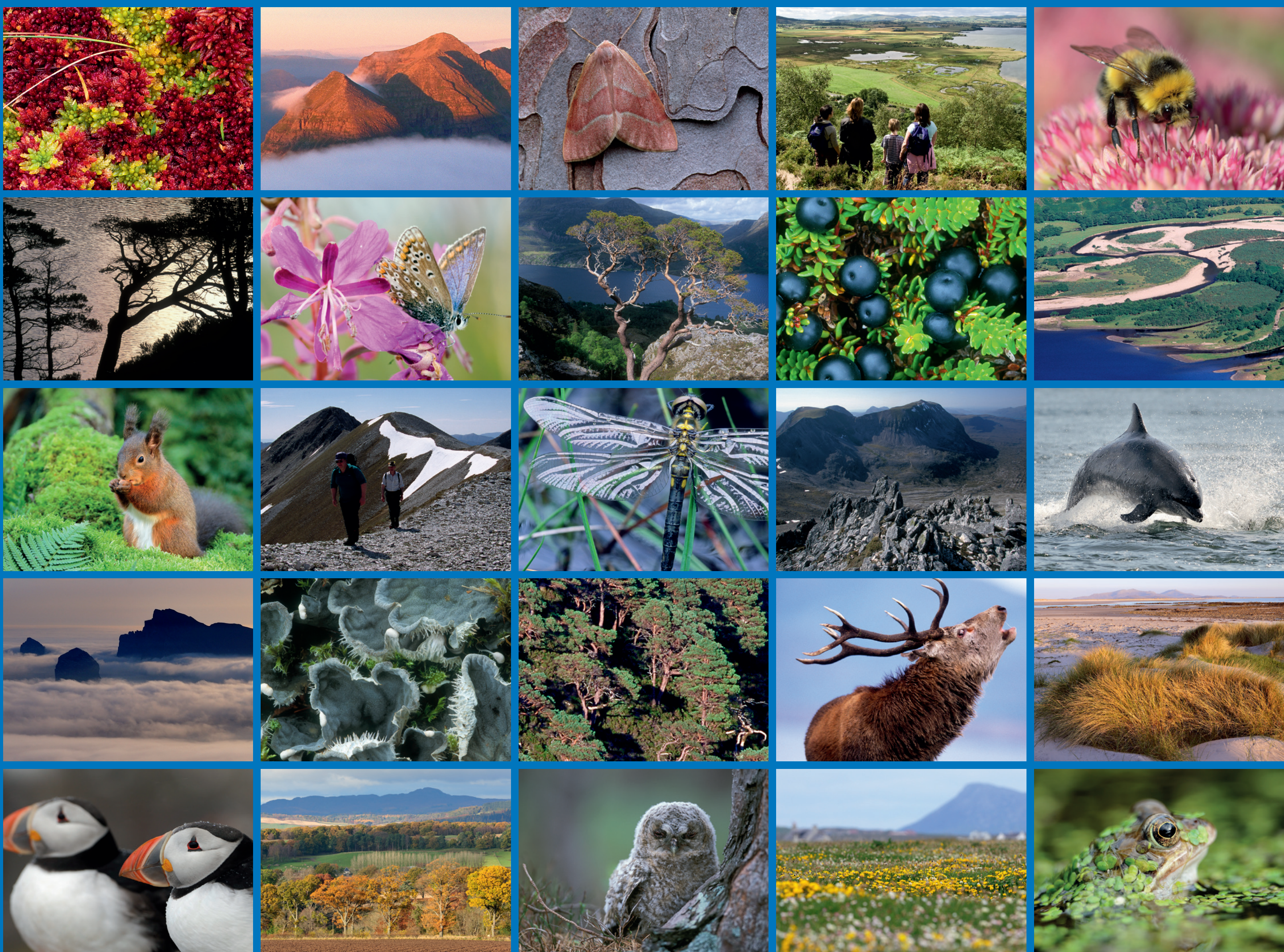
Scottish Natural Heritage
Research Report No. 1105

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



RESEARCH REPORT

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

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RESEARCH REPORT

Summary

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Research Report No. 1105
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Keywords

nutrients; Kilconquhar Loch SSSI; diffuse pollution; wetland; SSSI; water; soil

Background

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

Main findings

- The surface water catchment for Kilconquhar Loch is relatively small. The loch is primarily fed by underground springs, with a small number of feeder streams. The water levels are controlled by a weir at the outflow.
- Groundwater samples taken at Kilconquhar Loch have been compared with the nutrient level requirements of the vegetation types known on site. This indicates that the water quality is not consistent with the requirements of vegetation in regard to Calcium, Magnesium, Sodium and Total Nitrogen (TN). However it is consistent for Phosphate. This will partly be due to the base-rich nature of the water source at Kilconquhar Loch but also seemingly from enrichment.
- Using the 2012 surface water samples and the SRBDD 2014 standards, the Loch exceeds standards for Total Ammonia and also JNCC guidelines for TN. However it is emphasised that this is from a single within-loch sample. Phosphate appeared to be at borderline levels for Good Ecological Status.
- The Nitrogen concentrations at Kilconquhar Loch appear to reduce as water passes through the site, indicating that the underground springs and groundwater feed into the loch are diluting any enrichment effect, or that the site is acting as a sink for nutrients. The southern inflow in particular appears to be higher in Phosphate and Ammonia.
- Given that TN levels are significantly above thresholds for GES but that Phosphorus levels are only slightly above thresholds, this report concludes that the trophic state of Kilconquhar Loch surface water is borderline Mesotrophic.
- Assessment of vulnerability showed Kilconquhar Loch SSSI was most at risk from agricultural practices but also showed potential risk of enrichment from the residential areas to the north, as well as loch sediments.

- Further investigations are recommended for the site (such as monthly water quality sampling, sediment sampling within the loch and a hydrological walkover to establish silt build-up and hydrological functioning). A range of remedial options are proposed for consideration, once additional data has been gathered.

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Acknowledgements

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1. INTRODUCTION

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 Kilconquhar Loch, in order to assess the trophic status of the designated wetland and identify any likely sources of nutrient input. The results will then be used to inform site management 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 Kilconquhar Loch.

2.1 Sampling methodology

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

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

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

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

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

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

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

Samples were delivered to the EnviroCentre Glasgow Office and the SNH office at Battleby 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

Kilconquhar Loch SSSI is located immediately to the south of the village of Kilconquhar, 2 km north of Elie on the east coast of Fife (Figure 1). The 46.44 ha site is comprised of a large eutrophic kettle hole loch with transitional mire and wet woodland present.

The loch is fringed by tall fen dominated by reed, with local stands of sedge and bulrush. On the southern edge of the loch a mosaic of swamp communities are present, while the eastern and western shores are dominated by reed and then alder/willow carr.

Kilconquhar Loch has in the past supported a diverse breeding bird community which includes several regionally uncommon waterfowl species and one nationally rare (the black-necked grebe). Pochard and tufted duck winter on the loch in nationally important numbers.

Along the northern shore are residential gardens, while the remainder of the surrounding land is under agricultural use. The SSSI forms part of a lowland estate and is mainly used for recreation at low levels. Two owners have consent to use rowing boats on the loch and two have consent to occasionally shoot wildfowl. There is a permit system for birdwatchers resulting in limited trampling on the northern shoreline. If activities take place during the breeding season there is the potential to cause disturbance to breeding birds. The owners whose gardens border the northern shore have permission to control reed growth on the edge of their property. Figure 2 shows Kilconquhar Loch in the 1800s. The shoreline of the loch appears to have altered very little since then.

Figure 1. Site Boundary – Kilconquhar Loch

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

3.1.1 *Site designations and specific targets*

The SSSI was first notified in 1955 and 1971 and then re-notified in 1984 with a reduction in area. The features for which the site is notified are detailed in Table 1, along with their identified pressures.

Table 1. Kilconquhar Loch SSSI designated features and their pressures.

SSSI features	Feature Category	Summary Condition / Latest Condition	Pressure
Breeding bird assemblage	Birds	Unfavourable No Change (Aug 2008)	No negative pressures
Eutrophic loch	Freshwater habitats	Unfavourable Declining (Aug 2015)	a) Natural event b) Water management c) Water quality
Open water transition fen	Wetlands	Favourable / Favourable Declining (Sept 2013)	a)Water quality
Pochard, non-breeding	Birds	Unfavourable Declining (Feb 2017)	a) Water management

The SNH management objectives for the site are:

1. To maintain and enhance the eutrophic loch habitat through sensitive management of diffuse pollution sources to limit nutrient enrichment.
2. To maintain and enhance open water transition fen through occasional reed cutting.
3. To maintain and enhance the wet woodland habitat through reduction of sycamore and rhododendron.
4. Maintain and enhance the breeding bird assemblage and wintering duck populations by providing suitable habitat and limiting recreational disturbance.

3.1.2 *Site hydrology*

As Figure 3 shows, the surface water catchment for Kilconquhar Loch is relatively small. The loch is primarily fed by underground springs, with a small number of feeder streams (Figure 4). The water levels are controlled by a weir at the outflow.

There is a SEPA standing water sample point at Kilconquhar Loch but no sediment or water monitoring points. There are however a number of water monitoring points in the upper reaches of a surface water inflow to the loch, which are analysed for algae, freshwater invertebrates and macrophytes.

Kilconquhar Loch is underlain by the East Fife bedrock and localised sand and gravel aquifers. In 2008, the quality of the groundwater was classified as ‘Good’ whilst the quantity was classed as ‘Poor’ due to abstraction pressures for arable farming. No trends for pollution were identified. There is no historic rainfall data available for Kilconquhar 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 developed so far is the WetMec system (short for Wetland Mechanism) developed by Wheeler *et al* (2009). Each WetMec describes an assemblage of hydrological characteristics that determine functioning, and this is usually linked to a characteristic ecology. Crucially, wetland sites are not viewed as a single type (such as floodplain fen or groundwater fed valley fen), but are understood as inter-linked 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. However the nature of the loch as a kettle hole, with a sandy bed and the presence of springs in close proximity to the loch would suggest either WetMec 13: Seepage Percolation Basins (groundwater-fed basins typically with a transmissive surface layer and a buoyant surface) or possibly WetMec 20: Percolation Basins (where some groundwater feed can occur but the status of the supply compared to surface water is unclear). Both of these classifications have a sub-group for “Water Fringe” situations, as is found at Kilconquhar Loch SSSI.

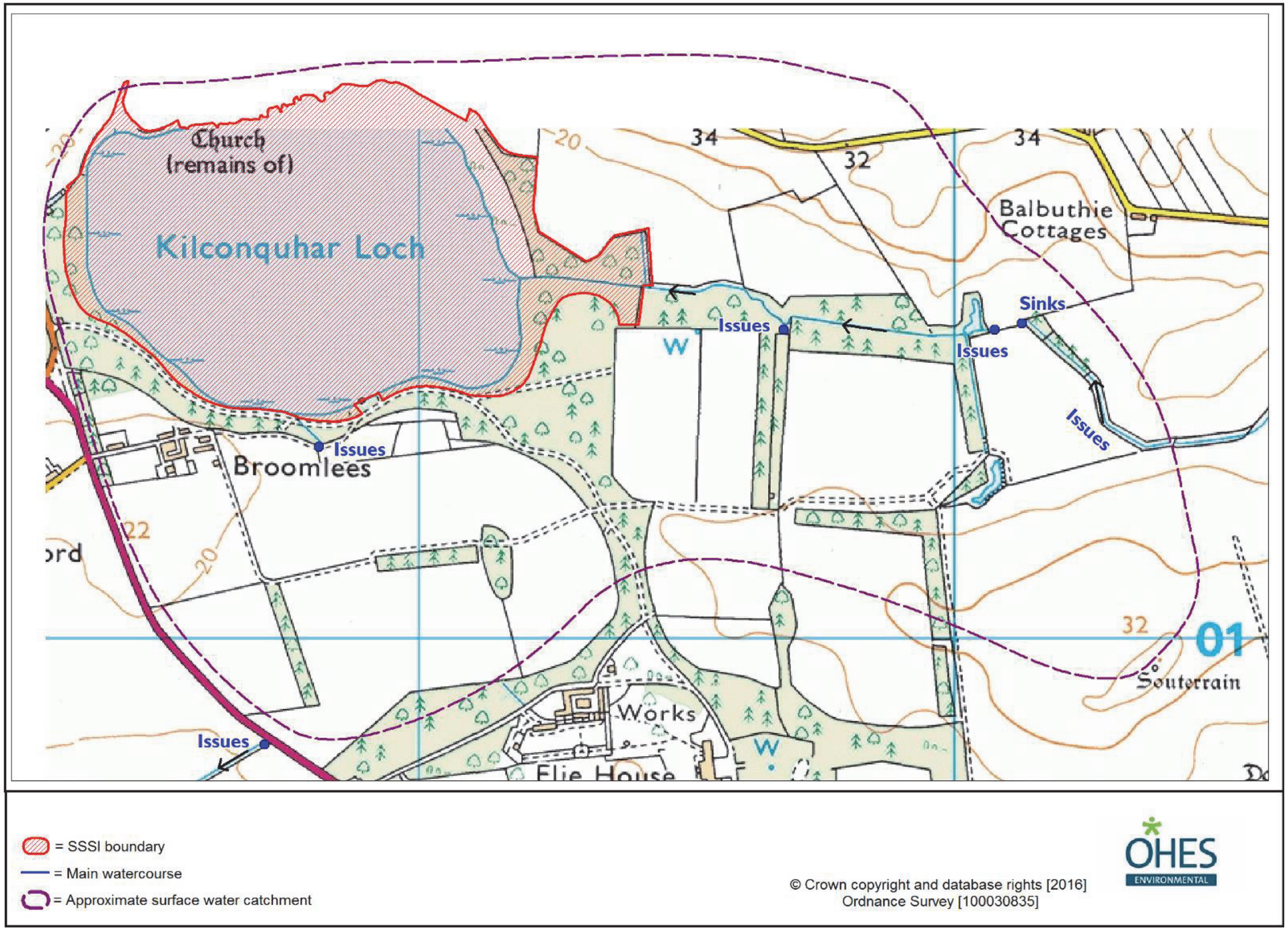

Figure 3. Kilconquhar Loch – approximate surface water catchment

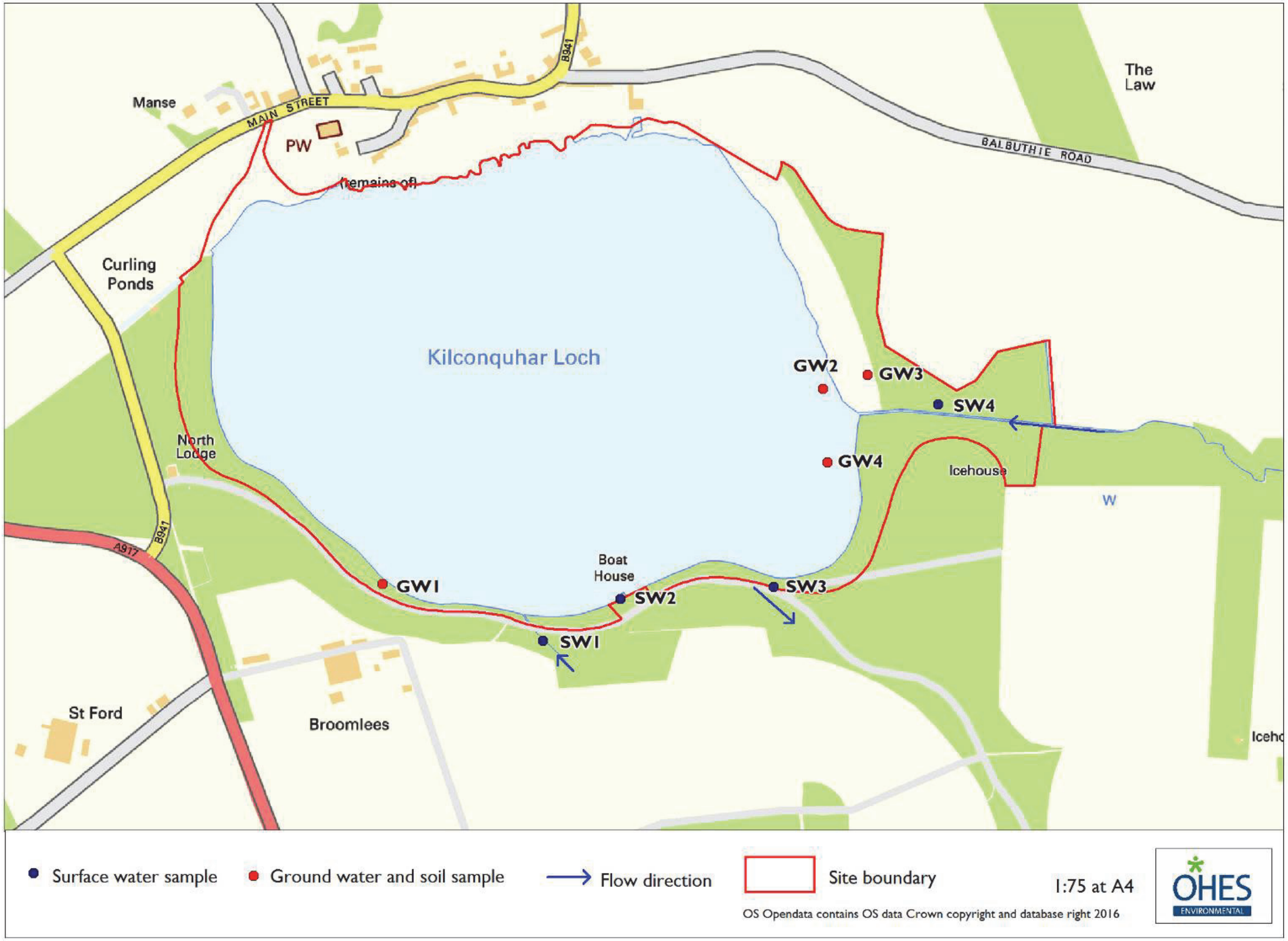

Figure 4. Kilconquhar Loch – Hydrology and Sample Locations

3.1.3 Site soils / sediments

Kilconquhar Loch is underlain by Alluvial Soils, derived from the post-glacial erosion 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 therefore range from clay to gravel with variations occurring both horizontally and vertically.

To the north east is an area (marked in yellow on Figure 5) of the imperfectly drained Rowanhill Association, developed on materials derived from Carboniferous sediments. The parent material is formed mainly from sandstones and shales.

The remainder of the site (shown in brown) is underlain by the freely draining Dreghorn Association, which are developed on raised beach deposits derived mainly from Carboniferous igneous and sedimentary rocks with some Old Red Sandstone material. These deposits vary in texture from sandy loam or loamy sand to sandy gravel, and frequently contain bands of fine sand or silt.

Observations made during the water sample collection by SNH in 2012 record thin layers of peat over coarse, saturated sand, sometimes mixed with shell material.

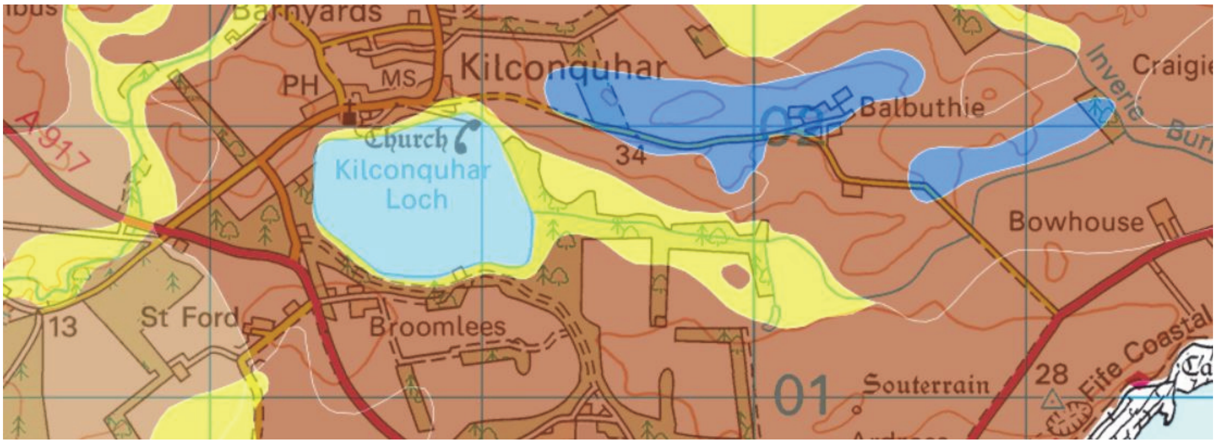

Figure 5. Kilconquhar Loch – Soil types (source: Soil Survey of Scotland Staff, 1987).

3.1.4 Site specific issues

The sources of high nutrient levels to the loch, which sporadically give rise to blue - green algae blooms, are unknown. Run-off and diffuse pollution from the surrounding agricultural land, as well as bird droppings are considered to be a possible source. Figure 6 shows the locations of these possible sources of nutrients.

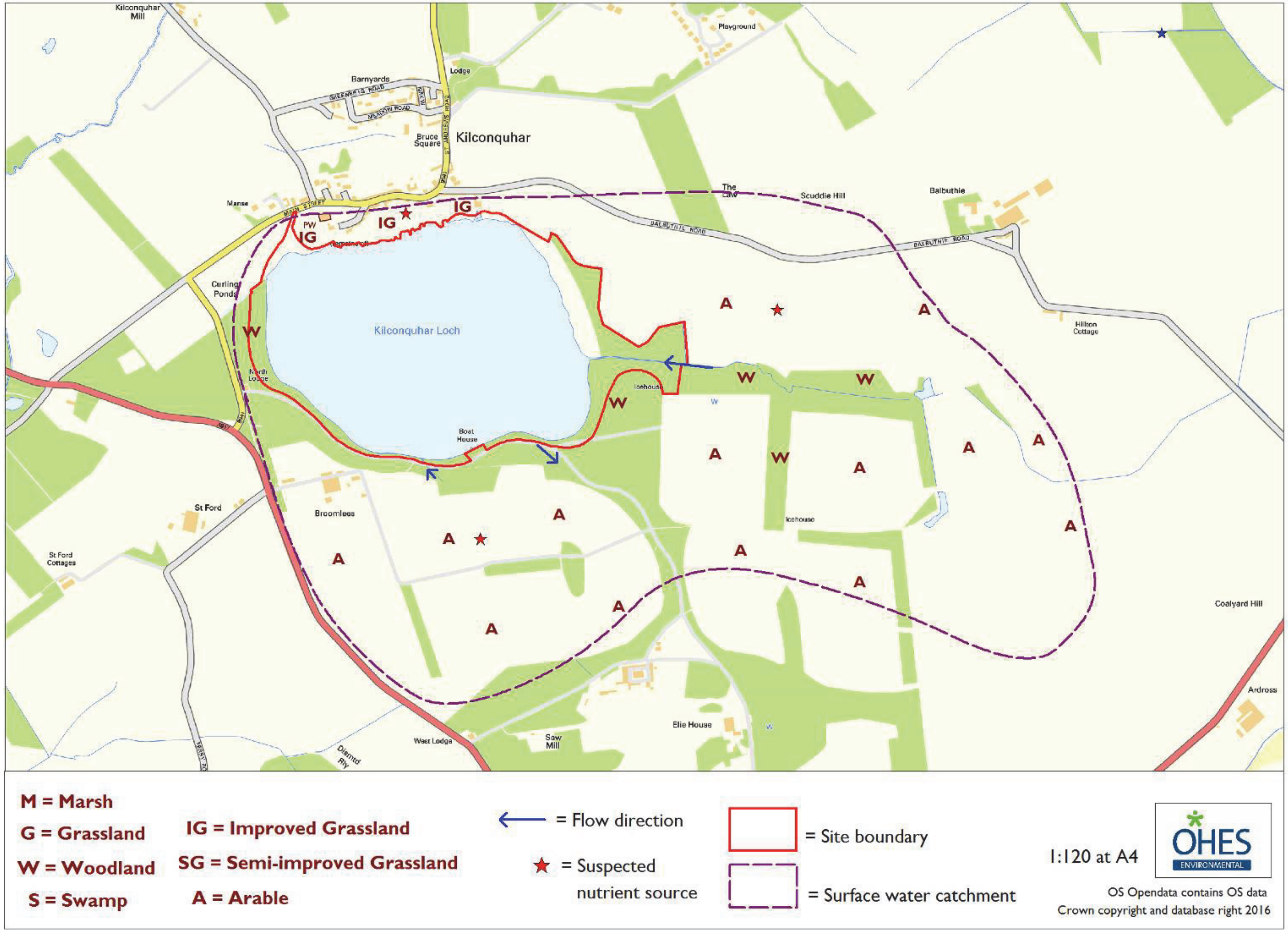

Figure 6. Land use and nutrient sources at Kilconquhar Loch

3.2 Assessment of vegetation data

Kilconquhar Loch SSSI contains a range of open water transition fen communities principally located around the margins of the loch and terrestrialised areas. Observations on the vegetation were recorded with a baseline NVC survey in 2002 and a SCM visit in 2013; however no quadrat data is available. Figure 7 shows the NVC communities recorded in 2002.

The NVC data suggests the presence of the following wetland communities:

- S4 *Phragmites australis* swamp and reed-beds
- S5 *Glyceria maxima* swamp
- S9 *Carex rostrata* swamp
- S12 *Typha latifolia* swamp
- W2 *Salix cinerea-Betula pubescens-Phragmites australis* woodland
- W6 *Alnus glutinosa-Urtica dioica* woodland

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:

- The 2013 SCM noted no loss of wetland feature or NVC communities when compared to the 2002 NVC survey and no loss in the S4 community or habitat transitions.
- It was noted that the 2002 NVC survey was unclear in relation to the communities on the south shore and therefore assessments (such as the 2013 SCM) can only be made in terms of presence / absence rather than changes in extent.

Figure 7. NVC communities recorded in 2002 (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 Kilconquhar Loch are:

- Type 1b: Other wet woodland
- Type 5: Swamp
- Type 6: Reedbed

3.2.2.1 Type 1b Other wet woodland

Wet woodland occurs on poorly drained or seasonally wet soils, with alder, ash, birch and willows as the predominant tree species. It is often found on floodplains, as successional habitat from (or to) fen, bog or swamp, alongside or within streams and rivers, within hill-side flushes and seepages, and in peaty hollows. 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* is an Annex 1 habitat type covered by the EC Habitats Directive. Wet woodlands are also priority habitats under the UK BAP.

The main NVC communities which are found at Kilconquhar Loch SSSI are:

- W6 *Alnus glutinosa-Urtica dioica* woodland
- W2 *Salix cinerea-Betula pubescens-Phragmites australis* woodland

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

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

Table 2. Groundwater targets for Wet Woodland in Good Condition (Source: ER37)

	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: Low altitude = 5 mg/l N-NO_3

3.2.2.2 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 which are found at Kilconquhar Loch SSSI 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.

- S12 *Typha latifolia /T. angustifolia* swamp - characteristic of mesotrophic to eutrophic waters within still or slow moving waters. S12 is highly tolerant of water level variations and prefers circumneutral to basic waters on silty substrates (Rodwell, 1995). It is generally rather species-poor and has a distribution throughout the UK, though it tends to be more uncommon in the north.

- The S5 *Glyceria maxima* swamp - characteristic of nutrient-rich, circumneutral to basic mineral substrates (such as alluvium) within still or slow-moving waters (Rodwell, 1995). The community is most extensive over level ground, but can occur in floating form. Wheeler *et al*. (2004) note that “prolonged flooding (especially in the growing season), coupled to elevated nutrient levels in the floodwater can favour S5 swamp at the expense of species-rich meadow communities, since S5 thrives in a poorly aerated root-zone”.

ER37 data and guidelines for Swamps are presented in Table 3. Mean Nitrate levels for groundwater-fed swamp in good condition are reported in UKTAG 2012 as 4.9 mg/l 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 3. 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)

3.2.2.3 Type 6 Reedbed

Equivalent NVC types covered:

- S4a *Phragmites australis* sub-community (present at Kilconquhar Loch SSSI)
- S4b *Galium palustre* sub-community
- S4c *Menyanthes trifoliata* sub-community

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

ER37 data and thresholds for Reedbed are presented in Table 4. 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 4. Groundwater thresholds for Reedbed in Good Condition (Source: ER37)

	Reedbed			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Threshold**
pH (-)	5.7	6.1	6.5	
Dissolved Oxygen (%)	18	20	22	
Electric Conductivity (mS/cm)	0.13	0.2	0.28	
Calcium (mg/l)	36	48	59	
Magnesium (mg/l)	5.8	12	18	
Sodium (mg/l)	12	13	19	
Phosphate (mg/l)	0.043	0.1	0.1	None set
Nitrogen (total) (mg/l)	1.1	3	6.9	
Nitrate (mg/l N-NO_3)	0.25	0.25	0.25	Threshold: 5 (or 22 mg/l as NO_3)

3.3 Assessment of ground water samples

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

Table 5 indicates the vegetation found around the sample locations is not consistent with the data recorded for Scotland (ER37) for Calcium, Magnesium, Sodium and TN but is consistent for Phosphate. This will partly be due to the base-rich nature of the water source at Kilconquhar Loch but also seemingly from enrichment. GW2 shows the highest Phosphate and TN concentrations, indicating the loch waters are enriched.

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

Table 5. Groundwater samples at Kilconquhar Loch and Wetland Type targets. Red text denotes sample exceeds target.

	Kilcon. Loch	Kilcon. Loch	Wet woodland			Kilcon. Loch	Kilcon. Loch	Reedbed		
Sample	**GW1 (in W6)**	**GW3 (in W2)**	**1st Quartile**	**3rd Quartile**	**Threshold**	**GW2 (in S4)**	**GW4 (near S4)**	**1st Quartile**	**3rd Quartile**	**Threshold**
pH (-)			6.8	7				5.7	6.5	
Dissolved Oxygen (%)			20	25				18	22	
Conductivity (mS/cm)			0.23	0.46				0.13	0.28	
Calcium (mg/l)	74	62	7	60		69	66	36	59	
Magnesium (mg/l)	12	24	1.7	8.8		20	24	5.8	18	
Sodium (mg/l)	55	18	6.6	12		30	31	12	19	
Phosphate (mg/l)	0.026	0.021	0.012	0.1	None set	0.087	0.044	0.043	0.1	None set
Nitrogen (total) (mg/l)	8.5	7	1.2	5		9	9	1.1	6.9	
Nitrate (mg/l N-NO_3)	<0.5	<0.5	0.1	0.25	Threshold: Low alt = 5 mg/l N-NO_3	<0.5	<0.5	0.25	0.25	Guideline: 5 (or 22 mg/l as NO3)

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, Kilconquhar Loch is classified as shallow (3 m to 15 m depth), freshwater, salmonid, low altitude (<80 mAOD) lake of high alkalinity (>50 mg/l) and ≥50 % calcareous bedrock. 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 6 presents the SRBDD standards compared to those recorded from Kilconquhar Loch, but owing to the fluid nature of the research and advice, represent a starting point.

Table 6. In-loch water quality standards for Kilconquhar Loch

Variable	**SRBDD 2014**		**JNCC**	**ECOFRAME**		**Kilconquhar Loch**
	GES	HES		Good	High	SW2
Total Ammonia as N	0.6 mg/l	0.3 mg/l	-	-	-	1.1 mg/l (Ammonium only)
Total Nitrogen	-	-	<1.5mg/l	0.6 – 1.0 mg/l	<0.6 mg/l	6.0 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	23 µg/l	16 µg/l	35 µg/l	30-50 µg/l	<30µg/l	26 µg/l (Phosphate only)
pH	-	-	7 - 9	6 - 9		?

3.4.2 Current surface water quality status

Four surface water sampling points were monitored by SNH during the single sampling round (conducted in February 2012). These include: the main input channel (SW4), surface water within the loch (SW2) a small inlet channel (SW1) and the outlet channel (SW3), see Appendix 1 for raw data.

Figure 8 shows the results of Ammonium recorded at Kilconquhar Loch against SRBDD standards for Total Ammonia. It indicates that, at the time of survey, the loch exceeded threshold concentrations, with readings well above the Good Ecological Status level. It appears that the loch has lower Ammonium levels than at least some of the inlet channels.

This could be because the loch is acting as a filter for ammonia, so that water quality is slightly improved after exiting the loch. However it seems more likely that the underground springs and groundwater feed into the loch are diluting any enrichment effect. Certainly the lower nutrient status of the super-saturated sands below the root zone would indicate a less enriched groundwater component at this depth. The results also indicate that the small inlet to the south (SW1) contains high concentrations of ammonia compared to the main inlet to the loch (SW4).

TN levels (as shown in Figure 9) indicate that other forms of Nitrogen are also problematic, with TN recorded in all surface samples exceeding ECOFRAME and JNCC target levels. The results once again suggest that the groundwater component of the loch is diluting enriched water generated off-site.

Total Phosphorus levels were recorded at Kilconquhar Loch but the levels of determination were below those useful in assessment against standards (i.e. all samples were marked as <0.2 mg/l). Phosphate low levels were recorded between Moderate Ecological Status (MES) and Good Ecological Status (GES) for the main inflow (SW4), Kilconquhar Loch (SW2) and outflow (SW3) (Figure 10). However phosphate levels for the southern inflow (SW1) were above Poor Ecological Status (PES). This indicates that the south of the surface water catchment is a source of enrichment to the loch both in terms of Nitrogen and Phosphorus.

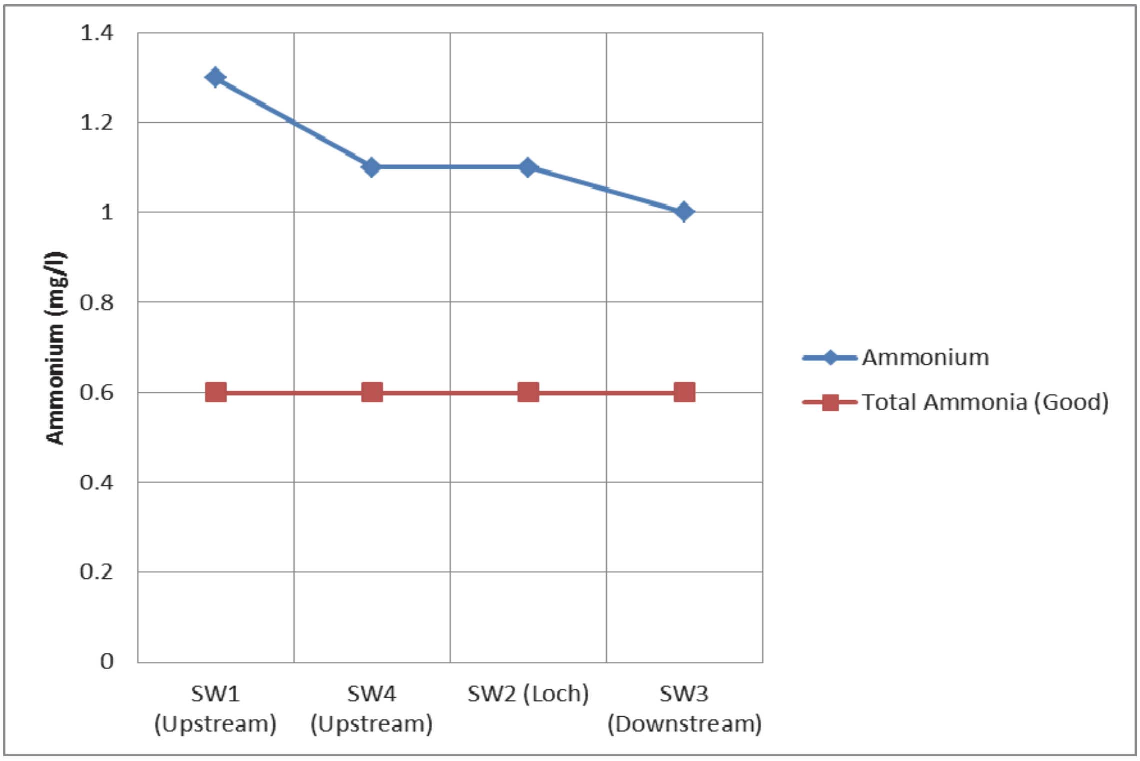

Figure 8. Ammonium recording at Kilconquhar Loch (blue line) against SRBDD standards for Total Ammonia

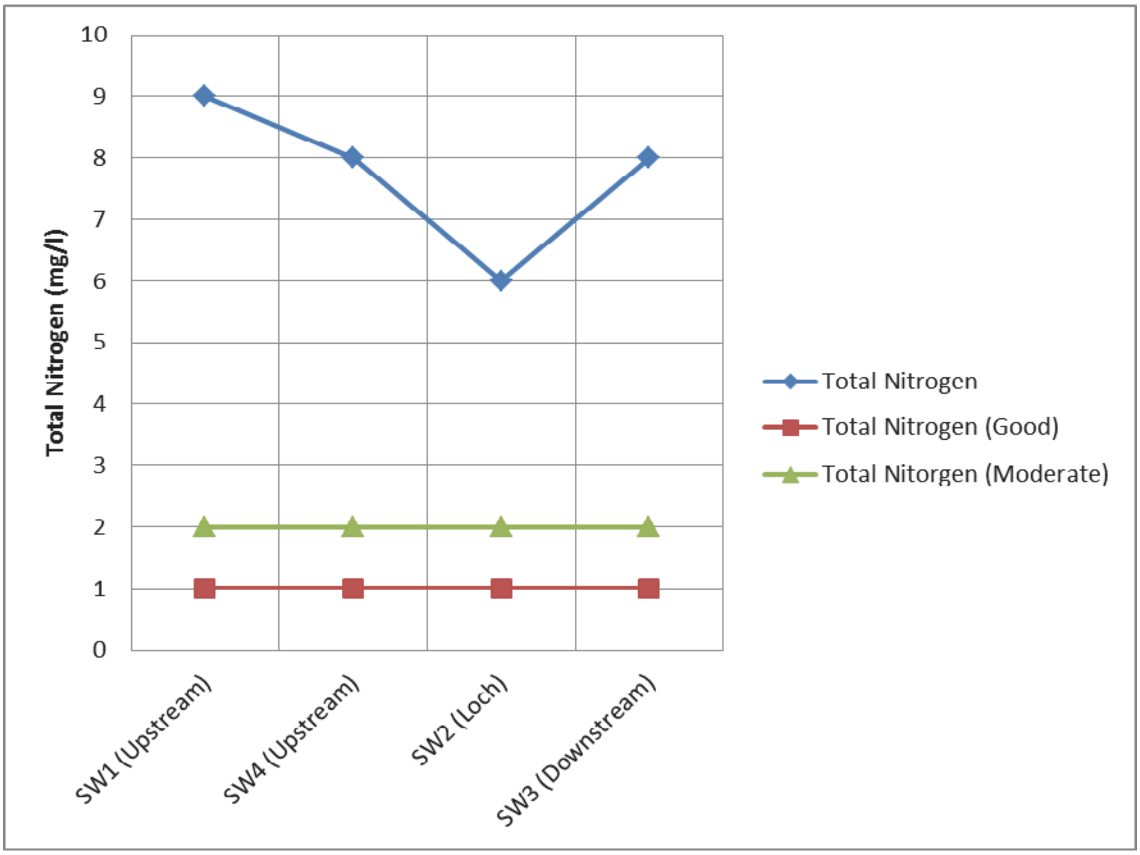

Figure 9. Total Nitrogen recording at Kilconquhar Loch (blue line) against JNCC standards

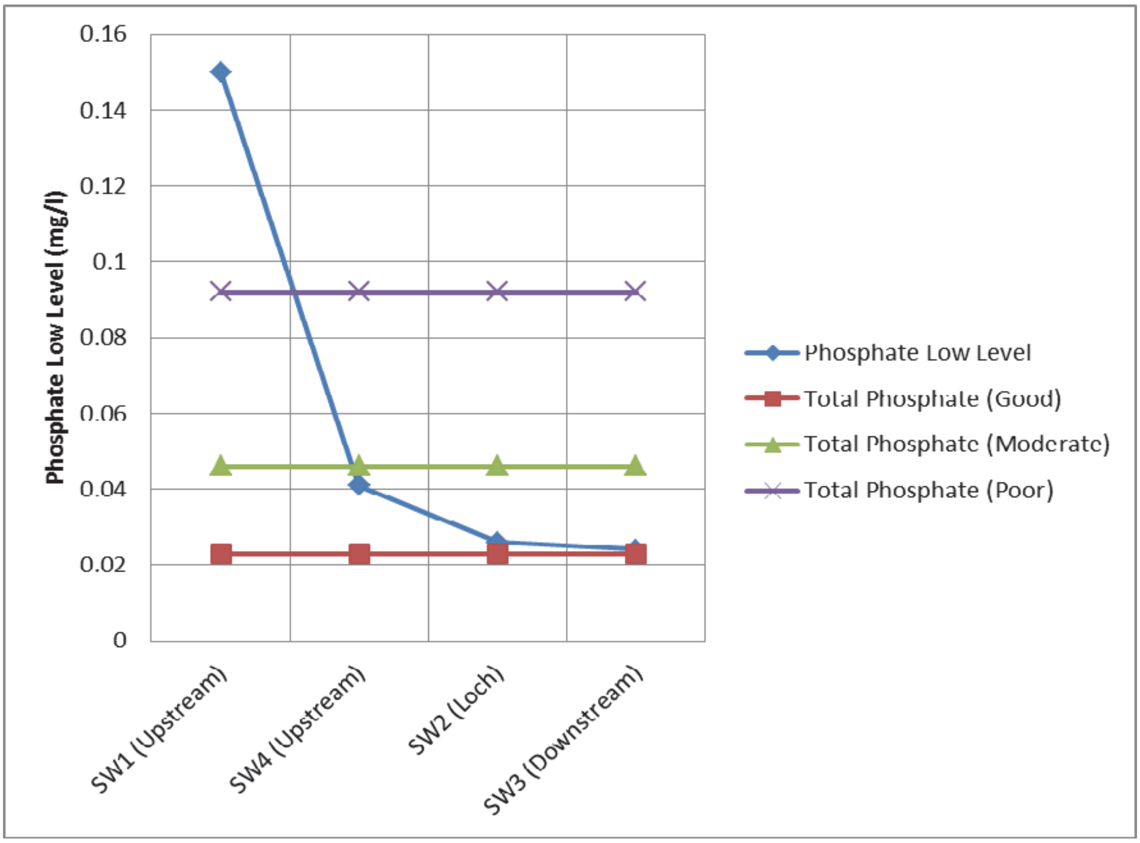

Figure 10. Total Phosphorus/Phosphate recording at Kilconquhar Loch (blue line) against SRBDD standards

3.4.3 Summary of trophic state and site vulnerability

<u>Trophic state:</u>

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 7.

Given that Nitrogen levels are significantly above thresholds for GES but that Phosphorus levels are only slightly above thresholds, this report concludes that <u>the trophic state of Kilconquhar Loch surface water is borderline Mesotrophic.</u>

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

Table 7. Nutrient status classification scheme (SEPA).

Description	Biological Factors	Chemical Factors
Oligotrophic (surrogate mean [TP] value; 8 μg 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 μg l^{-1}. Mean chlorophyll-a ≤ 2.5 μg l^{-1}. Max. chlorophyll-a ≤ 8.0 μg l^{-1}. Mean Secchi transparency ≥ 6.0 m. High oxygen concentration in hypolimnion.
Mesotrophic (surrogate mean [TP] value; 25 μg 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 μg l^{-1}. Mean chlorophyll-a 2.5-8 μg l^{-1}. Max. chlorophyll-a 8-25 μg l^{-1}. Mean Secchi transparency 6-3 m. Oxygen concentration may show some depletion in hypolimnion.
Eutrophic (surrogate mean [TP] value; 80 μg 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 μg l^{-1}. Mean chlorophyll-a 8-25 μg l^{-1}. Max. chlorophyll-a 25-75 μg 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 μg l^{-1}. Mean chlorophyll-a ≥ 25 μg l^{-1}. Max. chlorophyll-a ≥ 75 μg l^{-1}. Mean Secchi transparency ≤ 1.5 m. Severe oxygen concentration depletion in hypolimnion.

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

Source	**Kilconquhar Loch**	
	Vulnerability	**Details of Factors**
EXTERNAL SOURCES		
1. Agriculture	Moderate	- The majority of the catchment is in arable production, 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 appear to be entering the loch. - Pheasant rearing near the southern inlet may be causing local enrichment.
2. Human population	Moderate	- Residential areas to the north of the loch represent a potential nutrient source to the SSSI, depending on the sewage system used. - Runoff from the surrounding roads could also be a source of pollution.
3. Aerial deposition	Low-Moderate	- Deposition rates within this part of the UK are lower than recorded in the south. Thus atmospheric Total Phosphorus input into the catchment is small, although Total Nitrogen remains a major contributor.
4. Regional Groundwater	Low	- The site is fed by underground springs, with the local aquifer recently being classified as 'Good' for water quality.
INTERNAL SOURCES		
1. Wildlife	Low – Moderate	- Several bird species are recorded in large numbers on the SSSI, 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. - Roost sites (such as those of swallows within the reedbed) will cause eutrophication of the waterbody on a local scale. - However, TP coefficients for individual birds are very small so that, even when occurring in large numbers, overall contribution to the nutrient budget is likely to be small.
2. Lake sediment	Unknown	- A considerable store of nutrient may be present within the Loch in sediment form. The seasonal release of stored nutrients within the loch sediments will occur naturally under certain conditions. - 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 Kilconquhar Loch (2 of which were in S4 Reedbed and 2 within wet woodland W6 and W2). 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 9 presents the soil chemistry data for Kilconquhar Loch samples against the ER37 data. The results show that Calcium, Magnesium and Sodium are generally within normal ranges observed in Scottish samples although there are a couple of samples within the reedbed which exceed normal ranges. Phosphate was elevated in all but Soil sample 3 (GW3) in the reedbed.

All four samples were taken in peat which was underlain by supersaturated sand from c.20 cm depth (soil sample 3, taken to the north of the inflow, was underlain by sandy clay), which resulted in lower moisture contents for the ‘below root zone’ samples when compared to the root layer.

All four samples show noticeably higher TN levels in the root zone (consisting of peat) in contrast to the below root zone (in saturated sand).

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

	Kilconquhar Loch		Kilconquhar Loch		Reedbed		Kilconquhar Loch		Kilconquhar Loch		Wet woodland	
Sample	**Soil 2 Root (in S4)**	**Soil 2 below (in S4)**	**Soil 3 Root (in S4)**	**Soil 3 below (in S4)**	**1st Quartile**	**3rd Quartile**	**Soil 1 Root (in W6)**	**Soil 1 below (in W6)**	**Soil 3 Root (in W2)**	**Soil 3 below (in W2)**	**1st Quartile**	**3rd Quartile**
Calcium (mg/kg)	8,100	1,300	19,000	1,500	1,700	13,000	2,600	1,800	9,800	1,200	4,700	17,000
Magnesium (mg/kg)	450	120	610	410	200	2,700	430	240	430	130	1,600	2,700
Sodium (mg/kg)	230	21	70	12	32	44	180	24	110	9	140	270
Phosphate (available) (mg/l)	44	9.4	13	5.8	1.1	6	70	7.5	37	16	1.0	5.5
Nitrogen (total) (%)	2.1	0.1	2.2	0.2	0.99	1.7	2.4	0.1	2.2	0.8	0.78	2.1
Nitrogen (extractable) (mg/kg)	0.21	0.16	0.28	0.17	0.39	0.56	0.63	0.16	0.38	0.24	0.35	1.3
Total organic carbon (%)	13	0.62	44	1.5	5.5	22	29	0.51	6.3	1	6.8	21
Potassium (total)	440	47	45	50	-	-	140	30	110	20	-	-
Soil Moisture Content %	491	163	789	192	-	-	646	181	278	156	-	-

3.6 Limitations

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

- No site visit was possible as part of the analysis within this report and therefore there has been no opportunity to gain first-hand knowledge of the site.
- Data was collected from a single sampling round which, though providing consistency of timing could be very misleading if for example weather conditions were atypical. Clearly a single sample round will also not reflect conditions experienced through the various seasons (such as those times of the year when fertiliser may be added or heavy rain may increase the amount of suspended solids and therefore nutrient loadings).
- The relationship between wetland types and Phosphorus targets is still under review and therefore levels which may appear to be acceptable now may change status if Phosphorus targets are more clearly defined.
- There were insufficient data for any statistical analysis.
- NVC quadrat data was not available for the site, which prevented further analysis of the status of the vegetation types at Kilconquhar Loch.

3.7 Recommendations on future measures and / or data requirements

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

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

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

The initial assessment of Kilconquhar Loch SSSI, based on a single sampling round, suggests enriched water is present within the SSSI. The main source of this enrichment is unconfirmed but feeder ditches from the south of the loch are clearly contributing to TP and TN levels. 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. At least one spring source should also be analysed to gauge whether regional groundwater is the main contributing factor.
- Rainfall data in the region for the period when surface water sampling takes place.
- At least three sediment samples within the loch to identify any possible internal store of nutrients, as well as the average depth of sediment present. This could be combined with sampling of macrophytes presence (in order to better gauge the condition of the water body).

- A basic hydrological walkover of the site/catchment to confirm the extent of silt within the ditches and the condition of the peat.

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

- ***Reducing nutrient input*** - This is the most effective means of addressing eutrophication of the site. The primary exporters of nutrients appear to be a combination of agriculture to the south and east. Reduction of nutrient would require the support of neighbouring landowners prepared to reduce the application of fertiliser and slurry to their land, or to change their land use to semi-improved grassland in addition to reducing their livestock units per hectare. In the case of Kilconquhar it could also require relocating pheasant feeding stations away from water courses. The advantage of this approach is the long-term sustainability of the wetland interest in the catchment. There are also likely to be benefits to other habitats such as dry grassland through reduction in nutrients.

- ***Redirecting problematic water sources*** – It may be possible to redirect one of the feeder ditches away from the loch and directly into the outlet ditch if it represents a particular problem to loch water quality. The existing data is not detailed enough to suggest which spring sources feeding the site are best in terms of water quality. However, this method requires careful consideration of the water balance for the site to ensure sufficient water will still be available to supply the wetland. It is possible such a scheme could be detrimental to the site.

- ***Removing nutrient-rich sediments from the loch*** – This would be an expensive option and may be impractical given the presence of supersaturated sands (which are notoriously mobile in nature and often result in more loch material being removed than in necessary. However, there are methods of silt removal which may be more appropriate to this site, if removal of silt seems essential for the health of the SSSI. Consideration would also need to be given to suitable receiver sites and to whether long term measures (such as a change in landuse upstream of the SSSI) may also be required to prevent future build-up of sediment.

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

  Buffer Zones; Buffer zones of various kinds can be used to remove nutrients before they can enter the wetland (such as reedbeds, grass strips and woodland buffers). Nitrate in particular is removed both by bacterial processes (such as denitrification) and plant uptake. However the effectiveness of the buffer zone will depend on its size, condition of the vegetation, flow rate of water through the buffer and the underlying substrate. Hence buffer strips are generally more effective when they are 30-40 m wide, with vegetation a few years old, on flat or gently sloping ground consisting of clay or humified organic material. Initial review of the available data would suggest that suitable substrate and topography is present within some of the Kilconquhar loch catchment.

  Ditch management; Ditches can be profiled to permit marginal wetland vegetation to establish, thus acting as a buffer strip. In addition, ditch clearance is only undertaken over short sections at a time and only when absolutely necessary, in order to maximise plant uptake, reduce velocity and increase residence time. Such ditch management is already likely to take place within the SSSI but could be extended into neighbouring agricultural land for additional benefit.

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

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ANNEX 1: WATER AND SOIL SAMPLES

Water samples

			Sample ID	GW1	GW2	GW3	GW4	SW1	SW2	SW3	SW4
Parameter	**Unit**	**Detection Limit**	**Sample Date**	22/02/2012	22/02/2012	22/02/2012	22/02/2012	22/02/2012	22/02/2012	22/02/2012	22/02/2012
Phosphorus (total)	mg l^{-1}	0.2	Water	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ammonium	mg l^{-1}	0.01	Water	2	1.1	1.1	0.89	1.3	1.1	1	1.1
Nitrate	mg l^{-1}	0.5	Water	<0.5	<0.5	<0.5	<0.5	18	<0.5	<0.5	15
Phosphate Low Level	mg l^{-1}	0.02	Water	0.026	0.087	0.021	0.044	0.15	0.026	0.024	0.041
Nitrogen (total)	mg l^{-1}	1	Water	8.5	9	7	9	9	6	8	8
Calcium	mg l^{-1}	5	Water	74	69	62	66	68	58	59	58
Magnesium	mg l^{-1}	0.5	Water	12	20	24	24	31	19	18	21
Sodium	mg l^{-1}	0.5	Water	55	30	18	31	87	33	32	21
Iron (II)	µg l^{-1}	20	Water	180	200	400	100	<20	<20	<20	20
Iron (III)	µg l^{-1}	20	Water	1200	1900	600	1000	450	330	360	540
Iron (total)	µg l^{-1}	20	Water	1400	2100	1000	1100	450	330	360	560

Soil samples

			Sample ID	S1	S1	S2	S2	S3	S3	S4	S4
			Other ID	Below	Root	Below	Root	Below	Root	Below	Root
			Sample Date	22/02/2012	22/02/2012	22/02/2012	22/02/2012	22/02/2012	22/02/2012	22/02/2012	22/02/2012
Parameter	**Unit**	**Detection Limit**	**Type**								
Moisture	%	0.02	Soil	36.8	84.7	50.2	88.2	34	86	59.2	87.6
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	7.5	70	9.4	44	5.8	13	16	37
Phosphorus (total)	mg kg^{-1}	-	Soil	11000	7080	7900	9500	4000	2500	5900	4000
Nitrogen (total)	%	0.02	Soil	0.1	2.4	0.1	2.1	0.2	2.2	0.8	2.2
Nitrite (extractable)	mg kg^{-1}	0.1	Soil	0.16	0.63	0.16	0.21	0.17	0.28	0.24	0.38
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	1800	26000	1300	8100	1500	19000	1200	9800
Potassium (total)	mg kg^{-1}	0.2	Soil	30	140	47	440	50	45	20	110
Sodium (total)	mg kg^{-1}	0.2	Soil	24	180	21	230	12	70	9	110
Magnesium (total)	mg kg^{-1}	0.5	Soil	240	430	120	450	410	610	130	430
Total Organic Carbon	%	0.2	Soil	0.51	29	0.62	13	1.5	44	1	6.3
Moisture content	%	-	Soil	181	646	163	491	192	789	156	278
Bulk density	Mg/m3	-	Soil	1.2	0.91	1.25	0.95	1.14	1.01	1.26	1.07
Dry density	Mg/m3	-	Soil	0.43	0.12	0.47	0.16	0.39	0.11	0.49	0.28

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