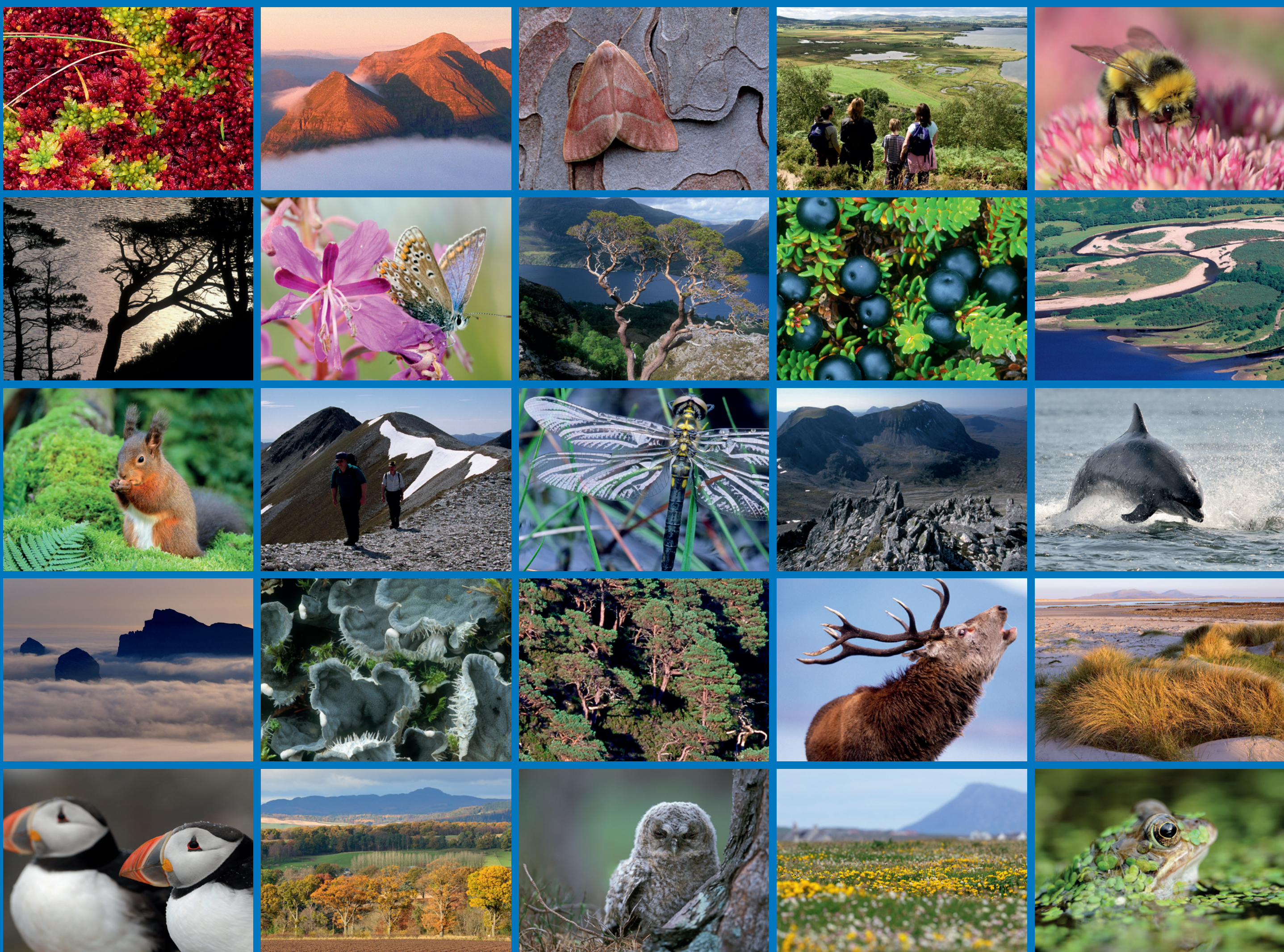
Scottish Natural Heritage
Research Report No. 1109

An assessment of the results of soil and water samples from a range of wetland sites – Hare Myre, Monk Myre and Stormont Loch SSSI



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An assessment of the results of soil and water samples from a range of wetland sites – Hare Myre, Monk Myre and Stormont Loch SSSI

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This report should be quoted as:

Spencer, K.L. & Pitcher, A. 2019. An assessment of the results of soil and water samples from a range of wetland sites – Hare Myre, Monk Myre and Stormont Loch SSSI. *Scottish Natural Heritage Research Report No. 1109.*

RESEARCH REPORT

Summary

An assessment of the results of soil and water samples from a range of wetland sites – Hare Myre, Monk Myre and Stormont Loch SSSI

Research Report No. 1109
Contractor: OHES Environmental Ltd
Year of publication: 2019

Keywords

nutrients; diffuse pollution; wetland; Hare Myre, Monk Myre and Stormont 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 Monk Myre, in order to assess the trophic status of the designated wetland and identify any likely sources of nutrient input.

Main findings

- Monk Myre is one part of the larger Hare Myre, Monk Myre and Stormont loch SSSI but for this study, all of the sampling was undertaken on Monk Myre.
- Monk Myre can be regarded as two separate lochs linked by a narrow ditch (Figure 3) and located within a small surface water catchment. The myre is fed by a small spring and is separated from the Stormont Loch and Hare Myre catchment by a ridge of glacial material, though they are presumed to be linked by the same underground aquifer.
- Groundwater samples taken at Monk Myre have been compared with the nutrient level requirements of the vegetation types known on site. This indicates that the Phosphate level 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). This is also generally the case for Calcium, Magnesium and Sodium. However, Nitrate levels exceed the guidelines/thresholds for marshy grassland, fen and swamp at points GW1 (western end) and GW2 (northern loch boundary). In contrast, Nitrate levels were within the ER37 range for the wet woodland and mire around the southern edge of the loch.
- The higher than typical Total Nitrogen levels are also some cause for concern, with all groundwater samples recorded between 7 to 10 mg/l TN (i.e. double the 3rd quartile concentrations recorded in fen for Scotland).
- Using the 2012 surface water sample and the SRBDD 2014 standards, the lochs appear to exceed standards for Total Ammonia and JNCC guidelines for Total Nitrogen.

However it is emphasised that this is from a single sample. Loch Phosphorus levels were within High Ecological Status standards.

- Nitrate levels (not included in the standards) reached concentrations of 70 mg/l in SW1 and 40 mg/l in SW2. This strongly indicates that it is the groundwater feed (presumably sourced from land to the north and west) which is the major source of Nitrogen enrichment within the lochs. It appears that the lochs may be acting as a sink in this respect, with water quality improving as it exits the loch.
- All Phosphate levels were recorded within Good Ecological Status (GES). When combined with the groundwater sample data, it confirms that enrichment via Phosphate does not appear to be an issue at this site.
- Classification of the trophic state of Monk Myre is somewhat complicated by the conflicting Phosphate and Nitrogen levels. In Phosphorus terms, the lochs would be borderline Oligotrophic / Mesotrophic status. However, the extremely high concentrations of certain forms of Nitrogen mean that the surface waters exceed the SRBDD standards. Measurements of Chlorophyll-a concentrations may clarify this issue but with the information available to this study, it is proposed that the lochs be considered as Meso-Eutrophic.
- Assessment of vulnerability showed Hare's Myre, Monk Myre and Stormoont SSSI was most at risk from agricultural practices, historic input of effluent and possibly release of stored nutrient from loch sediments and bird guano.
- Further investigations are recommended for the site (such as monthly water quality sampling on all inflows and outflows, sediment sampling within the loch and a full NVC survey). A range of remedial options are proposed for consideration, once additional data have been gathered.

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Acknowledgements

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

1. INTRODUCTION

1.1 Project background and aims

In 2012, SNH conducted soil and water sampling from 17 designated wetland sites (Sites of Special Scientific Interest and Special Areas of Conservation). The samples were collected to establish whether the sites were subject to nutrient enrichment from either diffuse or point source pollution. The aim of this report is to analyse the data collected at Monk Myre, 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 Monk Myre.

2.1 Sampling methodology

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

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

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

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

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

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

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

Samples were delivered to the EnviroCentre Glasgow Office and 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).

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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 within the report.

3. ASSESSMENT

3.1 Site review

Monk Myre (21.89 ha), along with Hare Myre and Stormont Loch forms part of a SSSI 3 km south east of Blairgowrie (Figure 1). The three lochs are part of a wider network of kettle hole lochs (formed by melted isolated blocks of ice) which extended from Dunkeld to Blairgowrie. The site (lying at approximately 52 m AOD) is important for its open water transition fens, assemblage of rare vascular plant species, wintering greylag goose population (an SPA under the Birds Directive) and geomorphology. The site lies in the fertile agricultural landscape of Strathmore.

Monk Myre is a partially silted up kettle hole lying on fluvioglacial outwash sands. The lochs have a fringe of emergent vegetation, mixed deciduous woodland and wet woodland. Monk Myre has a surface area of 10 ha and a mean depth of 1.5 m (maximum of 3.7 m) with a substrate of stones, sand and gravel, as well as silt.

Other species of wetland birds (not part of the notified interest) make use of the site and include great crested grebe, shoveler, mallard, teal, wigeon, pochard, tufted duck and goldeneye. Red squirrel, otter and roe deer make use of the site. The eutrophic waters provide excellent conditions for pike and perch. The myre is popular for fishing and is used as a rainbow trout fishery.

Monk Myre is shown on the 1843-1882 OS map as one large loch rather than two linked by a burn (Figure 2). It is possible that the lochs could be man-made, perhaps from marl extraction. The site is entirely surrounded by arable fields or permanent pasture. The lochside fringe is open to grazing by cattle except where fenced enclosures have been erected to prevent poaching and enhance the fen and emergent vegetation. Some areas are completely ungrazed, others are grazed for part of the year.

Figure 1. Site Boundary – Monk Myre

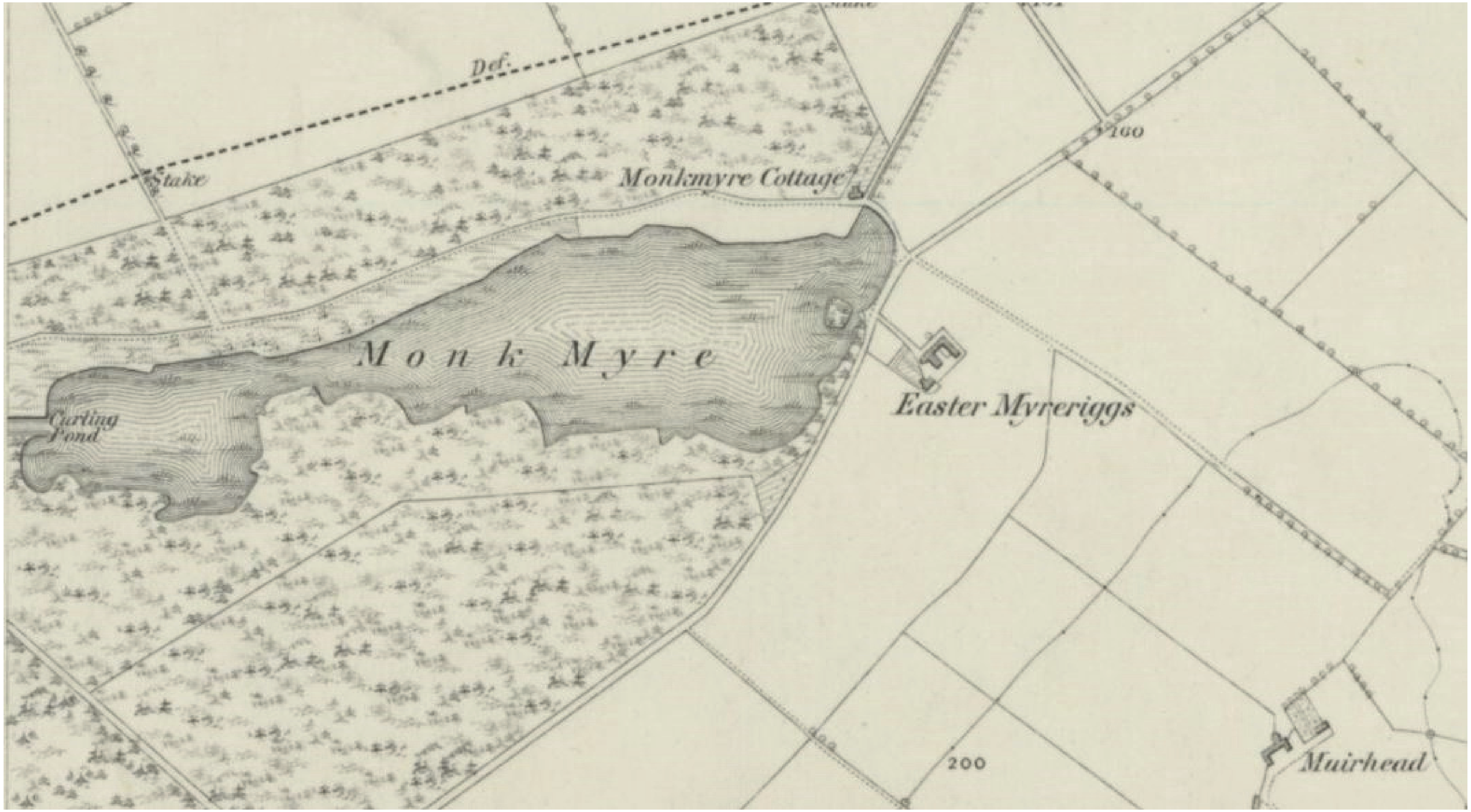

Figure 2. Ordnance Survey Six Inch 1843 – 1882 map (Source: National Library of Scotland)

3.1.1 Site designations and specific targets

The features for which Monk Myre is notified are detailed in Table 1, along with their pressures. The site was notified in 1972 and re-notified in 1985. The site has areas of wet grassland, fen and swamp. The wetland habitats provide important areas for breeding birds and a number of locally rare and uncommon plant species.

Table 1. Hare Myre, Monk Myre and Stormont loch SSSI notified features and their pressures

SSSI features	Feature Category	Summary Condition / Latest Condition	Pressure
Greylag goose	Birds	Unfavourable Declining	Natural event
Open water transition fen	Wetlands	Favourable Maintained	No negative pressures
Vascular plant assemblage	Vascular plants	Favourable Maintained	No negative pressures
Quarternary of Scotland	Earth sciences	Favourable Maintained	No negative pressures

3.1.2 Site hydrology

Monk Myre can be regarded as two separate lochs linked by a narrow ditch (Figure 3) and located within a small surface water catchment (Figure 4). The myre is fed by a small spring (at the western end of the myre) and is separated from the Stormont Loch and Hare Myre catchment by a ridge of glacial material, though they are presumed to be linked by the same underground aquifer. There is a natural outflow draining to the River Ericht in the north-east.

Monk Myre is underlain by the Vale of Strathmore bedrock and extensive sand and gravel aquifers. In 2008 the groundwater quality was classified as ‘Good’, whilst the quantity was classed as ‘Poor’ due to abstraction for arable farming. An upward trend in pollutants was also identified.

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.

Only limited data were available on the hydrological functioning and substrates present for this site. As application of systems such as the WetMecs scheme requires detailed information on both these factors, the WetMec types present can only be estimated at this stage. However, the setting of this kettle hole formation, with thin-moderate peat overlying coarse sands and gravels, would suggest the presence of WetMec 13: Seepage Percolation Basin (groundwater-fed basins typically with a transmissive surface layer and a buoyant surface).

At the western end of the site, the presence of a spring feed and communities such as M10 *Carex dioica-Pinguicula vulgaris* mire indicate WetMec 10: Permanent Seepage Slopes (summer wet surfaces usually on sloping, shallow peat) or possibly WetMec 15: Seepage Flow Tracks (groundwater-fed flow paths in mires). Around the margins of the waterbody, where the vegetation is encroaching directly upon the water body, sub-type WetMec 13c: Seepage Percolation Water Fringe appears to be present. Areas of M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire may coincide with WetMec 13b Seepage Percolation Quag (quaking or buoyant surface over rhizome mat).

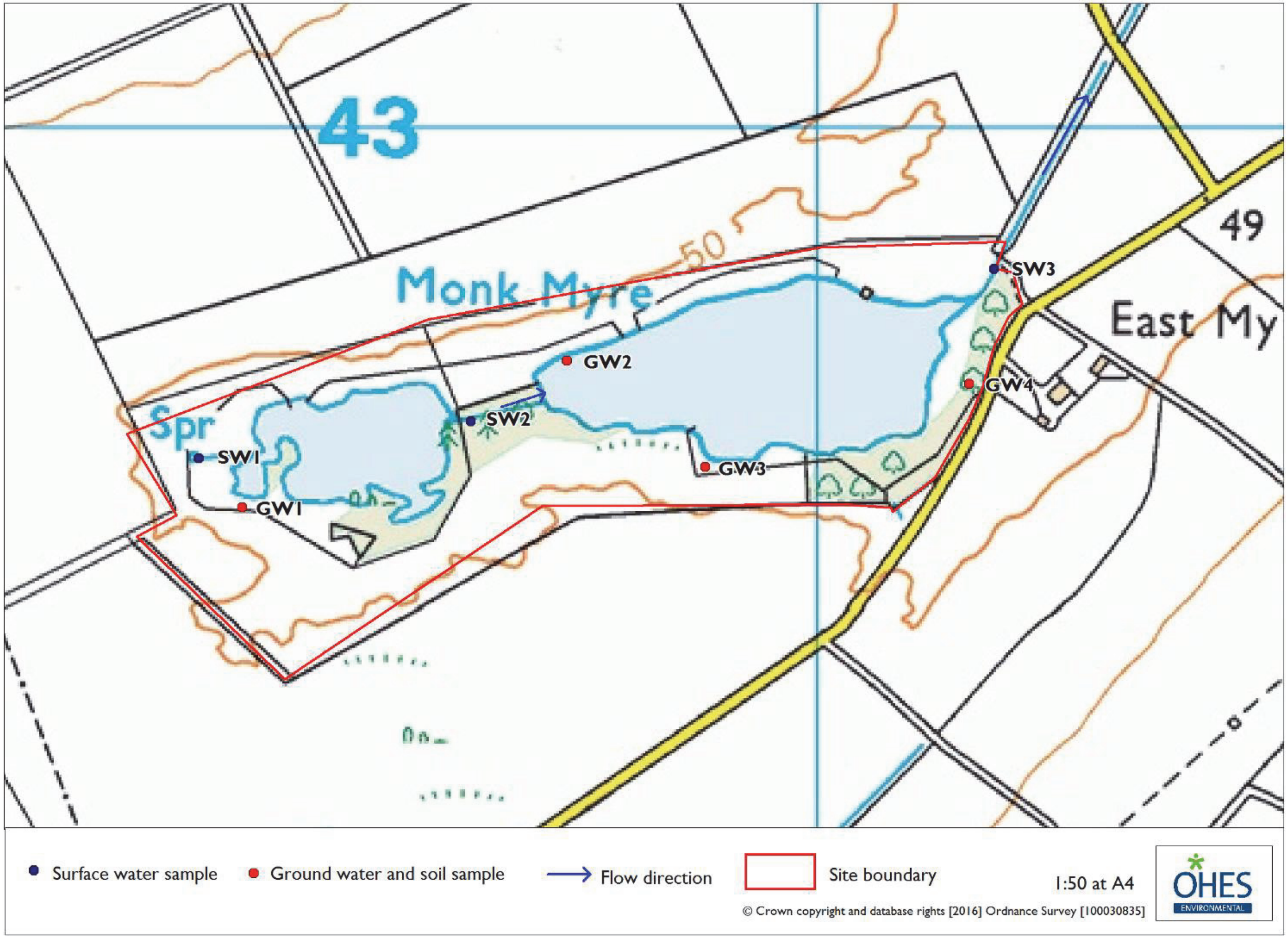

Figure 3. Monk Myre – Hydrology and Sample Locations

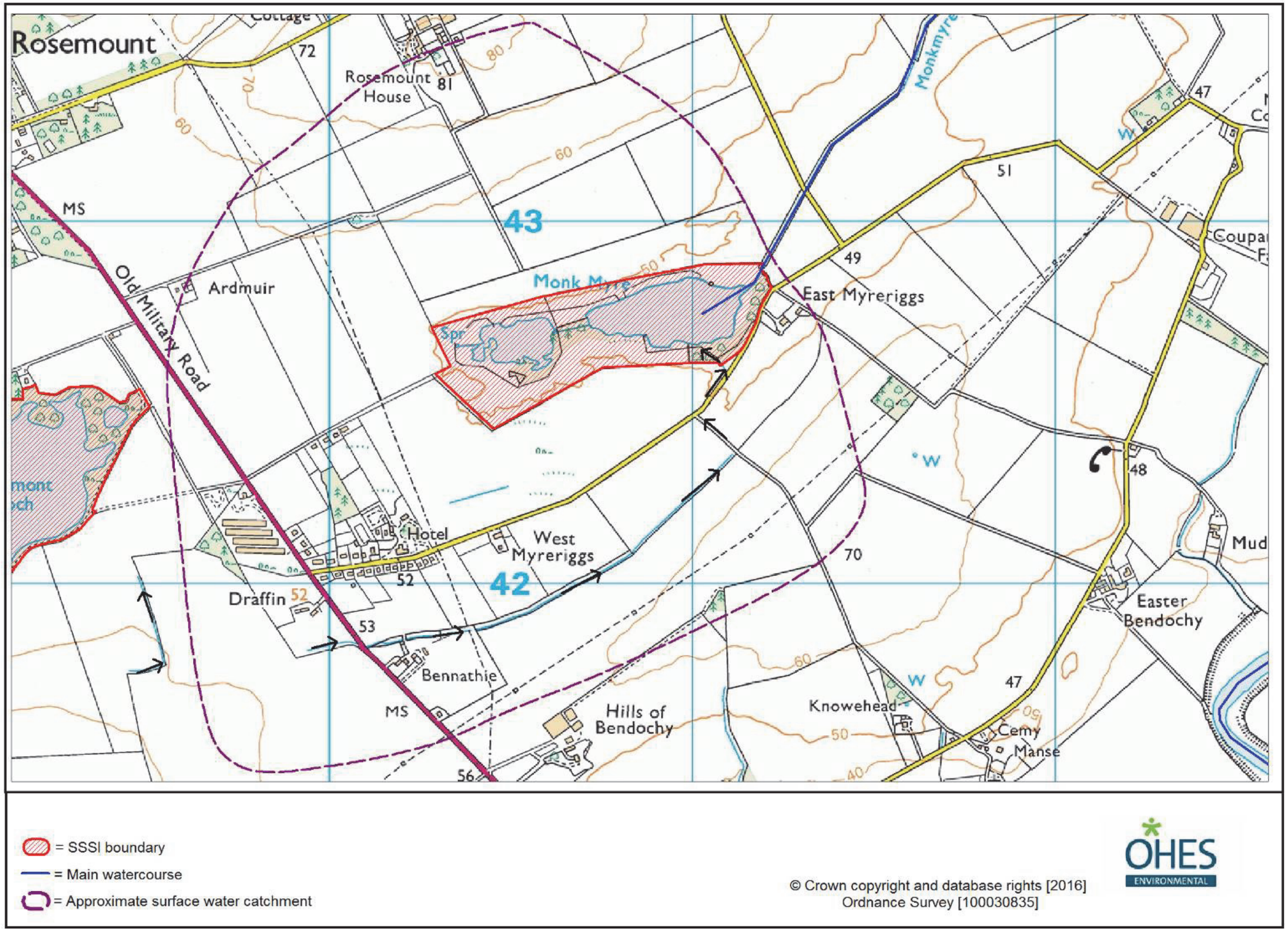

Figure 4. Monk Myre – approximate surface water catchment

3.1.3 Site soils / sediments

Monk Myre is underlain by Alluvial Soils (shown in pale yellow, Figure 5), derived from the post-glacial erosion cycle and laid down as sediments from a suspension in water. They are normally well sorted with the modal grain size depending upon the current of the suspension. Textures range from clay to gravel, with variations horizontally and vertically. Surrounding the Alluvial Soils is the Corby Association (shown in orange). These freely drained soils are developed on fluvio-glacial and raised beach sands and gravels derived from acid schists and granite. Textures tend to be coarse, varying from sandy loam or loamy sand. The stone content can be very high and consist mainly of rounded and subrounded stones of varying sizes.

Around the margins of the catchment is the imperfectly drained Balrownie Association (shown in brown). This association was developed on drifts, often water-modified, which are derived from Lower Old Red Sandstone sediments containing both coarse-grained massive sandstones and fine-grained flaggy sandstones. The drift, which is generally reddish brown in colour, varies in texture from fine sandy loam to clay loam and has a moderate stone content of sandstones with occasional schist erratics. The upper layers have had some degree of water-sorting associated with the last ice sheet and as a result the soils have frequently partially sorted sandy loam or loam upper horizons overlying compact sandy clay loam or clay loam drift.

Observations made during the collection of water samples in 2012 recorded thin layers of fibrous peat over supersaturated, amorphous peat (to around 50 to 60 cm below ground surface). In all cases the peat was underlain with coarse sand and gravel, occasionally with a silty layer in between.

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

3.1.4 Site specific issues

Water quality appears to have been affected by nutrient enrichment from agricultural runoff, effluent discharge from storm drains in Rosemount and potentially enrichment sourced from wildfowl presence. Palaeolimnological data indicates that the loch supported diatom communities typical of a mesotrophic loch. Enrichment is known to have occurred on the site, most notably during the 1950's-1970's. There are a number of recently built houses (30 in total), most with septic tanks / soakaways which may be adding Phosphorus to the loch. There is also a disused hotel (with an assumed septic tank / soakaway) which may be converted into flats in the future. Furthermore, a poultry farm is also present which may be within groundwater serving Monk Myre (covered by a SEPA licence). SEPA have modelled the surface flow paths for the catchment, as well as mapping the surrounding land use (Figures 6 and 7 respectively). Figure 8 shows the land use within the Monk Myre catchment.

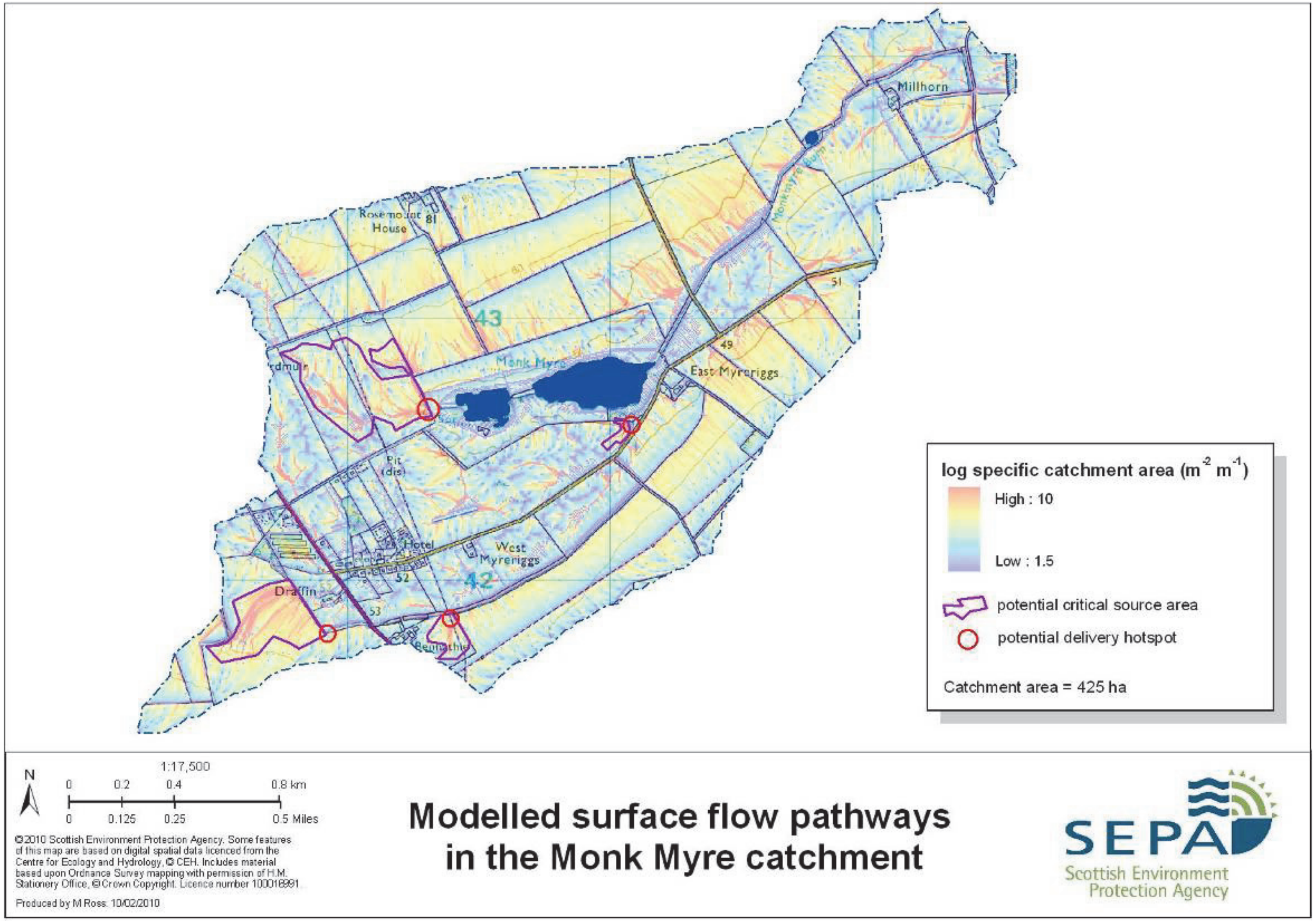

Figure 6. Surface flow pathways within the Monk Myre catchment

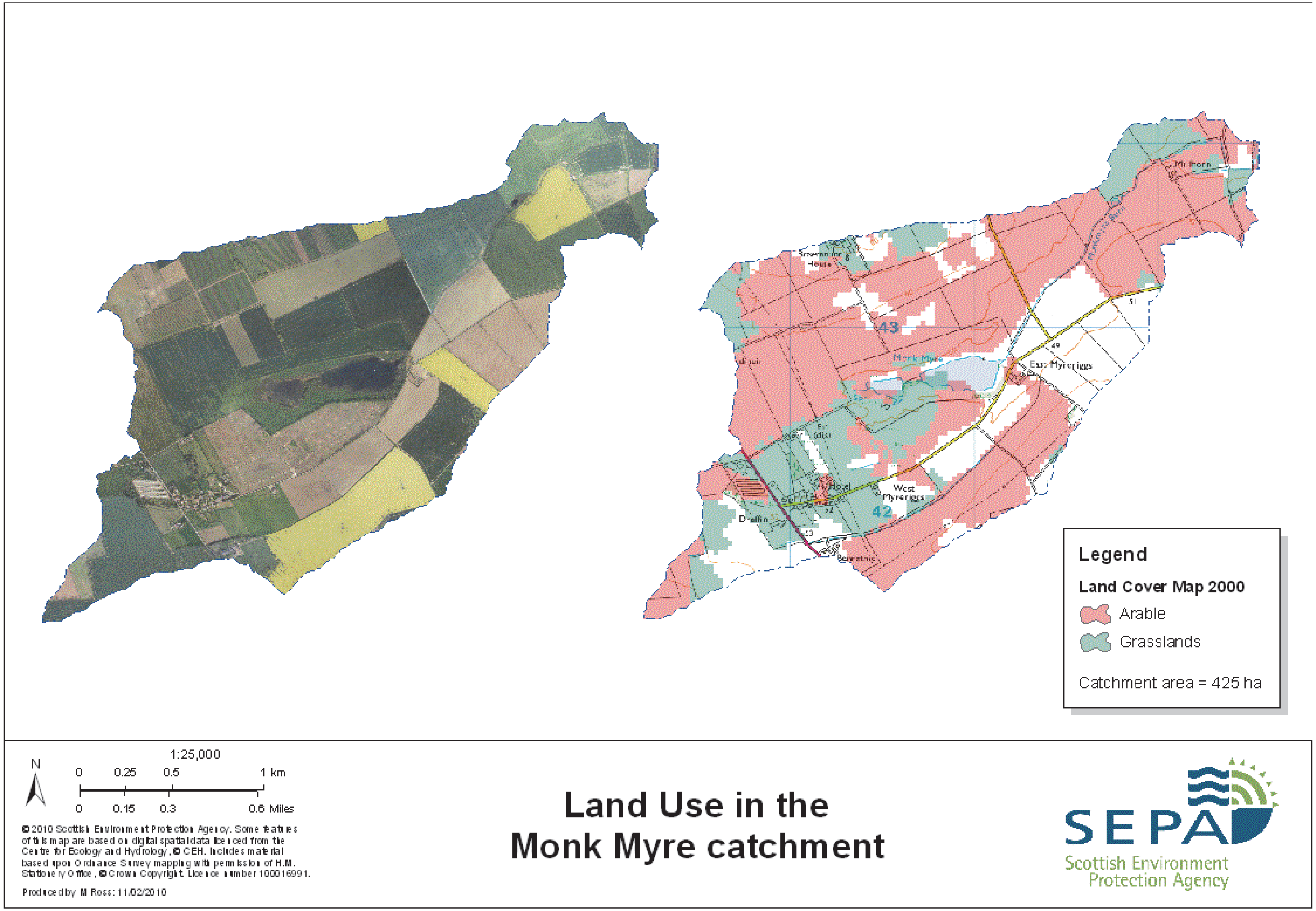

Figure 7. Land use in the Monk Myre catchment

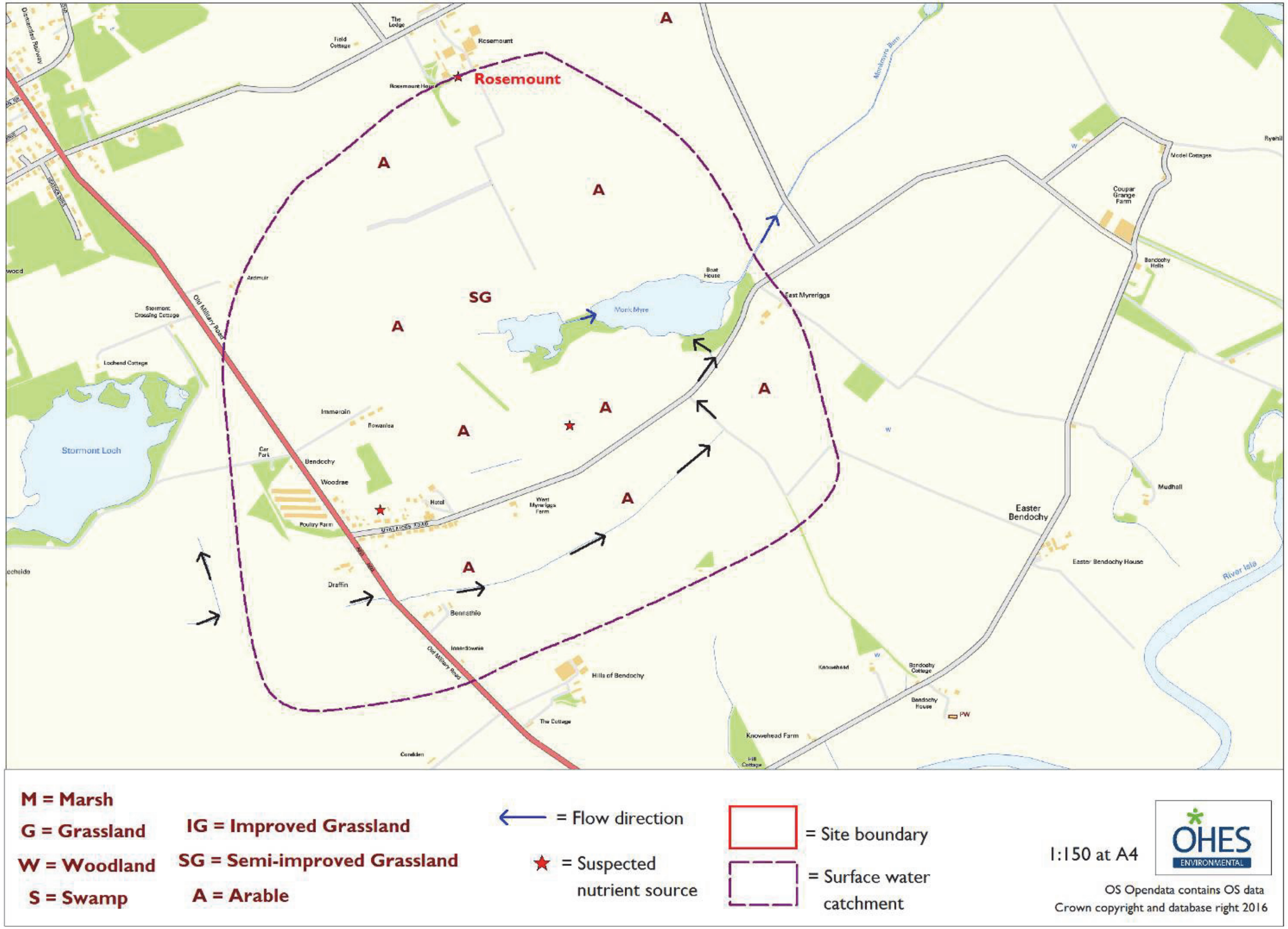

Figure 8. Land use and potential nutrient sources at Monk Myre

3.2 Assessment of vegetation data

Monk Myre contains a range of open water transition fen around the margins of the loch. Observations on the vegetation have been recorded in the late 1980's, 1991, 2005 and 2006. NVC communities were mapped for the whole site in 1991 (with no available quadrat data) and have subsequently been checked during Site Condition Monitoring. Figure 9 shows the NVC communities recorded in 1991.

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

- MG7 *Lolium perenne* leys and related grassland
- MG10 *Holcus lanatus-Juncus effusus* rush pasture
- M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire
- M10 *Carex dioica-Pinguicula vulgaris* mire
- M23 *Juncus effusus/acutiflorus-Galium palustre* rush-pasture
- M27 *Filipendula ulmaria-Angelica sylvestris* mire
- S4 *Phragmites australis* swamp and reed-beds
- S9 *Carex rostrata* swamp
- S27 *Carex rostrata-Potentilla palustris* fen
- U4 *Festuca ovina-Agrostis capillaris-Galium saxatile* grassland
- W4 *Betula pubescens-Molinia caerulea* woodland

3.2.1 Historic evidence of community change

There is insufficient data to quantify changes in the total coverage of each community, however some key points from SCM and the Site Management Statement are summarised below:

- There was some loss of unimproved ground in the early 1980s.
- In 1991 A10 *Polygonum amphibium* community was thought to be the dominant aquatic community at Monk Myre. Algal scum has sporadically covered large areas of the open water, which seems to be highly eutrophic.
- The small area of M9b *Carex rostrata-Calliergon cuspidatum* mire, historically present between the two lochs and adjacent to one loch, is still recorded in recent SCM.
- Comparisons of aerial photographs from 1986, NVC 1991 map and the SCM in 2004 showed that the area of open water transition fen has expanded, most likely due to a general expansion of swamp communities and the protection of vegetation from grazing / poaching.
- The mosaic of habitats and water levels were found to be maintained during the 2006 SCM, as was the quaking raft of vegetation (resulting in the site target being met).
- There has been no loss of NVC communities at the site, with key species being present and no negative indicators found during the 2006 SCM, resulting in the site targets being met.

Figure 9. NVC communities recorded in 1991 (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 Monk Myre are:

- Type 1b: Other Wet Woodland
- Type 2a: Marshy grassland
- Type 3: Spring flush and seepage
- Type 4: Fen
- Type 5: Swamp
- Type 6: Reedbed

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

3.2.2.1 Type 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 community is present at Hare Myre, Monk Myre and Stormont SSSI:

- W4 *Betula pubescens-Molinia caerulea* woodland – a widespread but locally occurring woodland, characteristic of moderately acid, peaty soils in a variety of mire settings (Rodwell, 1991). It can occur in both soligenous and topogenous situations, but is especially associated with drying ombrogenous peat around the margins of mires which have become elevated above the influence of ground water. The *Sphagnum* sub-community is more typical of deeper and wetter peats.

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. Other 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: <175 m = 5 mg/l N-NO_3 (22 mg/l NO_3)

3.2.2.2 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 Monk Myre include:

- M23 *Juncus effuses/acutiflorus – Galium palustre* rush-pasture
- MG10 *Holcus lanatus-Juncus effusus* rush-pasture

These communities range from relatively species-poor communities whose distribution is widespread across Scotland (such as MG10), 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.

SNIFFER data and guidelines for marshy grassland are presented in Table 3. Mean Nitrate results for wet grassland in good condition are given in UKTAG (2014) as 6mg/l N. The UK third quartile value is 5.9 mg/l N-NO_3. The SNIFFER values in groundwater for Scotland are significantly lower, with a third quartile value of 0.25 mg/l N-NO_3 (ER37).

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

Table 3. 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: 6 (or 26 mg/l as NO_3) for <175 m AOD

3.2.2.3 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 Monk Myre 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 community listed under Type 3c and d which has been recorded at Monk Myre is:

- 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 4. 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 6.4 mg/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 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 4. Groundwater guidelines 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)

3.2.2.4 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 Monk Myre are:

- M9 *Carex rostrata–Calliergon cuspidatum (Calliergonella cuspidata)/ Calliergon giganteum* mire – occurs on slope, stream-side, lochside and valley bottom/basin.
- M10 *Carex dioica-Pinguicula vulgaris* mire – see notes above under springs and seepages.
- M27 *Filipendula ulmaria-Angelica sylvestris* mire - occurs on slopes, floodplains, stream-sides, lochsides and valley bottoms and is associated with high water level fluctuation (ER37). It is generally associated with moderate to high fertility.
- S27 *Carex rostrata-Potentilla palustris* tall-herb fen - occurring in wet valley bottom/basin locations, where strongly sub-surface water levels are outside of normal conditions for the community. Despite containing a high number of total species, most

stands are relatively species-poor (Wheeler, Shaw & Tanner, 2009). It is typically of moderate fertility, with transitions to M9 in mesotrophic conditions, and S9 in deeper, oligotrophic waters (ER37). Stands of S27 may be resistant to moderate nutrient inputs, but high levels of eutrophication lead to impoverishment, with an increased prominence of species like *Agrostis stolonifera, Juncus effusus* and *Phragmites australis* (Wheeler, Shaw & Tanner, 2009).

ER37 data and thresholds for Fens are presented in Table 5. Under the UKTAG report (2012 & 2014), mean nitrate levels in groundwater fed fens in good condition are 3.4 and 2.9 mg/l N-NO_3 for mesotrophic and oligotrophic fen respectively, and the 3rd quartile values are 5.7 and 5.0 mg/l N-NO_3. However, ER37 reports that Nitrate levels in Scotland are significantly lower, with a 3rd quartile value of 0.25 mg/l N-NO_3 for groundwater, suggesting that most fen samples for Scotland are in good condition).

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

Table 5. 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 = 5 (or 22 mg/l as NO_3) Olig = 4.5 (or 20 mg/l as NO_3)

3.2.2.5 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 Monk Myre are:

- S9 *Carex rostrata* swamp - occurring within shallow to moderately deep swamps within oligotrophic to mesotrophic waterbodies/wetlands. It can occur at variable altitudes on organic substrates, or more infrequently on silty or sandy substrates (Rodwell, 1995). It is widespread across the north and west of the UK in suitable situations.

ER37 data and guidelines for Swamps are presented in Table 6. Mean Nitrate levels for groundwater-fed swamp in good condition are reported in UKTAG 2012 as 4.9 and 3.5 mg/l N-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-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-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 6. 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-NO_3)	0.25	0.25	0.25	Guideline: Meso = 5 (or 22 mg/l as NO_3) Olig = 4.1 (or 18 mg/l as NO_3)

3.2.2.6 Type 6 Reedbed

Equivalent NVC types covered:

- S4a *Phragmites australis* sub-community (present at Monk Myre)
- 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 reedbeds are presented in Table 7. 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 1 mg/l and UKTAG threshold of 22 mg/l should be viewed as an increasing risk.

Table 7. Groundwater threshold for reedbeds 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 Monk Myre 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.

Table 8 indicates that for all vegetation currently found around the sample locations, Phosphate levels are consistent with the data recorded for Scotland (ER37), as generally are Calcium, Magnesium and Sodium. However, Nitrate levels exceed the guidelines/thresholds for marshy grassland, fen and swamp at points GW1 (western end) and GW2 (northern loch boundary). In contrast, nitrate levels were within the ER37 range for the wet woodland and mire around the southern edge of the loch.

The higher than typical Total Nitrogen levels are also some cause for concern, with all groundwater samples recorded between 7 to 10 mg/l TN (i.e. double the 3rd quartile concentrations recorded in fen for Scotland).

Table 8. Groundwater samples at Monk Myre compared to Wetland Type for Scotland. Red text denotes sample exceeds guidelines or 3rd quartile.

	Monk Myre	Marshy Grassland			Monk Myre	Wet woodland		
Sample	**GW2 (nr M23)**	**1st Quartile**	**3rd Quartile**	**Guideline**	**GW4 (in W4)**	**1st Quartile**	**3rd Quartile**	**Threshold**
pH (-)		6.6	7.1	5 to 8		6.8	7.0	
Dissolved Oxygen (%)		35	40			20	25	
Conductivity (mS/cm)		0.13	0.18			0.23	0.46	
Calcium (mg/l)	29	18	24		47	7	60	
Magnesium (mg/l)	4.4	4.5	8.7		4.3	1.7	8.8	
Sodium (mg/l)	4.2	9.2	12		13	6.6	12	
Phosphate (mg/l)	0.024	0.06	0.065	Indicator: 0.065	0.043	0.012	0.1	None set
Nitrogen (total) (mg/l)	7	4	7		10	1.2	5.0	
Nitrate (mg/l N-NO_3)	4.3	0.25	0.25	Guideline: 6 (or 26 mg/l as NO_3) for <175 m AOD	<0.5	0.1	0.25	Threshold: <175 m 5 mg/l N-NO_3 (22 mg/l NO_3)

Table 8 continued. Groundwater samples at Monk Myre compared to Wetland Type for Scotland. Red text denotes sample exceeds guideline or 3rd quartile.

	Monk Myre	Monk Myre	Fen			Monk Myre	Swamp		
Sample	**GW1 (in M10)**	**GW3 (in M9)**	**1st Quartile**	**3rd Quartile**	**Indicator**	**GW2 (in S9)**	**1st Quartile**	**3rd Quartile**	**Guideline**
pH (-)			6.4	7.4			5.7	7.1	
Dissolved Oxygen (%)			18	28			15	36	
Conductivity (mS/cm)			0.37	0.69			0.24	0.43	
Calcium (mg/l)	34	23	12	55		29	10	44	
Magnesium (mg/l)	7	3.6	3.4	14		4.4	3.6	16	
Sodium (mg/l)	17	8.3	5.4	14		4.2	5.5	18	
Phosphate (mg/l)	0.03	<0.02	0.064	0.1	None set	0.024	0.024	0.1	None set
Nitrogen (total) (mg/l)	10	10	1	5.1		7	2	7	
Nitrate (mg/l N-NO_3)	54	<0.5	0.25	0.25	Threshold: <175 m AOD Meso = 5 (or 22 mg/l as NO_3) Olig = 4.5 (or 20 mg/l as NO_3)	4.3	0.25	0.25	Guideline: Meso = 5 (or 22 mg/l as NO_3) Olig = 4.1 (or 18 mg/l as NO_3)

3.4 Assessment of surface water samples

3.4.1 Threshold levels

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

For the purposes of this study, the primary standards used for variables are sourced from the SRBDD 2014 because they are the latest interpretation of the European 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, Monk Myre is classified as very shallow (<3 m depth), freshwater, salmonid, low altitude (<80 mAOD) lake of high alkalinity (>50 mg/l). This equates to Ecotype 14 (Small temperate lake, with a catchment geology of rock and conductivity between 100 – 800 uScm) within the ECOFRAME document (Moss, 2003). Table 9 presents the SRBDD standards compared to those recorded from Monk Myre, but owing to the fluid nature of the research and advice, represent a starting point.

Table 9. In-loch water quality standards for Monk Myre. Red text indicates site exceeds standard.

Variable	**SRBDD (2014)**		**JNCC**	**ECOFRAME**		**Monk Myre**
	GES	HES		Good	High	SW2[3]
Total Ammonia as N	0.6 mg/l	0.3 mg/l	-	-	-	0.99 mg/l (Ammonium only)
Total Nitrogen	-	-	<1.5mg/l	0.6 – 1.0mg/l	<0.6 mg/l	16 mg/l
Acid Neutralising Capacity	>20 µeq/l	>40 µeq/l	>40 µeq/l	-	-	?
Dissolved Oxygen	7 mg/l	9 mg/l	As SRBDD	-	-	?
Salinity/Conductivity	<1000 µScm		-	100 – 800 µScm		?
Total Phosphorus	31 µg/l	23 µg/l	35 µg/l	30-50 µg/l	<30 µg/l	20 µg/l (Phosphate only)
pH	-	-	7 - 9	6 - 9		?

3.4.2 Threshold levels

Three surface water sampling points were monitored by SNH during the single sampling round (conducted in February 2012). These include: the main input channel (SW1), the stream connecting the two lochs (SW2) and the outlet channel (SW3), see Appendix 1 for raw data.

[3] SW2 is not within the main waterbodies, but lies within the connecting channel. It is however, the only indication of loch water quality available to this study.

Figure 10 shows the results of the Ammonium recording at Monk Myre against SRBDD standards for Total Ammonia. It indicates that, at the time of survey, the loch was above standards for GES, with increasing concentrations of Ammonium progressively downstream. This may be due to in-loch factors (such as the large geese population) or from sources outside of the catchment (such as the inflow at the south-eastern corner of the loch).

Total Nitrogen levels (as shown in Figure 11) were extremely high in SW1 (taken from a surface upwelling of groundwater) and gradual declines downstream. Nitrate levels (not included in the standards) reached concentrations of 70 mg/l in SW1 and 40 mg/l in SW2. This strongly indicates that it is the groundwater feed (presumably sourced from land to the north and west) is the major source of Nitrogen enrichment within the loch. It appears that the loch may be acting as a sink in this respect, with water quality improving as it exits the loch.

Total Phosphorus levels were recorded at Monk Myre but the levels of determination were below those useful in assessment against standards (i.e. all samples were marked as <0.2 mg/l). All Phosphate low levels were recorded within Good Ecological Status (GES) (Figure 12). Despite these values not taking into account the full Phosphorus concentration, it can be assumed that Total Phosphorus levels are within SRBDD standards. From the results is appears that the most upstream body of water is a source of slightly increased Phosphate levels, but this could also be the natural result of the channel temporarily containing increased concentrations of suspended sediments.

When combined with the groundwater sample data, it confirms that enrichment through Phosphate does not appear to be issue at this site.

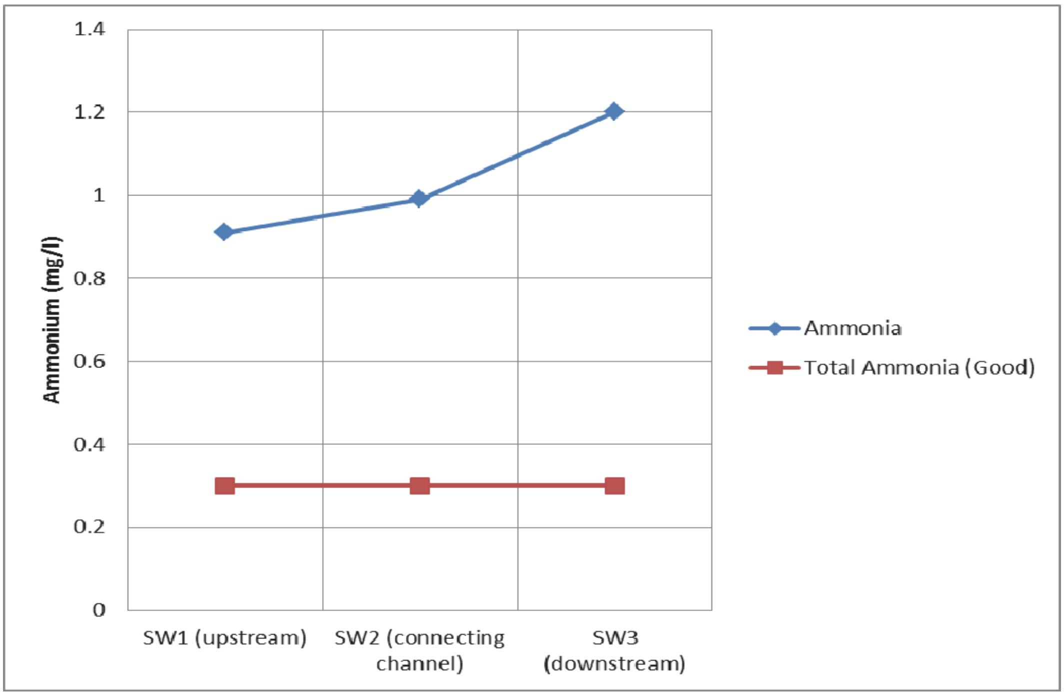

Figure 10. Ammonium recording at Monk Myre (blue line) against SRBDD standards for Total Ammonia

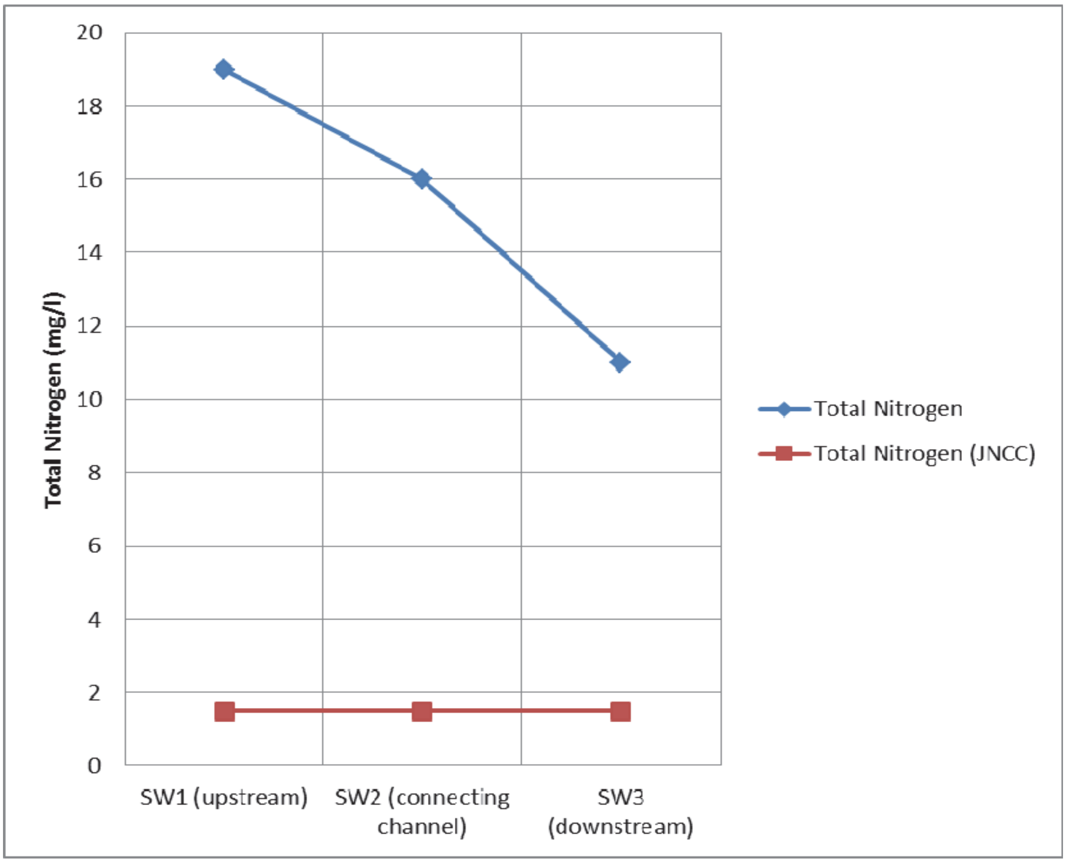

Figure 11. Total Nitrogen recording at Monk Myre (blue line) against JNCC levels

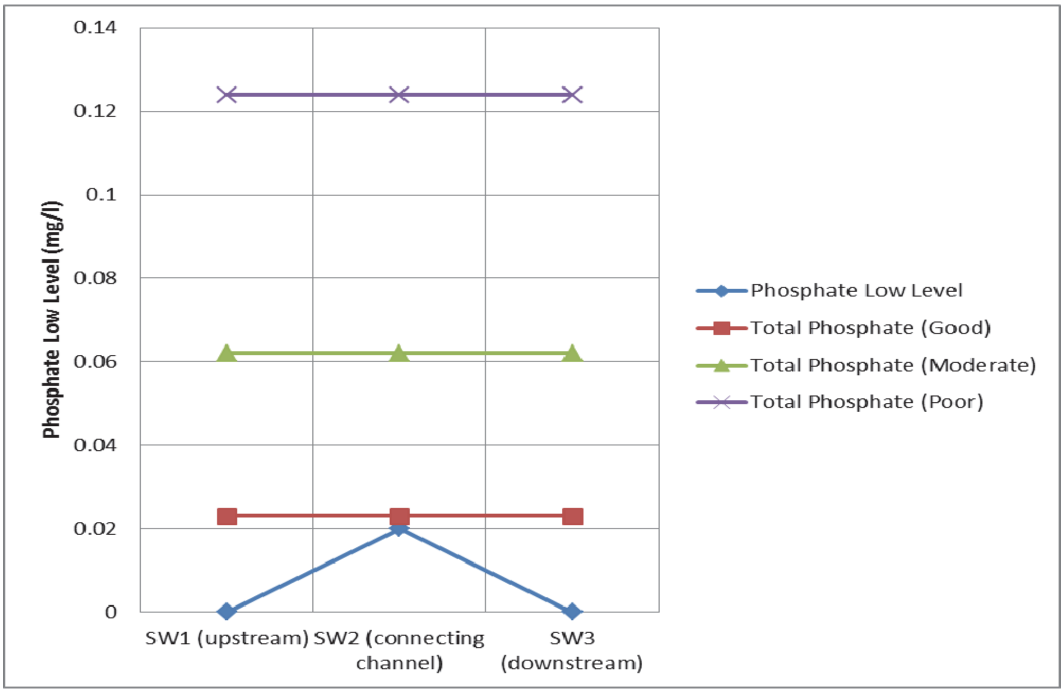

Figure 12.Total Phosphorus/Phosphate recording at Monk Myre (blue line) against SRBDD standards

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 10.

Classification of the trophic state of Monk Myre is somewhat complicated by the criteria given in the table below. In Phosphorus terms, the loch would be borderline Oligotrophic / Mesotrophic status. However, the extremely high concentrations of certain forms of Nitrogen mean that the surface waters exceed the SRBDD standards. Measurements of Chlorophyll-a concentrations may clarify this issue but with the information available to this study, it is proposed that the loch be considered as <u>Meso-Eutrophic.</u>

Table 10. Nutrient status classification scheme (SEPA)

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

An assessment of vulnerability of the site to enrichment is given in Table 11 below.

Table 11. Assessment of the vulnerability of Monk Myre to eutrophication from catchment sources, and their relative importance. Negative factors are shown in black, positive factors in blue.

Source	Monk Myre	
	Vulnerability	**Details of Factors**
EXTERNAL SOURCES		
1. Agriculture	Moderate	- The catchment is either in arable production or in permanent pasture, some of which is in close proximity to the loch. - Drainage of the catchment permits the flushing of fertiliser and nutrients into nearby watercourses which will eventually lead into the loch.
2. Human population	Moderate - High	- Historic input of effluent from storm drains in Rosemount to the north. - Potential sources of enrichment from the residential and farm buildings to the west of the site.
3. Aerial deposition	Low-Moderate	- Deposition rates within this part of the UK are lower than recorded in the south. Thus atmospheric Total Phosphorus input into the catchment is small, although Total Nitrogen remains a major contributor.
4. Regional Groundwater	Low High	- The site is spring fed however regional groundwater was recently classified as 'Good' quality. - Localised groundwater inputs show evidence of nitrogen enrichment.
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. - 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 store of nutrient may be present within the lochs in sediment form. The seasonal release of stored nutrients within the loch sediments will occur naturally under certain conditions. - 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.

3.5 Assessment of soil samples

Soil chemistry was sampled at four locations within Monk Myre (1 within M10 *Carex dioica-Pinguicula vulgaris* mire, 1 within S9 *Carex rostrata* swamp / M23 *Juncus effusus/acutiflorus-Galium palustre* rush-pasture and 1 in S27 *Carex rostrata-Potentilla palustris* tall-herb fen / M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire and 1 within S4 *Phragmites* swamp / W4 woodland). 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 12 presents the soil chemistry data for Monk Myre samples against the ER37 data. The results show that levels of Magnesium, Sodium and extractable Nitrogen are all at the lower end of the range observed in Scottish samples. However, Phosphate levels were elevated in three of the four samples, particular in soil sample 2 (both root and below), which was taken in the second of the two lochs at Monks Myre. The soil here was fibrous peat overlying coarse supersaturated sand and gravel. The soil moisture content was considerably higher at the root layer than below.

Soil sample 1 (GW1) was taken in the west of the site within the Myre and consisted of dark humified fen peat over sloppy peat, with coarse sands / gravel starting at c 25 cm. The moisture content below the root layer was much higher than above, and the water table was recorded at mire surface. It is generally within the levels recorded within Scotland (ER37), with the exception of slightly higher Phosphate levels.

Soil sample 2 (GW2) was taken on the northern edge of the loch and showed similar substrate layering to sample 1, with peat over sands and gravels. However, here the water table was 10cm above the surface, with a supersaturated sand layer and very high moisture content in the root zone. This sample showed higher Phosphate levels than the interquartile range for Scotland, despite the groundwater phosphate levels being low. One possible explanation could be localised enrichment from bird guano, or historic stores of nutrient present in the substrate which have since ceased, but there is insufficient data to confirm these suppositions.

Soil sample 3 (GW3) was taken in the south of the site. Here Calcium levels were very high compared to those observed in ER37 Scottish samples. The sample consisted of fibrous sedge peat, over supersaturated peat, with clayey silt at c60 cm and coarse sand at 80 cm. Once again moisture content was high in the root zone, matching a high watertable (recorded at the mire surface). Total Nitrogen was elevated at this location within the root layer, which may be the result of inflows from agricultural land to the south entering the loch around this area.

Soil sample 4 (GW4) was taken in the east of the site, also with elevated Calcium, Phosphate and total organic carbon at the root layer. The sample consisted of a fibrous mat with reed rhizomes at the surface (0-30 cm) followed by peat and then a silt and sand layer (at 70 cm and 80 cm respectively). As with previous samples, the moisture content was much higher at the root layer than below at this location, and the water table was recorded at the surface of the peat.

Table 12. Soil samples at Monk Myre and soil chemistry recorded by Wetland Type in Scotland (ER37). Red text denotes sample exceeds typical range.

	Monk Myre		Swamp		Monk Myre		Reedbed		Monk Myre		Monk Myre		Fen		Monk Myre		Marshy grassland	
Sample	**Soil 2 Root (in S9)**	**Soil 2 below (in S9)**	**1st Quartile**	**3rd Quartile**	**Soil 4 Root (in S4)**	**Soil 4 below (in S4)**	**1st Quartile**	**3rd Quartile**	**Soil 1 Root (in M10)**	**Soil 1 below (in M10)**	**Soil 3 Root (in M27 / M9)**	**Soil 3 below (in M27 / M9)**	**1st Quartile**	**3rd Quartile**	**Soil 2 Root (in M23)**	**Soil 2 below (in M23)**	**1st Quartile**	**3rd Quartile**
Calcium (mg/kg)	2,400	1,800	140	5,800	20,000	7,700	1,700	13,000	6,400	4,000	19,000	4,200	960	12,000	2,400	1,800	160	4,200
Magnesium (mg/kg)	120	610	410	3,400	320	640	200	2,700	110	1,300	280	1,700	1,500	3,800	120	610	1,100	2,700
Sodium (mg/kg)	33	2.5	17	140	34	10	32	44	34	19	55	23	74	280	33	2.5	43	200
Phosphate (available) (mg/l)	81	24	2.9	12	6.6	4.4	1.1	6	14	9.5	7.4	7.8	2.7	9.5	81	24	3.4	9.5
Nitrogen (total) (%)	0.62	0.16	0.17	1.2	1.7	0.83	0.99	1.7	0.78	0.14	2.2	0.18	0.25	1.4	0.62	0.16	0.05	0.78
Nitrogen (extractable) (mg/kg)	0.3	0.15	0.43	0.9	0.19	0.22	0.39	0.56	0.43	0.27	0.16	0.17	0.4	1.4	0.3	0.15	0.35	0.93
Total organic carbon (%)	4.7	0.54	4.1	25	45	6	5.5	22	9.4	1.3	49	0.92	3.7	12	4.7	0.54	2.1	20
Potassium (total)	110	800	-	-	75	130	-	-	240	270	65	500	-	-	110	800	-	-
Soil Moisture Content %	1,019	48	-	-	1,014	662	-	-	220	79	1,332	69	-	-	1,019	48	-	-

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.
- Conclusive evidence of vegetative change is limited due to the absence of a recent NVC survey.
- 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 sampling did not include measurements from all of the inflow channels, or include a true "within-loch" sample. Therefore it cannot be confirmed which source is the main contributor of nutrients into the loch, though the spring feed to the west seems to be a major source of Nitrogen.
- 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.
- 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 has been gathered. In the short term, this means that wetland types such as Fens, which currently contains a wide range of NVC communities, may appear to be more tolerant of nutrient-rich situations than is actually the case. For example, assessment of lowland wetland communities across England and Wales (by Wheeler, Shaw and Tanner, 2009), states that M5 has a mean substrate fertility[4] (mg phytometer) of 13.8 (and a range of 4 to 29), whereas M10 has a mean substrate fertility of 6.5 (and a range of 3 to 18). Both of these communities are currently placed within the same wetland type of "Fen" and are given the same threshold/guidance levels.
- 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

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

concern and can undergo risk/benefit assessment prior to implementation. The remedial options identified below are merely put forward for further consideration based on the characteristics of each site.

The initial assessment of Monks Myre, based on a single sampling round, suggests Nitrogen enriched water is present within the SSSI at extremely high levels in some cases. The main source of this enrichment appears to be from localised groundwater sourced from the surrounding agricultural land. However, there is also the possibility of surface water enrichment of inflows from the south (which do not appear to have been directly sampled). Confirmation would need to be obtained by the following data input:

- 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.
- Rainfall data in the region for the period when surface water sampling takes place.
- At least two sediment samples within the waterbody to identify possible internal store of nutrients, as well as the average depth of sediment present.
- A repeat of the full NVC to map the current extent of communities present.

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

- ***<u>Reducing nutrient input</u>*** - This is the most effective means of addressing eutrophication of the site, and possibly the only means of addressing enrichment sourced from the spring inflow to the west. 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.

- ***<u>Redirecting problematic water sources</u>*** – It may be possible to redirect the southern inflow to a point downstream of the loch outfall, to improve loch water quality. However, as this may not be the main source of enrichment, and risks reducing the water balance of the loch, it is not recommended at this stage.

- ***<u>Removing nutrient-rich sediments from the loch</u>*** – 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.

- ***<u>Soft engineering options</u>*** - 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:

  <u>Buffer Zones</u>; 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 the substrate is not ideal for the use of buffer strips, though the topography may be. Also, some of the existing woodland and swamp will already be acting as a partial buffer strip for the loch. However, it may be possible to utilise buffer strips within other parts of the surface water catchment, if conditions are appropriate.

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.

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ANNEX 1: WATER AND SOIL SAMPLES

Water samples

			Sample ID	GW1	GW2	GW3	GW4	SW1	SW2	SW3
Parameter	**Unit**	**Detection Limit**	**Sample Date**	23/02/2012	23/02/2012	23/02/2012	23/02/2012	23/02/2012	23/02/2012	23/02/2012
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	1.6	1.4	1.3	1.5	0.91	0.99	1.2
Nitrate	mg l^{-1}	0.5	Water	54	4.3	<0.5	<0.5	70	45	26
Phosphate Low Level	mg l^{-1}	0.02	Water	0.03	0.024	<0.02	0.043	<0.02	0.02	<0.02
Nitrogen (total)	mg l^{-1}	1	Water	10	7	10	10	19	16	11
Calcium	mg l^{-1}	5	Water	34	29	23	47	43	39	45
Magnesium	mg l^{-1}	0.5	Water	7	4.4	3.6	4.3	6.2	6.3	6.3
Sodium	mg l^{-1}	0.5	Water	17	4.2	8.3	13	6.7	13	12
Iron (II)	µg l^{-1}	20	Water	100	800	100	<20	<20	<20	80
Iron (III)	µg l^{-1}	20	Water	220	<20	100	450	220	240	200
Iron (total)	µg l^{-1}	20	Water	320	800	200	450	220	240	280

Soil samples

Parameter	Unit	Detection Limit	Sample ID	S1	S1	S2	S2	S3	S3	S4	S4
			Other ID	Root	Below	Root	Below	Root	Below	Root	Below
			Sample Date	23/02/2012	23/02/2012	23/02/2012	23/02/2012	23/02/2012	23/02/2012	23/02/2012	23/02/2012
Moisture	%	0.02	Soil	72.2	32	80.6	34.5	91.5	95.3	94.1	65.5
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	14	9.5	81	24	7.4	7.8	6.6	4.4
Phosphorus (total)	mg kg^{-1}	-	Soil	5600	8800	4200	800	2100	8600	5400	5000
Nitrogen (total)	%	0.02	Soil	0.78	0.14	0.62	0.16	2.2	0.18	1.7	0.83
Nitrite (extractable)	mg kg^{-1}	0.1	Soil	0.43	0.27	0.3	0.15	0.16	0.17	0.19	0.22
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	6400	4000	2400	1800	19000	4200	20000	7700
Potassium (total)	mg kg^{-1}	0.2	Soil	240	270	110	95	65	500	75	130
Sodium (total)	mg kg^{-1}	0.2	Soil	34	19	33	2.5	55	23	34	10
Magnesium (total)	mg kg^{-1}	0.5	Soil	110	1300	120	610	280	1700	320	640
Total Organic Carbon	%	0.2	Soil	9.4	1.3	4.7	0.54	49	0.92	45	6
Moisture content	%	-	Soil	220	79	1019	48	1332	69	1014	662
Bulk density	Mg/m3	-	Soil	1.23	1.5	0.91	1.72	1.02	1.52	0.99	1.28
Dry density	Mg/m3	-	Soil	0.38	0.84	0.08	1.16	0.07	0.9	0.09	0.17

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ISBN: 978-1-78391-754-9

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