2

3.4.2 Summary of site vulnerability

Groundwater flushing of the substrate appears to be the primary source of enrichment at Redmyre SSSI and as such, the condition of the groundwater will define the health of the vegetation communities present. However spring sources appear to be very localised, with hummocks of *Sphagnum* seemingly occurring in close proximity to communities such as M5 or M10. One surface water sample in the east of the site, if not erroneous, suggests localised enrichment of the surface from some unknown source.

An assessment of vulnerability of the site to enrichment is given in Table 8 below.

Table 8. Assessment of the vulnerability of Redmyre to eutrophication from catchment sources and their relative importance. Negative factors are shown in black, positive factors in blue.

Source	Redmyre	
	Vulnerability	**Details of Factors**
EXTERNAL SOURCES		
1. Agriculture	Low	- The site has a minimal surface water catchment with no intensive farming practices in obvious operation.
2. Human population	None	- No residential properties are present within the surface water catchment.
3. Aerial deposition	Low	- Deposition rates within this part of the UK are lower than recorded in England. Thus atmospheric Total Phosphorus input into the catchment is small, although Total Nitrogen remains a contributor.
4. Regional Groundwater	Low-Moderate	- Regional groundwater may be contributing to the site's water balance, and is understood to be of poor water quality.
INTERNAL SOURCES		
1. Wildlife	Low	- The site does not contain large numbers of bird species which would significantly contribute to the nutrient balance.
2. Site management	Low-Moderate	- Grazing history of the site is not continuous and periods of no grazing appear to have taken place. This could exacerbate problems of nutrient build-up over time.
3. Internal flushing	Moderate?	- Complex interactions between substrates and groundwater may be resulting in release of nutrients such as Phosphate previously bound up in the substrate. However, not enough is known about the groundwater source or its movement through the site to accurately gauge its significance.

3.5 Assessment of soil samples

Soil chemistry was sampled at four locations within Redmyre (one of which was in M23, with the remainder in combinations of M9 with possible M5 and M10). 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
12 samples across 5 sites for Springs, Seepages and Flushes.

Table 9 presents the soil chemistry data for Redmyre samples against the ER37 data. It shows some unusually high readings for Sodium, Phosphate (particularly in the root zone) and Total Organic Carbon, particularly in those groundwater sampling points in the centre and west of the site.

Soil sample 1 (GW1) was taken in the west of the site in silty peat underlain by sand at 60 cm. the water level was at the surface at this location, with higher moisture content than below, most likely due to the presence of a sand layer and surface flushing.

Soil samples 2 (GW2), 3 (GW3) and 4 (GW4) were taken in the centre of the site. Samples 2 and 3 were taken in peat, underlain by silty sand / sandy silt at 90 cm and 40 cm respectively. The water table was at the surface for sample 2 and 5 cm below at sample 3. Again, the root layer had a higher moisture content than below, most likely due to the sandy layer and surface flushing.

Sample 4 was taken towards the east of the site. Here there were unconsolidated and liquid mud and roots, until approximately 1 m where a grey silty layer was present. Again the root layer had a higher moisture content than below.

Table 9. Soil samples at Redmyre and soil chemistry recorded by Wetland Type in Scotland (ER37). Red text denotes sample exceeds typical range.

	Redmyre		Redmyre		Redmyre		Fen		Redmyre		Marshy Grassland	
Sample	**Soil1 Root (in M5 or M9)**	**Soil1 below (in M5 or M9)**	**Soil 2 Root (in M9 or M10)**	**Soil 2 below (in M9 or M10)**	**Soil 4 Root (in M9)**	**Soil 4 below (in M9)**	**1st Quartile**	**3rd Quartile**	**Soil 3 Root (in M23)**	**Soil 3 below (in M23)**	**1st Quartile**	**3rd Quartile**
Calcium (mg/kg)	4,500	1,500	820	1,400	280	1,300	960	12,000	2,200	1,500	1,400	4,200
Magnesium (mg/kg)	1,700	490	1,700	480	1,800	970	1,500	3,800	1,400	460	1,900	2,700
Sodium (mg/kg)	1,500	450	450	580	80	330	74	280	680	210	75	200
Phosphate (available) (mg/l)	29	11	56	9.4	65	5.1	2.7	9.5	45	4.1	5.7	9.5
Nitrogen (total) (%)	1.4	0.38	0.56	0.59	0.25	0.54	0.25	1.4	2	0.17	0.29	0.78
Nitrogen (extractable) (mg/kg)	0.11	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	1.4	<0.1	<0.1	0.43	0.93
Total organic carbon (%)	28	3.3	51	11	7.3	5.4	3.7	12	38	13	6.6	20
Potassium (total)	2,600	450	450	380	110	150	-	-	2,100	140	-	-
Soil Moisture Content %	978	103	913	69	1,284	142	-	-	415	90	-	-

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 were collected from a single sampling round which, though providing consistency of timing, could be very misleading if 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 heavy rain may increase the amount of suspended solids or surface water flushing and therefore nutrient loadings).
- Clearly there is considerable complexity in the relationship between groundwater flushing and the nature of the peats and silts at Redmyre SSSI. This relationship could only be clarified through detailed soil survey (ideally tied in with topographic levels). These data are currently not available.
- 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).

3.7 Recommendations on future measures and / or data requirements

Options for remedial measures within wetland systems such as Redmyre SSSI are relatively limited because the source of enrichment does not appear to be the result of land management within the surface water catchment. Some measures, such as the implementation of buffer zones, though generally representing very little risk of negative impact on most sites, will not be appropriate here because it would result in some loss of the interest feature (i.e. M9 mire). Other remedial measures, such as re-routing water supplies or addition of water control structures, are unlikely to be easily applied to this site because the flushing may be diffuse and unpredictable.

The key recommendation proposed for this site is therefore to conduct further investigation on the nature and extent of the substrate types, together with more detailed water sample analysis, so that the necessity for any remedial measures can be better defined. In particular:

- Soil/peat survey of the site with at least one North-South transect and one East-West transect (centred on the GW2 sample point), with ground levels recorded so that a cross-section can be built up showing how water is moving through the site. Levels would not need to be at Ordnance Datum, but would need to be based off a site Benchmark that can be returned to if necessary.

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

- Ideally, surface water sampling every 1 to 2 months within existing points SW1, GW2 (spring observed) and SW3 for a full year to ascertain the patterns of enriched water movement across the site. pH and Dissolved Oxygen to be added to the parameters.
- Rainfall data in the region for the period during which water sampling takes place.
- Further examination of the vegetation to ascertain if communities such as M4, M5 and M10 are present and, if so, where they are located.

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	GW4	SW1	SW2	SW3
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
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	2.9	2.7	2.6	6.5	5.8	3.7	2
Nitrate	mg l^{-1}	0.5	Water	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	4.3
Phosphate Low Level	mg l^{-1}	0.02	Water	0.074	0.062	0.066	0.06	0.056	0.058	0.053
Nitrogen (total)	mg l^{-1}	1	Water	7	4	7	6	2	1.5	4
Calcium	mg l^{-1}	5	Water	16	25	6.6	11	9.8	8.3	7.8
Magnesium	mg l^{-1}	0.5	Water	2.4	2.9	3.3	1.7	1.9	1.5	1.6
Sodium	mg l^{-1}	0.5	Water	9.7	9.7	6.8	8.3	8	7.4	7.1
Iron (II)	µg l^{-1}	20	Water	20	200	500	210	120	<20	20
Iron (III)	µg l^{-1}	20	Water	58	170	340	<20	50	340	140
Iron (total)	µg l^{-1}	20	Water	78	370	840	210	170	340	160

Soil samples

			Sample ID	S1	S1	S2	S2	S3	S3	S4	S4
			Other ID	Below	Root	Below	Root	Below	Root	Below	Root
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	21/02/2012
Moisture	%	0.02	Soil	44.4	86.6	61.6	92.7	33.9	91	61	94.8
Stones content (>50mm)	%	0.02	Soil	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Phosphorus (available)	mg l^{-1}	10	Soil	11	29	9.4	56	4.1	45	5.1	65
Phosphorus (total)	mg kg^{-1}	-	Soil	3900	9200	2500	3700	4100	8200	5300	6200
Nitrogen (total)	%	0.02	Soil	0.38	1.4	0.59	0.56	0.17	2	0.54	0.25
Nitrite (extractable)	mg kg^{-1}	0.1	Soil	<0.10	0.11	<0.1	<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	<0.01	<0.01
Calcium (total)	mg kg^{-1}	100	Soil	1500	4500	1400	820	1500	2200	1300	280
Potassium (total)	mg kg^{-1}	0.2	Soil	450	2600	380	450	140	2100	150	110
Sodium (total)	mg kg^{-1}	0.2	Soil	450	1500	580	450	210	680	330	80
Magnesium (total)	mg kg^{-1}	0.5	Soil	490	1700	480	1700	460	1400	970	1800
Total Organic Carbon	%	0.2	Soil	3.3	28	11.00	51	13	38	5.4	7.3
Moisture content	%	-	Soil	103	978	69	913	90	415	142	1284
Bulk density	Mg/m3	-	Soil	1.24	1.01	1.46	0.99	1.34	1.12	1.35	0.98
Dry density	Mg/m3	-	Soil	0.61	0.09	0.87	0.1	0.7	0.22	0.56	0.07

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