Scottish Natural Heritage
Research Report No. 1103

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

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RESEARCH REPORT

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

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RESEARCH REPORT

Summary

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

Research Report No. 1103
Contractor: OHES Environmental Ltd
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Keywords

nutrients; Dunbog Bog 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 Dunbog Bog, 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 Dunbog bog is relatively small and appears to be fed by a combination of groundwater and surface water run-off. The groundwater is sourced from two springs emerging from the upland to the south; one of which runs directly into the site via a ditch, while the second appears to terminate before reaching the site boundary (but may be the interrupted source of the issues appearing within the site). The surface water is sourced from the surrounding gently sloping agricultural land to the east and west.
- The water table at the site is reported as being too low at various points, most likely due to the large drainage channel running the length of the site.
- The site occupies a natural basin and therefore receives water from adjacent higher land which is in agricultural use. There is evidence of local enrichment all along the inflow, with Common nettles frequently found throughout the site.
- Groundwater samples taken at Dunbog Bog have been compared with the nutrient level requirements of the vegetation types known on site. This indicates that the groundwater quality is consistent with the requirements of the vegetation currently found around the sample locations (and is consistent with the data recorded for Scotland (ER37) and for guideline/threshold levels for these habitats). However Nitrate was elevated in all three of the swamp sampling locations, strongly indicating enriched waters are entering the site from the inflow to the south. The sample point in the west of the site appears to be less enriched.
- The groundwater samples taken in or near fen communities showed some samples exceeded Nitrate guidelines. It is therefore likely that, where the inflow waters reach into the wetland core, communities such as M27 and S27 will deteriorate but where these

communities are supplied by either rainwater or seepage from the less intensively farmed grassland to the east, the communities should be able to persist.

- The water quality is not consistent with the vegetation currently found around the sample locations (ER37). Total nitrogen levels were particularly high in one of the fen vegetation samples.
- At the head of the surface water system, Nitrogen levels are modest. As the water reaches the centre of the site, calcium, magnesium, sodium and forms of Nitrogen increase with the addition of further inflows from the south. By the time the water reaches the outflow, Phosphate levels have increased slightly and Total Nitrogen levels are at their highest.
- Assessment of vulnerability showed Dunbog Bog was most at risk from agricultural practices, poor regional groundwater and possibly the sporadic nature ofgrazing/cutting on site.
- Further investigations are recommended for the site (such as monthly water quality sampling and seasonal water level recording. 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 Dunbog Bog, 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 Dunbog Bog.

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

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

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

Water samples were analysed for the following suite:

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

2.2 Analysis of results

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

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

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

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

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

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

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

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

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

3. ASSESSMENT

3.1 Site review

Dunbog Bog is located approximately 2 km south-east of Newburgh, Fife. The 24.92 ha site (Figure 1) includes the most extensive area of inland basin fen vegetation in North East Fife, with representative examples of tall sedge, reed swamp, fen meadow and wet woodland communities.

A large number of vascular plant species (142) are present, including 13 sedges, one of which is found only at one other locality in Fife. There is also a good diversity of invertebrates on the site, including six butterfly species and damselflies. Breeding birds such as the sedge warbler, reed bunting, teal, tufted duck, water rail with occasional snipe, oystercatcher, curlew, lapwing and willow warbler are found at Dunbog Bog. Hen harriers and marsh harriers are also known to use the site.

The site has traditionally been used for shooting (both wildfowl and mammals such as foxes and deer) so the management has been targeted towards this use. In 1990 a strip of willow and alder carr in the southern portion of the site was cut to improve the pheasant shoot.

Dunbog Bog was grazed occasionally by ponies in the 1960s and by cattle in the winter of 1976 and lightly grazed by sheep in 1989.

Reeds were burnt and cut on a regular basis in the south of the site during the early 1980s but following the designation in 1984 these practices were undertaken away from areas of high botanical interest. Cutting and burning no longer takes place on the site, this has led to the spread of reedswamp, resulting in a loss of species diversity. Figure 2 shows the Dunbog site in the 1800s.

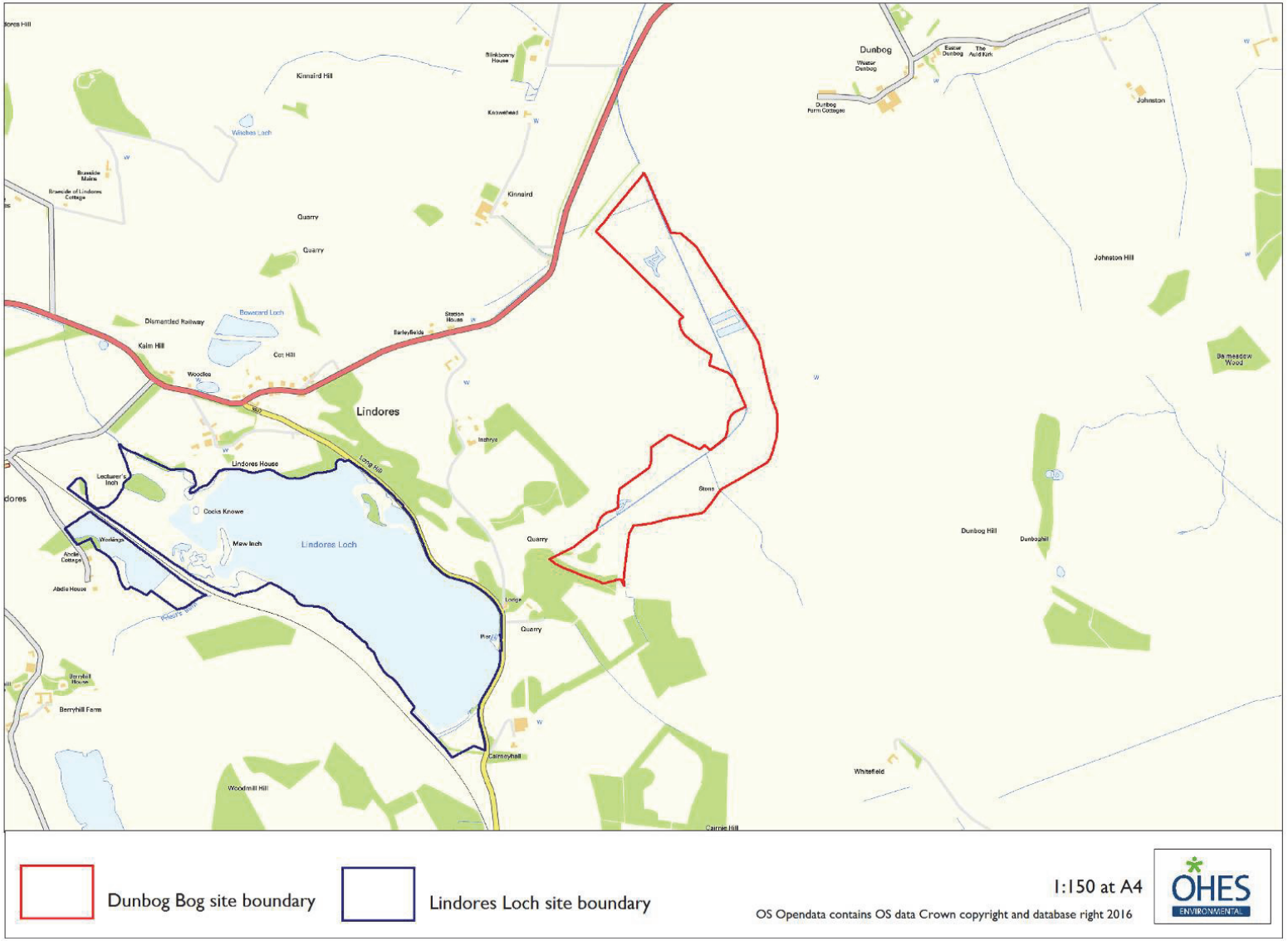

Figure 1. Site Boundary – Dunbog Bog

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

3.1.1 Site designation and specific targets

Dunbog Bog SSSI was first notified in 1984. The feature for which it is notified is detailed in Table 1, as well as the pressures that have been identified. Until February 2012, the notified feature was fen meadow.

Table 1. Dunbog Bog notified features and their pressures.

SSSI features	Feature Category	Summary Condition / Latest Condition	Pressure
Basin fen	Wetland	Unfavourable No Change (Jul 2011)	a) Under-grazing b) Water management

The site specific targets identified in the condition monitoring undertaken in 2011 and site management targets are:

1. No loss in component habitat types for the whole of the basin fen feature, not just the M27 community.
2. No reduction in the total combined extent of wetland in relation to the established baseline for the whole of the basin feature, not just the M27 community.
3. Invasive non-native species should be absent throughout the whole of the basin fen feature rather than just the M27 community.
4. Woody species should be no more than scattered, which is a target for the whole of the basin fen feature rather than just the M27 community.
5. Saplings and seedlings should be no more than rare for the whole of the basin fen feature.
6. Establish buffer strips along site boundary to reduce nutrients input, which could also include surfacing of land drains and installation of silt traps in open ditches.
7. Re-establish reed cutting for nutrients removal and to enhance plant diversity.
8. Cut and graze areas of fen meadow dominated by rush and meadowsweet.
9. Possible removal of Sitka spruce at the southern end of the site.

Ditch blocking is not recommended within the site management targets as, although it would be hydrologically beneficial, the spread of nutrient rich water across the site would encourage the spread of reeds.

3.1.2 Site hydrology

The surface water catchment for Dunbog bog is relatively small (see Figure 3). It appears to be fed by a combination of groundwater and surface water run-off (Figure 4). The groundwater is sourced from two springs emerging from the upland to the south; one of which runs directly into the site via a ditch, while the second appears to terminate before reaching the site boundary (but may be the interrupted source of the issues appearing within the site). The surface water is sourced from the surrounding gently sloping agricultural land to the east and west.

The water table at the site is reported as being too low at various points, most likely due to the large drainage channel running the length of the site. Water flows from south to north. An ornamental duck pond has been present since 1938 and in 1986 a small (0.08 ha) shallow shooting pond was excavated in the southern section of the site which was planted with willows. A further pond was created in the 1990's in the northern section. In 1976, drought conditions led to the excavation of two irrigation ponds in the main reed stand in the northern arm to provide water for spray irrigation on adjacent farmland.

There are no SEPA standing water, sediment monitoring or water monitoring points at Dunbog, the nearest monitoring point is at Lindores Loch to the west. Dunbog is underlain by

Glenfarg bedrock and localised sand and gravel aquifers. In 2008, the quality of the groundwater was 'Poor' with quantity classed as 'Good'. An upward trend in pollutants has been identified, with pressures including diffuse source pollution from mixed farming and non-urban land management measures.

Evaluating the impact of nutrient sources on a wetland feature depends on a good understanding of how that wetland feature functions hydrologically and ecologically. The best system 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 was available to define detailed hydrological functioning and substrate for this site. Application of systems such as the WetMecs framework requires detailed information on these elements before it can be accurately applied. As a consequence, all that can currently be stated is that the site occupies a trough of shallow peat over sand deposits, surrounded by free-draining land. Quaking fen is known to be present and the site is at least partially groundwater-fed. It could therefore be postulated that Wetmec 18: Percolation Trough is the most likely type to be present (where a site is mainly fed by rain-generated run-off, but can also include some groundwater outflow, though the importance of groundwater is not clear). Alternatively, if the substrate surface proves to be soft and quaking over wider areas, it could be classified as WetMec 14: Seepage Percolation Troughs (occurring in groundwater-fed valleyheads and troughs, where the water table is at the surface for much of the year). Seepage slopes such as WetMec 10: Permanent and 11: Intermittent may also be present.

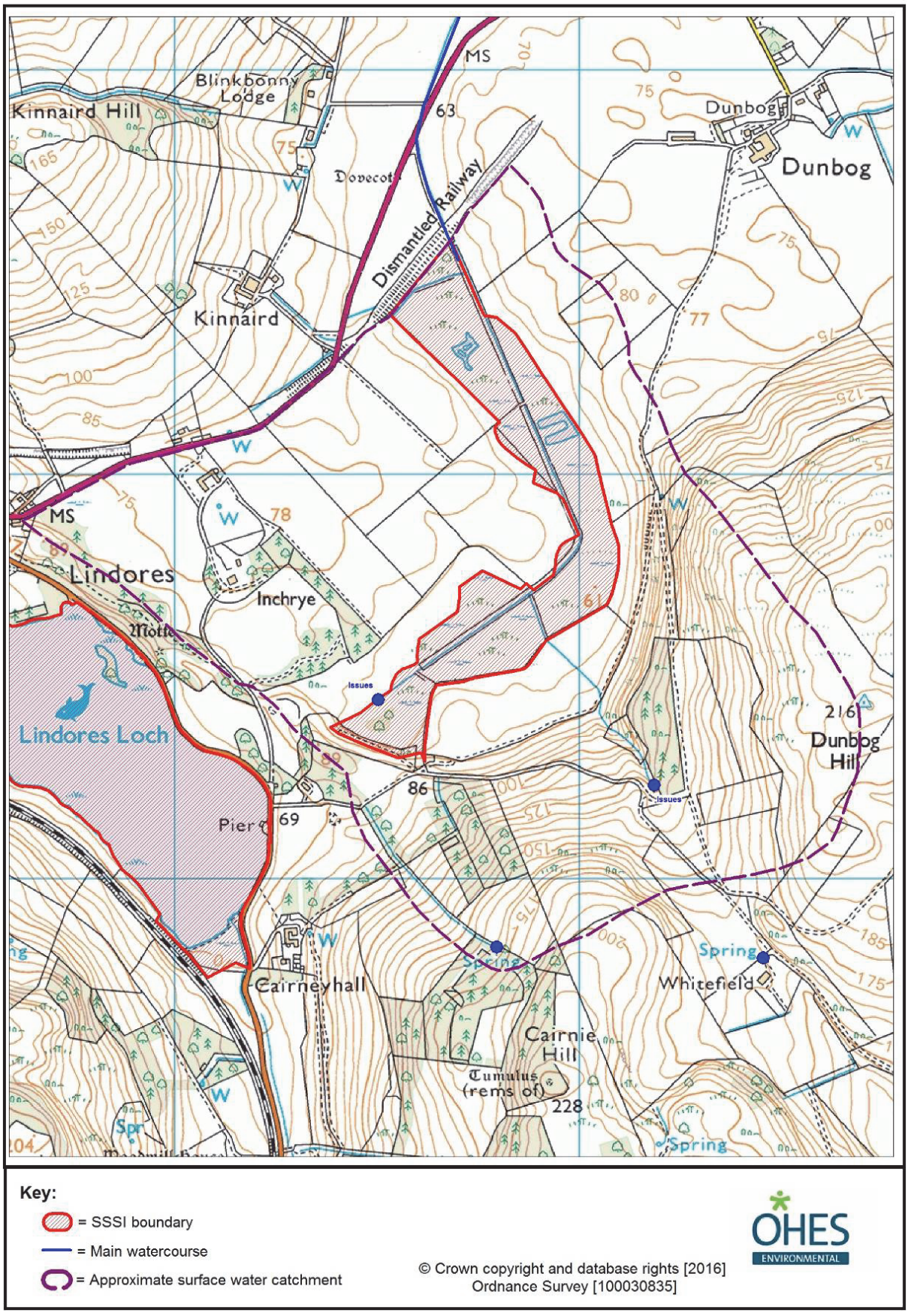

Figure 3. Dunbog Bog – approximate surface water catchment

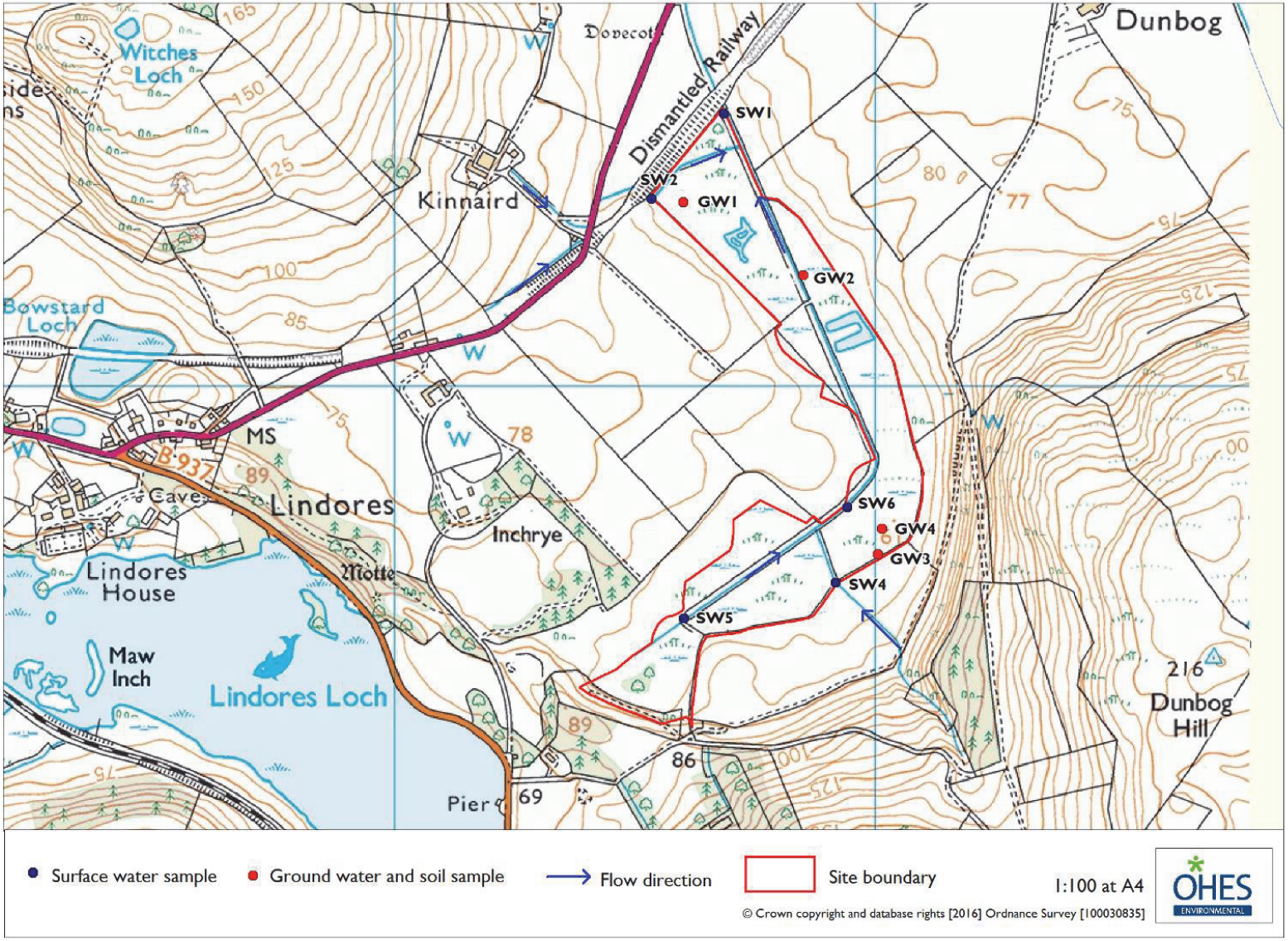

Figure 4. Dunbog Bog – Hydrology and Sample Locations

3.1.3 Site soils / sediments

The south of the site is underlain by the Organic Soils Association, comprised of basin, valley and blanket peats and is a major component of many other units. The north of the site is underlain by alluvial soils 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 on the current of suspension. Profile development is absent or negligible except in the oldest deposits where an incipient B horizon exists.

To the north-east and south-west of the site is the Gleneagles Association, which is a freely draining glacio-fluvial deposit of sands and gravels derived mainly from sediments and lavas of Lower Old Red Sandstone age with some acid schists.

To the north-west and south-east of the site is the Sourhope Association, a free draining drift derived from andestitic and intermediate lavas of Lower Old Red Sandstone age. Figure 5 shows the distribution of soil types at Dunbog Bog.

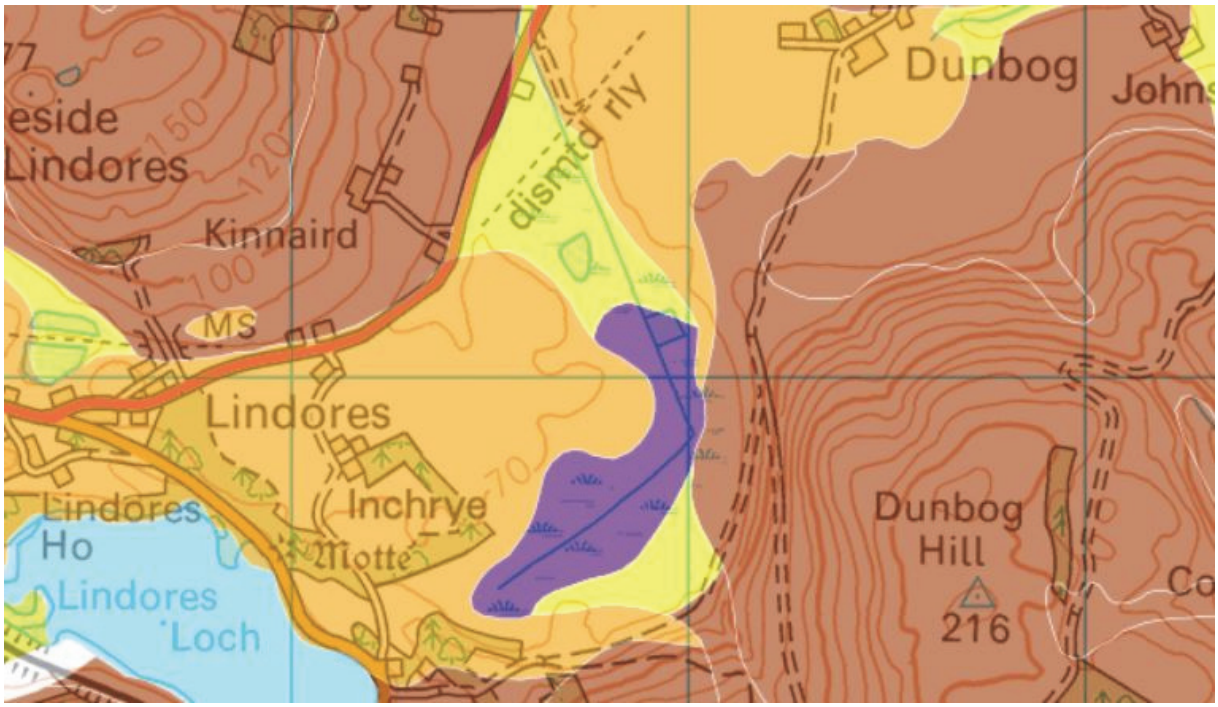

Figure 5. Dunbog Bog – Soil types (Source: Soil Survey of Scotland Staff, 1987).

3.1.4 Site specific issues

The site occupies a natural basin and therefore receives water from adjacent higher land which is in agricultural use. There is evidence of local enrichment all along the inflow, the large central ditch, located outside the boundary near a disused quarry. Common nettles are frequently found throughout the site and reeds have spread into sedge-rich areas. Both of these occurrences can indicate high nutrient levels. Figure 6 gives indicative locations for nutrient input to the site.

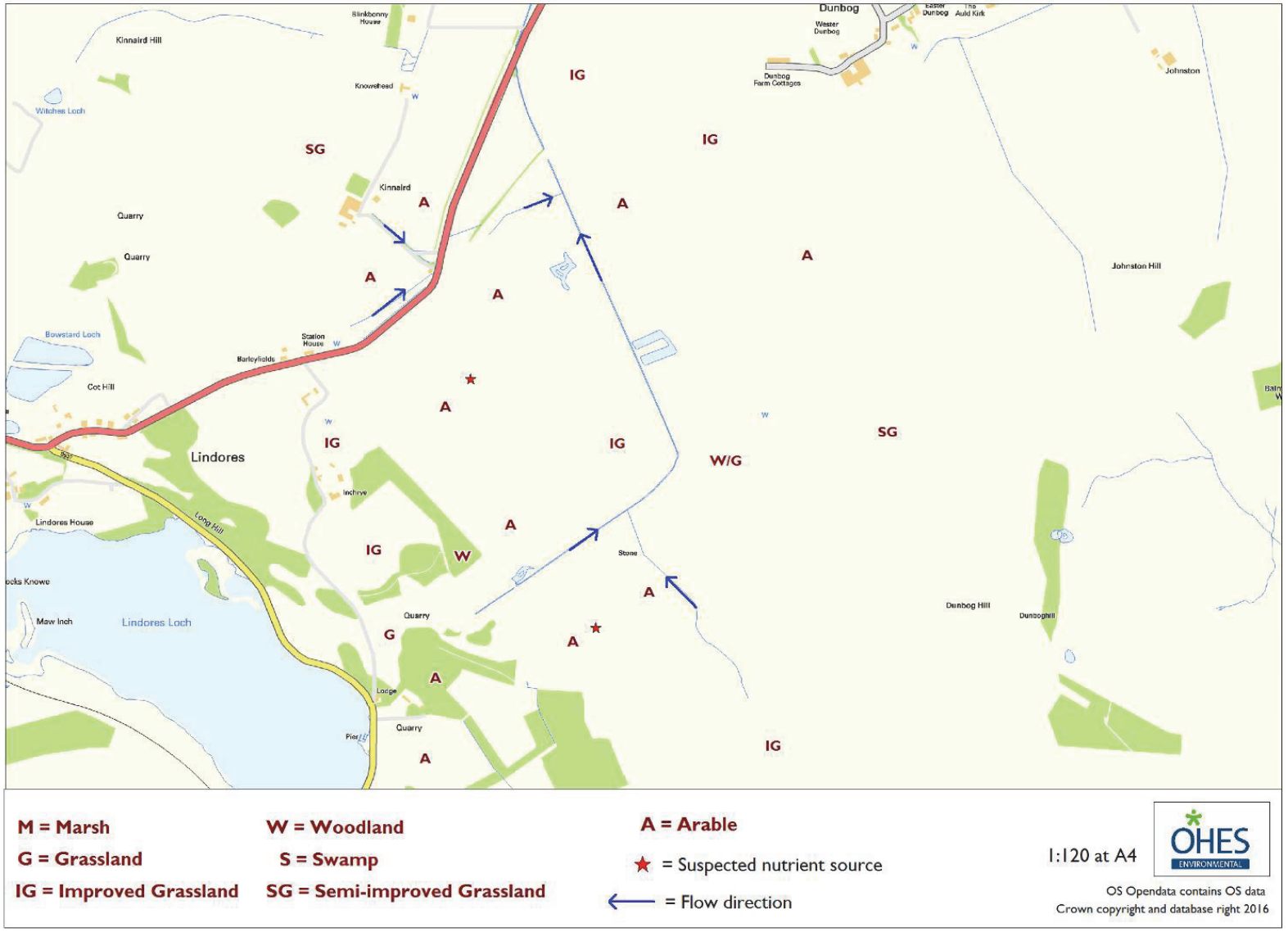

Figure 6. Landuse and potential nutrient sources at Dunbog Bog

3.2 Assessment of vegetation data

Dunbog Bog contains a range of basin fen vegetation, with tall sedge, reed swamp and fen meadow communities. Observations on the vegetation have been recorded in 2000 and 2011. NVC communities were only mapped for the whole site in 2000, with no available quadrat data. Figure 7 shows the NVC communities recorded in 2000.

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

- S3 *Carex paniculata* sedge-swamp
- S4 *Phragmites australis* swamp and reed-beds
- S5 *Glyceria maxima* swamp
- S9 *Carex rostrata* swamp
- S12 *Typha latifolia* swamp
- S26 *Phragmites australis-Urtica dioica* fen
- S27 *Carex rostrata – Potentilla palustris* tall-herb fen
- S28 *Phalaris arundinacea* tall-herb fen
- M23 *Juncus acutiflorus – Galium palustre* rush-pasture
- M27 *Filipendula ulmaria – Angelica sylvestris* mire
- MG1 *Arrhenatherum elatius* grassland
- MG9 *Holcus lanatus-Deschampsia cespitosa* grassland

3.2.1 Historic evidence of community change

There is insufficient data to quantify changes in the total coverage of each community because community maps were only available for 2000. However, some key points are summarised below;

- All NVC communities present in the site's original NVC survey were present in the 2011 Site Condition Assessment.
- The basin fen feature type was changed from fen meadow during the NCA review process. A baseline extent for basin fen was defined during the 2011 Site Condition Assessment.
- The 2011 Site Condition Assessment showed the SSSI as Unfavourable no change due to the lack of locally abundant dominants and lack of constant species such as *J. effusus* and *H. lanatus*. *Galium aparine* was also frequent in 50% of the quadrats with a target of 'no more than rare'. The combined cover of target sedges was approximately 16 % rather than >25 %. Associate species were not common, such as *Epilobium palustre, Mentha aquatica, Myosotis laxa* and *Cardamine pratense*, which resulted in a target failure.

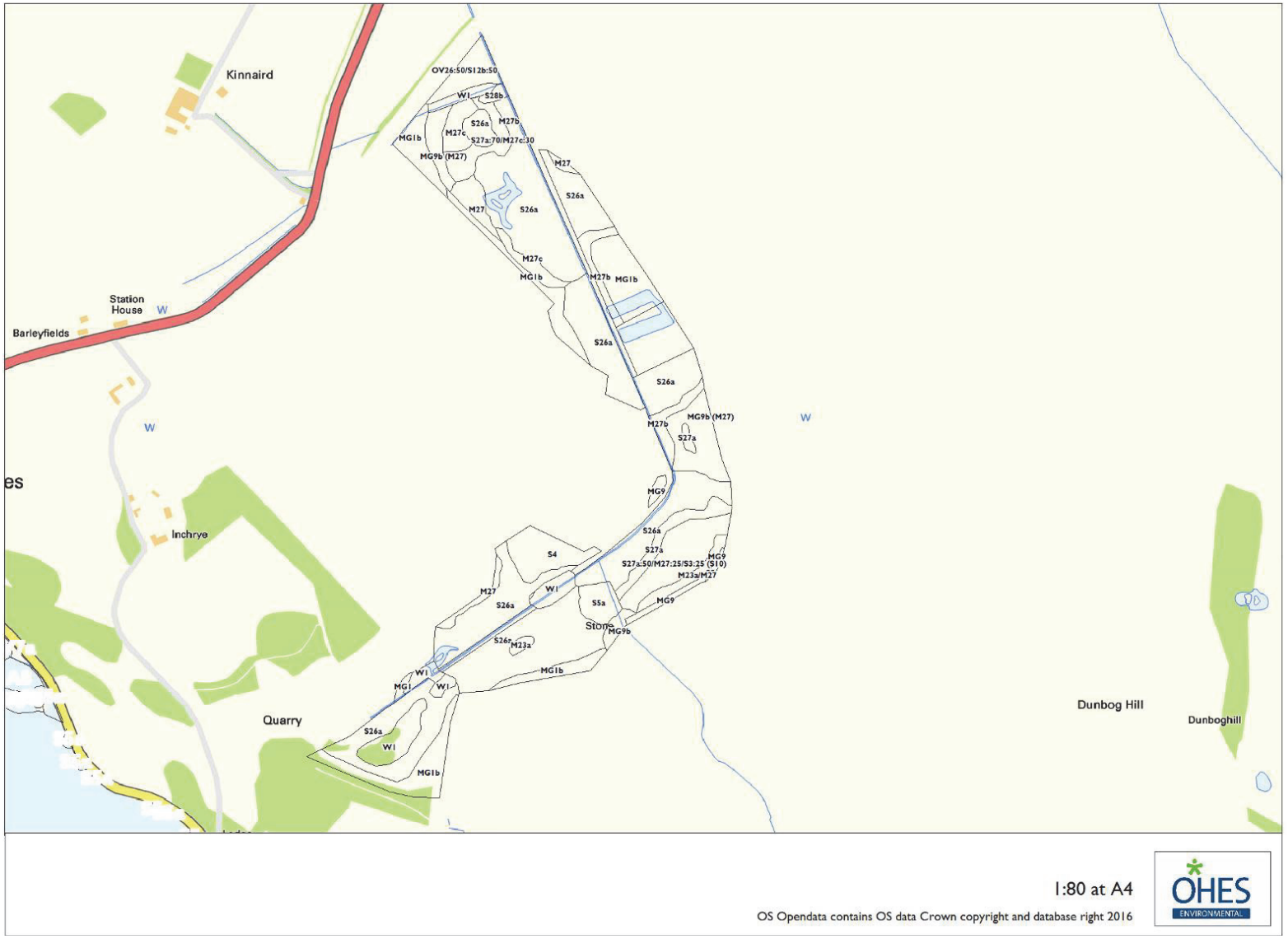

Figure 7. NVC communities recorded in 2000 (Source: SNH)

3.2.2 Community requirements

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

- Type 2a: Marshy grassland
- 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 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 Dunbog Bog include:

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

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

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 6 mg/l N. The UK third quartile value is 5.9 mg/l N-NO_3. The SNIFFER values in groundwater for Scotland are significantly lower, with a third quartile value of 0.25 mg/l N-NO_3 (ER37).

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

Table 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 26mg/l as N-NO3) for <175m AOD

3.2.2.2 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 Dunbog Bog are:

- 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, B.D., Shaw, S., & Tanner, K, 2009)

ER37 data and thresholds for Fens are presented in Table 4. 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 0.2 mg/l used in laboratory tests for some of the samples".

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

	Fen			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Threshold**
pH (-)	6.4	7.1	7.4	
Dissolved Oxygen (%)	18	21	28	
Electric Conductivity (mS/cm)	0.37	0.55	0.69	
Calcium (mg/l)	12	25	55	
Magnesium (mg/l)	3.4	6.4	14	
Sodium (mg/l)	5.4	9.7	14	
Phosphate (mg/l)	0.064	0.1	0.1	None set
Nitrogen (total) (mg/l)	1	3	5.1	
Nitrate (mg/l N-NO_3)	0.25	0.25	0.25	Threshold: <175 m AOD Meso = 5 (or 22 mg/l as NO3) Olig = 4.5 (or 20 mg/l as NO3)

3.2.2.3 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 Dunbog Bog are:

- S3 *Carex paniculata* sedge-swamp – typically occurring in lowland open water transitions but can also occur in basin and floodplain mires. It can be found on semi-floating to firm peats, with a water table fairly consistently around ground surface level (Rodwell, 1995). The community is widespread but local within the UK.

- 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".

- 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* 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.

- S26 *Phragmites australis* – *Urtica dioica* tall-herb fen - this type of swamp is classified within 4 sub-communities, to reflect the very variable floristics and physiognomy. Overall, it is a community of eutrophic situations, within mires and water margins. Water levels are sufficiently high to keep the substrate moist through most of the year, although surface flooding can occur in winter (Rodwell, 1995). Though the community marks enriched conditions, this can either be from external nutrient input or from drainage and disturbance of mires resulting in oxidation of organic material and the subsequent release of nutrients. Thus S26 is generally a secondary community (partly or wholly replacing richer fens as a result of enrichment and/or disturbance).

- S28 *Phalaris arundinacea* swamp – typically occurring on the margins of mesotrophic to eutrophic waters, with fluctuating water levels (though the community is not tolerant of permanent flooding). It tends to occur where summer water levels are consistently below the surface and is characteristic of mineral soils, but can be found on organic substrates also (Rodwell, 1995). S28 occurs across the UK within lowlands and on upland margins.

ER37 data and guidelines for Swamps are presented in Table 5. Mean nitrate levels for groundwater-fed swamp in good condition are reported in UKTAG 2012 as 4.9 and 3.5 mg/l $N\text{-}NO_3$ for mesotrophic and oligotrophic swamp respectively (ER37). Swamp groundwater sampled in Scotland was significantly lower than this (third quartile value of <0.25 mg/l $N\text{-}NO_{3)}$. This suggests that all sampled Scottish swamps are in good condition.

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

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

	Swamp			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Guideline:**
pH (-)	5.7	6.3	7.1	
Dissolved Oxygen (%)	15	24	36	
Electric Conductivity (mS/cm)	0.24	0.26	0.43	
Calcium (mg/l)	10	26	44	
Magnesium (mg/l)	3.6	5.4	16	
Sodium (mg/l)	5.5	9	18	
Phosphate (mg/l)	0.024	0.062	0.1	None set
Nitrogen (total) (mg/l)	2	3	7	
Nitrate (mg/l N-NO_3)	0.25	0.25	0.25	Guideline: Meso = 5 (or 22mg/l as NO3), Olig = 4.1 (or 18mg/l as NO3)

3.2.2.4 Type 6 Reedbed

Equivalent NVC types covered:

- S4a *Phragmites australis* sub-community
- S4b *Galium palustre* sub-community
- S4c *Menyanthes trifoliata* sub-community

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

ER37 data and thresholds for Reedbed are presented in Table 6. Nitrate guidelines under UKTAG for groundwater are 4.9mg/l N-NO_3 for groundwater feeding mesotrophic swamp and reedbed in good condition and 5.1mg/l N-NO_3 for poor conditions, but this value is significantly higher than was observed in Scottish reedbed. ER37 reports that "site specific investigations indicate mean concentrations of Welsh and Scottish swamp and reedbed of 0.3 and 0.5 mg/l N-NO_3 (16 wetlands in good condition) and 6.2 and 5.6 mg/l N-NO_3 (9 wetlands poor condition). On this basis a threshold value of 5.0mg/l N-NO_3 has been adopted by UKTAG (2012)". However, ER37 concludes values between observed 1mg/l and UKTAG threshold of 22mg/l should be viewed as an increasing risk.

Table 6. Groundwater thresholds for Reedbed in Good Condition (Source: ER37)

	Reedbed			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Threshold:**
pH (-)	5.7	6.1	6.5	
Dissolved Oxygen (%)	18	20	22	
Electric Conductivity (mS/cm)	0.13	0.2	0.28	
Calcium (mg/l)	36	48	59	
Magnesium (mg/l)	5.8	12	18	
Sodium (mg/l)	12	13	19	
Phosphate (mg/l)	0.043	0.1	0.1	
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 Dunbog Bog have been compared with the levels recorded in vegetation types as show in section 3.2. Groundwater targets were used as opposed to surface water targets for several reasons; firstly that almost all wetlands will have a component of groundwater influence and secondly that groundwater thresholds can often be more demanding than surface water targets.

Table 7 indicates that the vegetation currently found around the sample locations is typically consistent with the data recorded for Scotland (ER37) and for threshold levels. GW1. Nitrate was elevated in all three of the swamp sampling locations, strongly indicating enriched waters are entering the site from the inflow to the south. The sample point in the west of the site appears to be less enriched than was found in the southern swamp communities.

The groundwater samples taken in or near fen communities showed GW2 exceeding Nitrate guidelines. It is therefore likely that, where the inflow waters reach into the wetland core, communities such as M27 and S27 will deteriorate but where these communities are supplied by either rainwater or seepage from the less intensively farmed grassland to the east, the communities should be able to persist. The current influence of the enriched ditch water appears to be marked out by the occurrence of S5 *Glyceria* swamp.

No groundwater samples were taken within/near to the marshy grassland or reedbed habitat present on site and therefore no comparison could be made with published guidelines for this wetland type. However, as reedbeds are typically very tolerant of eutrophic waters, guidelines are unlikely to be exceeded for this wetland type.

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

	Dunbog Bog	Dunbog Bog	Dunbog Bog	Swamp			Dunbog Bog	Dunbog Bog	Dunbog bog	Fen		
Sample	**GW1 (in S9)**	**GW3 (in S3)**	**GW4 (in S3)**	**1st Quartile**	**3rd Quartile**	**Guideline:**	**GW2 (in M27)**	**GW3 (nr S27/M27)**	**GW4 (nr S27/M27)**	**1st Quartile**	**3rd Quartile**	**Threshold**
pH (-)				5.7	7.1					6.4	7.4	
Dissolved Oxygen (%)				15	36					18	28	
Conductivity (mS/cm)				0.24	0.43					0.37	0.69	
Calcium (mg/l)	160	22	30	10	44		37	22	30	12	55	
Magnesium (mg/l)	26	8	12	3.6	16		11	8	12	3.4	14	
Sodium (mg/l)	7.1	11	10	5.5	18		20	11	10	5.4	14	
Phosphate (mg/l)	0.06	0.061	0.061	0.024	0.1	None set	0.062	0.061	0.061	0.064	0.1	None set
Nitrogen (total) (mg/l)	3	2.5	4	2	7		4	2.5	4	1	5.1	
Nitrate (mg/l N-NO_3)	<0.5	<0.5	2.7	0.25	0.25	Guideline: Meso = 5 (or 22 mg/l as NO3) , Olig = 4.1 (or 18 mg/l as NO3)	<0.5	<0.5	2.7	0.25	0.25	Threshold: <175 m Meso = 5 (or 22 mg/l as NO3) Olig = 4.5 (or 20 mg/l as NO3)

3.4 Assessment of surface water samples

3.4.1 Current surface water quality status

Five surface water samples were taken from Dunbog Bog. Due to the likely interaction of groundwater on surface water samples the two sets of results were compared to assess their similarities. The surface and groundwater results can be found in Table 8. The surface water results are different to the groundwater for a number of parameters, suggesting that the site does rely on a combination of surface and groundwater inputs. At the head of the system (SW5), Nitrogen levels are modest. As the water reaches the centre of the site, calcium, magnesium, sodium and forms of Nitrogen increase with the addition of further inflows from the south. By the time the water reaches the outflow, Phosphate levels have increased slightly and total nitrogen levels are at their highest.

Surface water results were compared to ER37 targets for the various vegetation communities at Dunbog Bog.

Table 8. Comparison of Surface water and Groundwater at Dunbog Bog

	SW1 (outflow)	**SW2 (inflow)**	**GW1**	**SW5 (inflow)**	**SW4 (inflow)**	**SW6**	**GW3**	**GW4**
Calcium (mg/l)	28	48	160	22	37	59	22	30
Magnesium (mg/l)	9	13	26	11	13	15	8	12
Sodium (mg/l)	20	17	7.1	12	20	17	11	10
Phosphate (mg/l)	0.067	0.065	0.06	0.062	0.059	0.061	0.061	0.061
Nitrogen (total) (mg/l)	22	8	3	6.5	9	15	2.5	4
Nitrate (mg/l N-NO_3)	16	26	<0.5	22	32	18	<0.5	2.7

The surface water results were compared with targets given for vegetation types as shown in section 3.2. Table 9 indicates that the vegetation currently found around the sample locations is not consistent with data recorded for Scotland (ER37). Total nitrogen levels were particularly high in one of the fen vegetation samples, indicating that this community could deteriorate over time if water quality supplied to this area (and others within the site) is not improved.

Table 9. Surface water samples at Dunbog Bog compared with Wetland Type for Scotland (ER37). Red text denotes sample exceeds 3rd quartile.

	Dunbog Bog		Marshy grassland		Dunbog Bog		Fen		Dunbog Bog	Swamp	
Parameter	**SW2 (in MG1)**	**SW4 (in MG9)**	**1st Quartile**	**3rd Quartile**	**SW5 (in S26)**	**SW6 (in S26)**	**1st Quartile**	**3rd Quartile**	**SW1 (in S12)**	**1st Quartile**	**3rd Quartile**
pH (-)			6.5	7.5			6.7	7.4		7.2	7.8
Dissolved Oxygen (%)			61	70			53	57		65	90
Electric Conductivity (mS/cm)			0.2	0.71			0.25	0.62		0.2	0.56
Calcium (mg/l)	48	37	8.5	44	22	59	13	38	28	23	36
Magnesium (mg/l)	13	13	3.2	9	11	15	5	8	9	5.4	14
Sodium (mg/l)	17	20	6	14	12	17	7	12	20	7.2	14
Phosphate (mg/l)	0.065	0.059	0.005	0.058	0.062	0.061	0.02	0.084	0.067	0.01	0.061
Nitrogen (total) (mg/l)	8	9	1.5	6	6.5	15	1.8	5	22	1	6
Nitrate (mg/l $N\text{-}NO_3$)	26	32	0.4	8.6	22	18	0.25	5.2	16	0.25	5.3

3.4.2 Summary of site vulnerability

Groundwater is considered to be a significant component of water feeding Dunbog bog and as such, the condition of the groundwater, and the land which it passes through, will define the health of the vegetation communities present here.

Groundwater assessment provided in the previous sections shows that high Nitrate and Phosphate levels were recorded in some areas, which exceed guidelines for fens and swamps. This is corroborated by surface water assessment, which also showed high Nitrate and Total Nitrogen levels.

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

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

Source	Dunbog bog	
	Vulnerability	**Details of Factors**
EXTERNAL SOURCES		
1. Agriculture	High	- A significant proportion of the land surrounding the SSSI is used as improved grassland or arable, some of which appears to be providing enriched waters into the site.
2. Human population	Low	- Very few residential properties are present within the surface water catchment.
3. Aerial deposition	Low	- Deposition rates within this part of the UK are lower than recorded in England. Thus atmospheric Total Phosphorus input into the catchment is small, although Total Nitrogen remains a contributor.
4. Regional Groundwater	Moderate	- Regional groundwater may be contributing to the site's water balance and is understood to be of poor water quality.
INTERNAL SOURCES		
1. Wildlife	Low	- The site does not contain large numbers of bird species which would significantly contribute to the nutrient balance.
2. Site management	Moderate	- Grazing and/or cutting occurs only occasionally within the SSSI, resulting in accumulation of plant material and loss of diversity.

3.5 Assessment of soil samples

Soil chemistry was sampled at four locations within Dunbog Bog (1 of which was in S9 *Carex rostrata* swamp, 2 in S3 *Carex paniculata* sedge-swamp and 1 in M27 *Filipendula ulmaria-Angelica sylvestris* mire).

Very little has been published about soil chemistry targets in terms of wetland types or NVC communities. However, the ER37 report presents summaries of the soil chemistry recorded across a number of sample locations in Scotland, which are used here as an indicator of any site abnormalities.

The ER37 data is based on: 20 samples across 8 sites for Reedbeds
49 samples across 13 sites for Marshy Grassland
60 samples across 19 sites for Fens
87 samples across 23 sites for Swamps

Table 11 presents the soil chemistry data for Dunbog Bog samples against the ER37 data. The results show that Soil sample 2 (GW2) taken from the fen vegetation was within normal ranges observed in Scotland for all parameters; however the soil moisture content was much lower at this location in comparison to the other three samples taken within the swamp communities due to the occurrence of sand here. This sample was taken from the north east of the site near the main channel that flows through the site.

Within the swamp community samples, calcium was above normal ranges for Scotland for soil sample 1 (GW1), both at the root layer and below. This sample was taken in the north east of the site in brown fibrous peat with gravelly sandy soil below, with the soil moisture content being significantly reduced below the root layer as expected based on the soil description. Soil sample 3 (GW3), taken in the south east of the site, was above normal ranges for phosphate, total nitrogen and total organic carbon in the root layer, whereas soil sample 4 (GW4), taken nearby, was only above normal ranges for sodium below the root layer. Both samples had high moisture contents at the root layer, which reduced significantly below, which may be explained by the presence of grit and stones at approximately 80cm overlain by fen peat.

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

	Dunbog Bog		Dunbog Bog		Dunbog Bog		Swamp		Dunbog Bog		Fen	
Sample	**Soil1 Root (in S9)**	**Soil1 below (in S9)**	**Soil 3 Root (in S3)**	**Soil 3 below (in S3)**	**Soil 4 Root (in S3)**	**Soil 4 below (in S3)**	**1st Quartile**	**3rd Quartile**	**Soil 2 Root (in M27)**	**Soil 2 below (in M27)**	**1st Quartile**	**3rd Quartile**
Calcium (mg/kg)	5,900	6,500	<100	190	<100	<100	140	5,800	1,400	2,000	960	12,000
Magnesium (mg/kg)	2,900	2,400	1,800	2,900	1,900	600	410	3,400	2,500	2,600	1,500	3,800
Sodium (mg/kg)	75	75	55	75	70	280	17	140	60	60	74	280
Phosphate (available) (mg/l)	4.1	5.2	23	3.7	8.2	4.9	2.9	12	4.5	5.9	2.7	9.5
Nitrogen (total) (%)	0.2	0.41	1.4	0.41	1.8	0.94	0.17	1.2	0.78	0.78	0.25	1.4
Nitrogen (extractable) (mg/kg)	<0.1	0.1	<1.0	<0.1	0.26	<0.1	0.43	0.9	<0.1	<0.1	0.4	1.4
Total organic carbon (%)	2.1	3.9	44	11	52	12	4.1	25	6.2	8.4	3.7	12
Potassium (total)	150	150	95	150	110	310	-	-	150	150	-	-
Soil Moisture Content %	216	68	1,199	622	1,584	212	-	-	106	43	-	-

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.
- Analysis of the samples could only be conducted by eye as there was insufficient data for any statistical analysis.

3.7 Recommendations on future measures and / or data requirements

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

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

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

The initial assessment for Dunbog Bog, based on a single sampling round, suggests enriched water is entering the SSSI from the south and west (where improved grassland is present).

This indication would need to be confirmed by the following data requirements:

- Ideally, monthly surface water sampling within all existing points SW1-6 (as well as an additional sample taken from a spring at source) 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.
- Further detail on the seasonal water levels present on the site (either through discussion with the site manager or, ideally, through collection of water level data by means of a gauge board or dipwell).

Once these data have 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. As the primary exporters of nutrients are improved grassland to the south and west it 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.

- ***Re-instating a regular cutting or grazing regime*** – This would enable nutrients to be removed from site and encourage greater diversity of species.

- ***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. Consequently, use of buffer zones would not be effective within fields containing steeply sloping land, which appears to be the case in certain parts of Dunbog bog. Furthermore, the effectiveness of the buffer zone will be dependant on management, to ensure nutrients are removed via, for example, cutting and removal of vegetation.

  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.

  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	SW4	SW5	SW6
Parameter	**Unit**	**Detection Limit**	**Sample Date**	20/02/2012	20/02/2012	20/02/2012	20/02/2012	20/02/2012	20/02/2012	20/02/2012	20/02/2012	20/02/2012
Phosphorus (total)	mg l-¹	0.2	Water	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ammonium	mg l-¹	0.01	Water	6.8	5.2	5.6	2.8	1.6	1.7	2.1	2.9	3
Nitrate	mg l-¹	0.5	Water	<0.5	<0.5	<0.5	2.7	16	26	32	22	18
Phosphate Low Level	mg l-¹	0.02	Water	0.06	0.062	0.061	0.061	0.067	0.065	0.059	0.062	0.061
Nitrogen (total)	mg l-¹	1	Water	3	4	2.5	4	22	8	9	6.5	15
Calcium	mg l-¹	5	Water	160	37	22	30	28	48	37	22	59
Magnesium	mg l-¹	0.5	Water	26	11	8	12	9	13	13	11	15
Sodium	mg l-¹	0.5	Water	7.1	20	11	10	20	17	20	12	17
Iron (II)	µg l-¹	20	Water	200	100	280	190	100	<20	<20	20	50
Iron (III)	µg l-¹	20	Water	410	250	<20	<20	430	250	130	390	290
Iron (total)	µg l-¹	20	Water	610	350	280	190	530	250	130	410	340

Soil samples

			Sample ID	S1	S1	S2	S2	S3	S3	S4	S4
			Other ID	Below	Root	Below	Root	Below	Root	Below	Root
			Sample Date	20/02/2012	20/02/2012	20/02/2012	20/02/2012	20/02/2012	20/02/2012	20/02/2012	20/02/2012
Parameter	**Unit**	**Detection Limit**	**Type**								
Moisture	%	0.02	Soil	46.1	63.1	32	61.5	66.4	92.7	64.7	93.5
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	5.2	4.1	5.9	4.5	3.7	23	4.9	8.2
Phosphorus (total)	mg kg^{-1}	-	Soil	1800	2300	2400	1900	1600	1100	1200	1500
Nitrogen (total)	%	0.02	Soil	0.41	0.2	0.78	0.78	0.41	1.4	0.94	1.8
Nitrite (extractable)	mg kg^{-1}	0.1	Soil	0.1	<0.1	<0.1	<0.1	<0.1	<1.0	<0.10	0.26
Nitrate (extractable)	g l^{-1}	0	Soil	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01
Calcium (total)	mg kg^{-1}	100	Soil	6500	5900	2000	1400	190	<100	<100	<100
Potassium (total)	mg kg^{-1}	0.2	Soil	150	150	150	150	150	95	310	110
Sodium (total)	mg kg^{-1}	0.2	Soil	75	75	60	60	75	55	280	70
Magnesium (total)	mg kg^{-1}	0.5	Soil	2400	2900	2600	2500	2900	1800	600	1900
Total Organic Carbon	%	0.2	Soil	3.9	2.1	8.4	6.2	11	44	12	52
Moisture content	%	-	Soil	68	216	43	106	622	1199	212	1584
Bulk density	Mg/m3	-	Soil	1.44	1.15	1.78	1.38	0.88	0.82	0.86	0.95
Dry density	Mg/m3	-	Soil	0.86	0.36	1.24	0.67	0.06	0.06	0.27	0.06

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