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Research Report No. 1112

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

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RESEARCH REPORT

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RESEARCH REPORT

Summary

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

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Keywords

nutrients; diffuse pollution; wetland; Pickletillem Marsh 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 Pickletillem Marsh SSSI, in order to assess the trophic status of the designated wetland and identify any likely sources of nutrient input.

Main findings

- Pickletillem Marsh has a relatively small surface catchment, within a free-draining landscape. Two large irrigation ponds were created as part of the golf course to the west of the site, with a smaller pond to the east. Pickletillem Marsh drains west towards the smaller of the two ponds and may be linked to the irrigation ponds, thereby affecting the marsh hydrology.
- Groundwater samples taken at Pickletillem Marsh have been compared with the nutrient level requirements of the vegetation types known on site. They indicate that the groundwater currently found around the sample locations exceeds the 3rd quartile range for Phosphate concentrations recorded within the fens and reedbed of Scotland (ER37 report). Total Nitrogen concentrations also exceed the 3rd quartile range for reedbed and fens, despite reedbed being able to tolerate eutrophic situations. Nitrate levels are within the threshold/guideline values but have not been analysed at sufficient detection levels to gauge whether they are within the inter-quartile range for Scotland.
- Surface water quality is generally typical for reedbed and swamp within Scotland, but Total Nitrogen and Nitrate levels reach the 3rd quartile within the central reedbed.
- The proportion of groundwater to surface water feeding Pickletillem Marsh is not clear. However both sources appear to have some issues with enrichment. Groundwater showed both high Phosphate and Total Nitrogen, while surface waters within the southern half of the site showed some localised Nitrate enrichment. The northern half of the SSSI appears to be less enriched and more groundwater fed.
- Assessment of vulnerability showed Pickletillem Marsh SSSI was most at risk from agricultural practices, historic drainage and possibly some input from septic tanks.

- Further investigations are recommended for the site (such as monthly water quality sampling on all inflows and outflows and seasonal water level data). A range of remedial options are proposed for consideration, once additional data have been gathered.

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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 Pickletillem Marsh, 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. METHODS

The following methodology was used at all 17 sites studied under this project, including Pickletillem Marsh.

2.1 Sampling methodology

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

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

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

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

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

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

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

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

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

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

Water samples were analysed for the following suite:

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

2.2 Analysis of results

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

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

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

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

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

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

[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

Pickletillem Marsh SSSI is within the Drumoig Golf Course, 4 km north of Leuchars, north east Fife (Figure 1). The 7.93 ha site is a small basin fen with representative acid bog and reed-swamp communities, with birch / willow carr, broom scrub and unimproved natural grassland. This habitat is very rare in Fife and therefore the site supports several locally uncommon plant species. The site is also of some value for wintering and breeding birds and has historically held species such as snipe and teal.

The site was grazed by cattle in the late 1960s and mid-1970s. In 1984-85, 2.5 ha of Scots pine around the mire were felled and replanted with Scots pine and Norway spruce. A number of conifers fell onto the fen, with a lot of unconsented brash burning occurring the following year and significant conifer regeneration on the moss carpet. Figure 2 shows the site in the 1800s.

The swamp in the south-eastern section is believed to have significantly dried out between the 1970s and 1989, leading to the disappearance of emergent aquatics. By 1996 birch, willow and reed canary-grass had significantly encroached onto the main fen.

In 1996, Drumoig Gold Course opened with associated hotel / clubhouse, leisure and residential housing, totalling 134 ha around the SSSI.

3.1.1 Site designation and specific targets

Pickletillem Marsh SSSI was notified in 1984. The features for which it is notified are detailed in Table 1, along with their associated pressures.

Table 1. Pickletillem Marsh SSSI designated features and pressures.

SSSI features	Feature Category	Summary Condition / Latest Condition	Pressure
Basin fen	Wetlands	Unfavourable Recovering (Sept 2013)	a)Invasive species

Figure 1. Site Boundary – Pickletillem Marsh

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

3.1.2 Site hydrology

Two large irrigation ponds were created as part of the golf course to the west of the site, with a smaller pond to the east. Pickletillem Marsh drains west towards the smaller of the two ponds (Figure 3). The surrounding landscape is free-draining so the groundwater of the SSSI may be linked to the irrigation ponds, thereby affecting the marsh hydrology. The site has a relatively small surface catchment (Figure 4).

Pickletillem Marsh is underlain by the North Fife Sand and Gravel aquifer. In 2008, the quality of the groundwater was classified as 'Poor', as was the quantity of groundwater. An upward trend in pollutants was also identified. Diffuse pollution through arable farming, non-urban land management measures and abstraction are identified pressures for the waterbody. There are no historic rainfall data available for Pickletillem Marsh.

Evaluating the impact of nutrient sources on a wetland feature depends on a good understanding of how that wetland feature functions hydrologically and ecologically. One of the best systems to describe wetland functioning is the WetMec system (short for Wetland Mechanism) developed by Wheeler *et al* (2009). Each WetMec describes an assemblage of hydrological characteristics that determine functioning, and this is usually linked to a characteristic ecology. Crucially, wetland sites are not viewed as a single type (such as floodplain fen or groundwater fed valley fen), but are understood as inter-linked hydrologies composed of more than one WetMec type.

One of the limitations to this study is that little data were available to define detailed hydrological functioning for this site. Similarly, only general information is available on the substrate present at Picikletillem Marsh. Application of systems such as the WetMec scheme requires detailed information on both these factors before it can be accurately applied. It is therefore only possible to postulate that, due to the substrate consisting of moss peat (*Sphagnum* and *Polytrichum* sp) over sand, with the water table typically just below the surface and *Phragmites* swamp dominating the open wetland vegetation, the most appropriate category would appear to be WetMec 20: Percolation Basin (where some groundwater feed can occur but the status of the supply compared to surface water is unclear).

There are slight indications from the field notes recorded during sampling that species more typical of mire communities, such as M4 *Carex rostrata-Sphagnum recurvum* mire or M5 *Carex rostrata-Sphagnum squarrosum* mire, are still present and may have previously existed in greater abundance on the site when it was wetter. These communities might previously have occupied WetMec 13: Seepage Percolation Basin situations (groundwater-fed basins typically with a transmissive surface layer and a buoyant surface) or even WetMec 3: Buoyant Weakly Minerotrophic Surfaces (transitional bogs where the marsh surface is a little above the watertable, so that water is principally sourced from precipitation). However there are insufficient data available to confirm these possibilities.

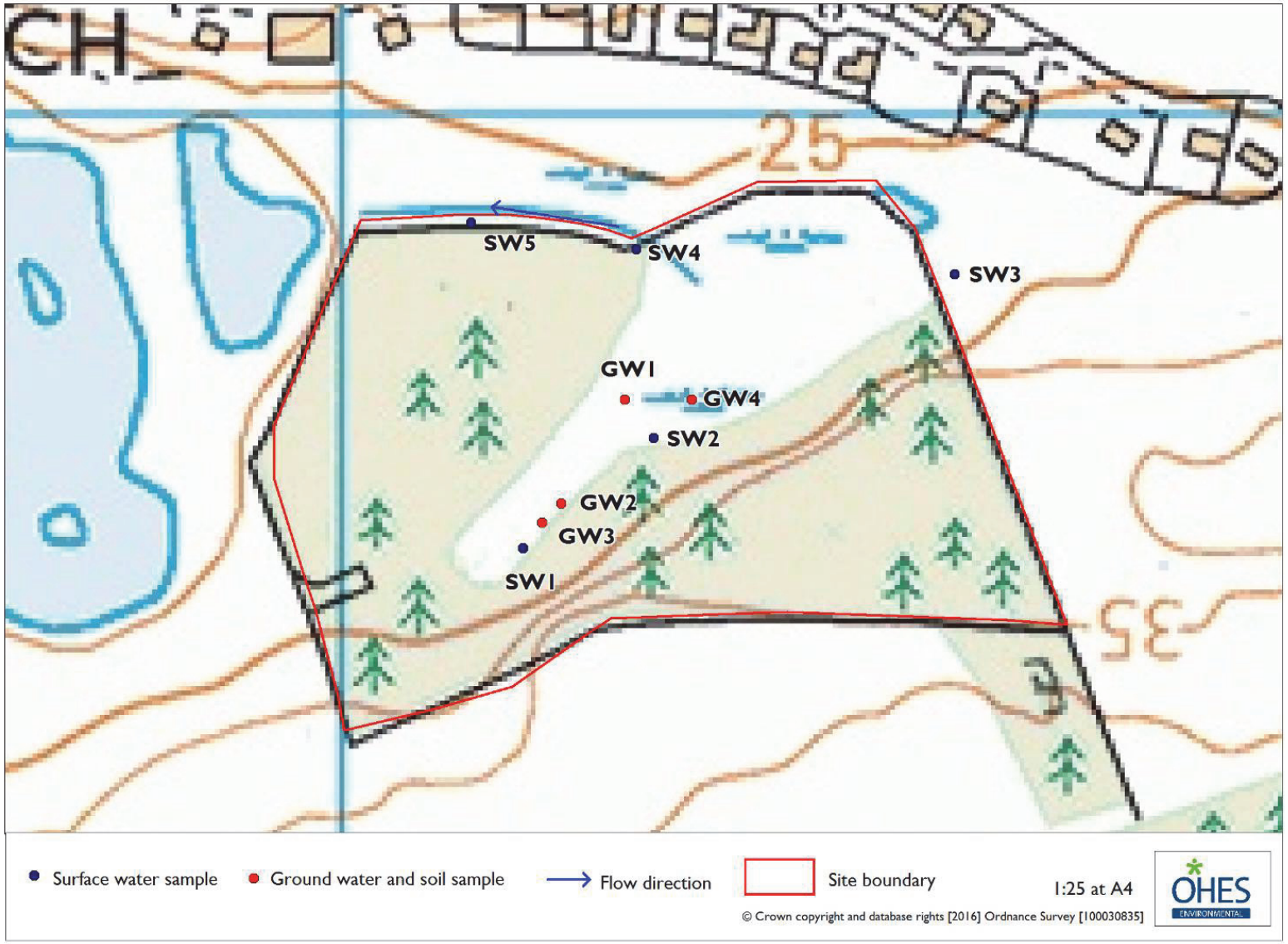

Figure 3. Pickletillem Marsh – Hydrology and Sample Locations

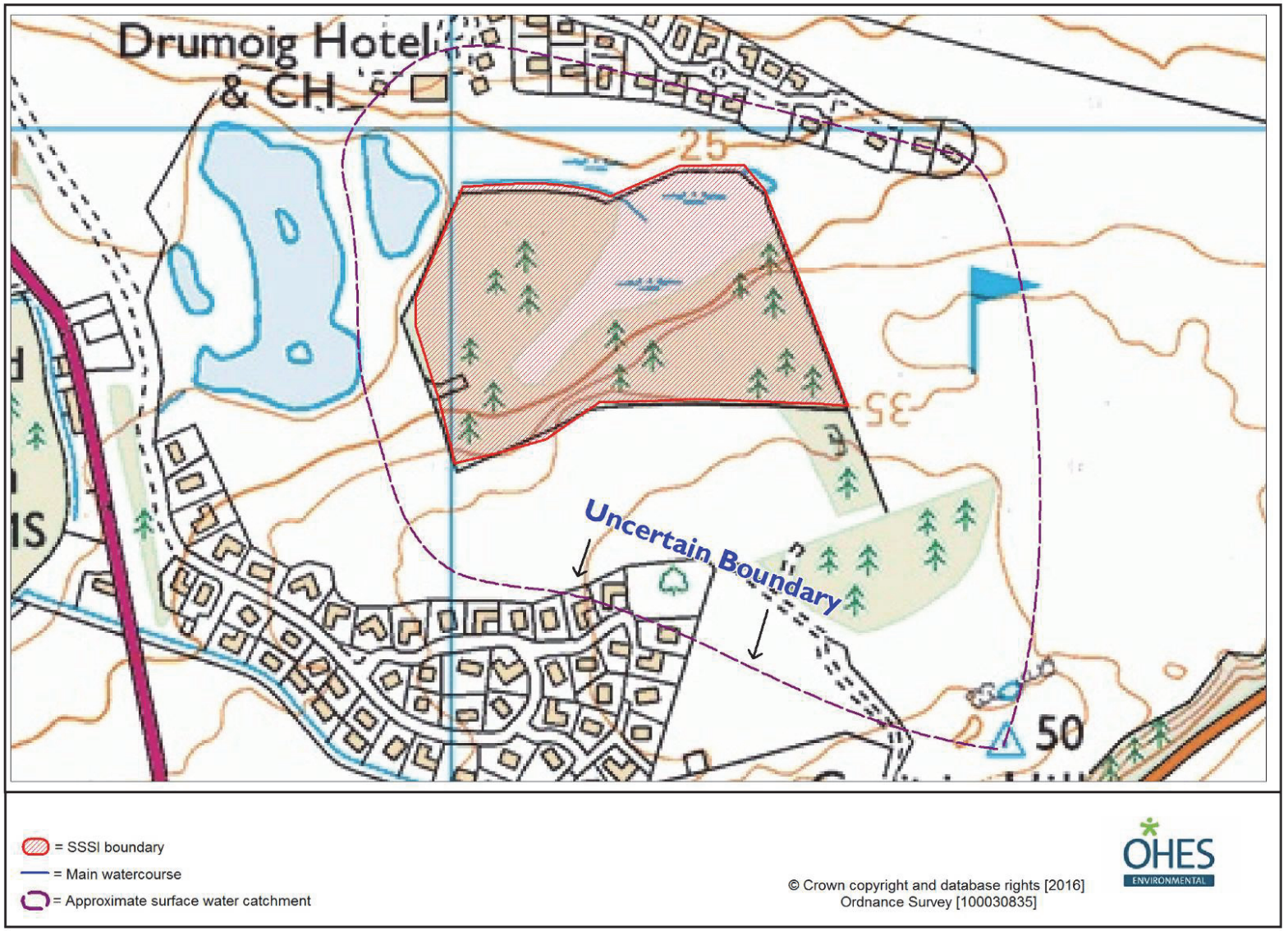

Figure 4. Pickletillem Marsh – approximate surface water catchment

3.1.3 Site soils / sediments

The centre ‘island’ and the margins of the site are underlain by the Auchenblae Association (shown below in orange), which are freely draining glacio-fluvial deposits of sands and gravels derived from Red Sandstone sediments and lavas and acid schists. The remainder of the site is underlain by Alluvial soils (shown in yellow) laid down as sediments from a suspension in water. They are normally well sorted with the modal grain size depending on the current of the suspension, ranging from clay to gravel with horizontal and vertical variations. Figure 5 shows the distribution of soil types at Pickletillem Marsh.

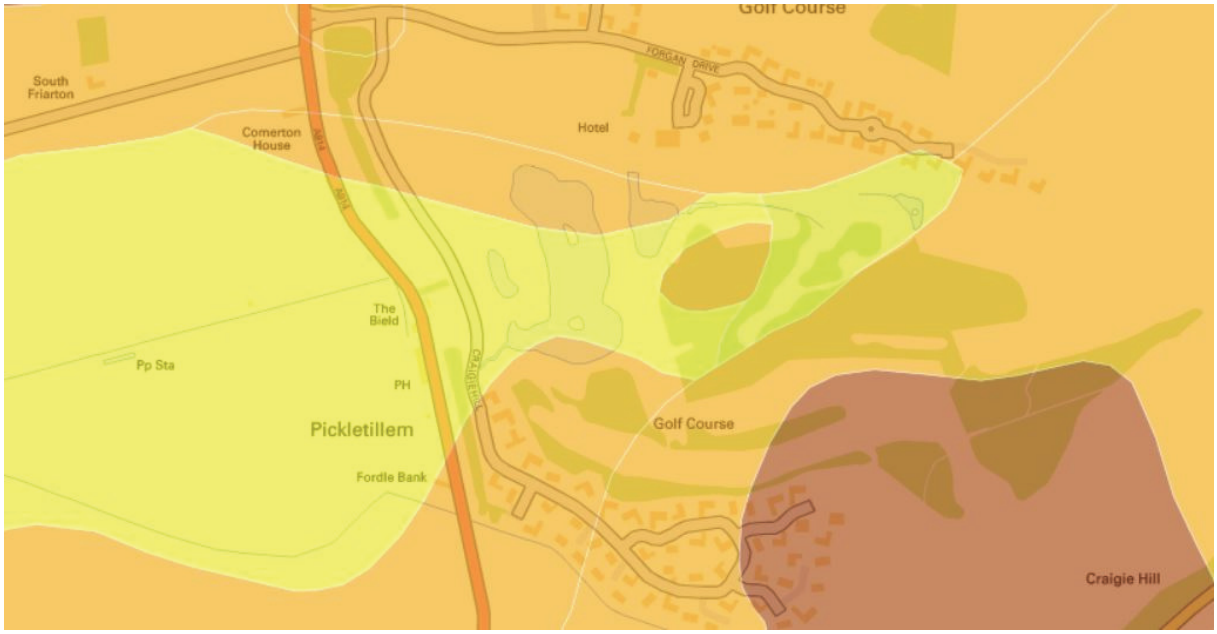

Figure 5. Pickletillem Marsh – Soil types (Source: Soil Survey of Scotland Staff, 1987)

3.1.4 Site soils / sediments

Nutrient run-off from the surrounding golf course may well increase the growth of reed-swamp within the site. Figure 6 shows the locations of these possible sources of nutrients.

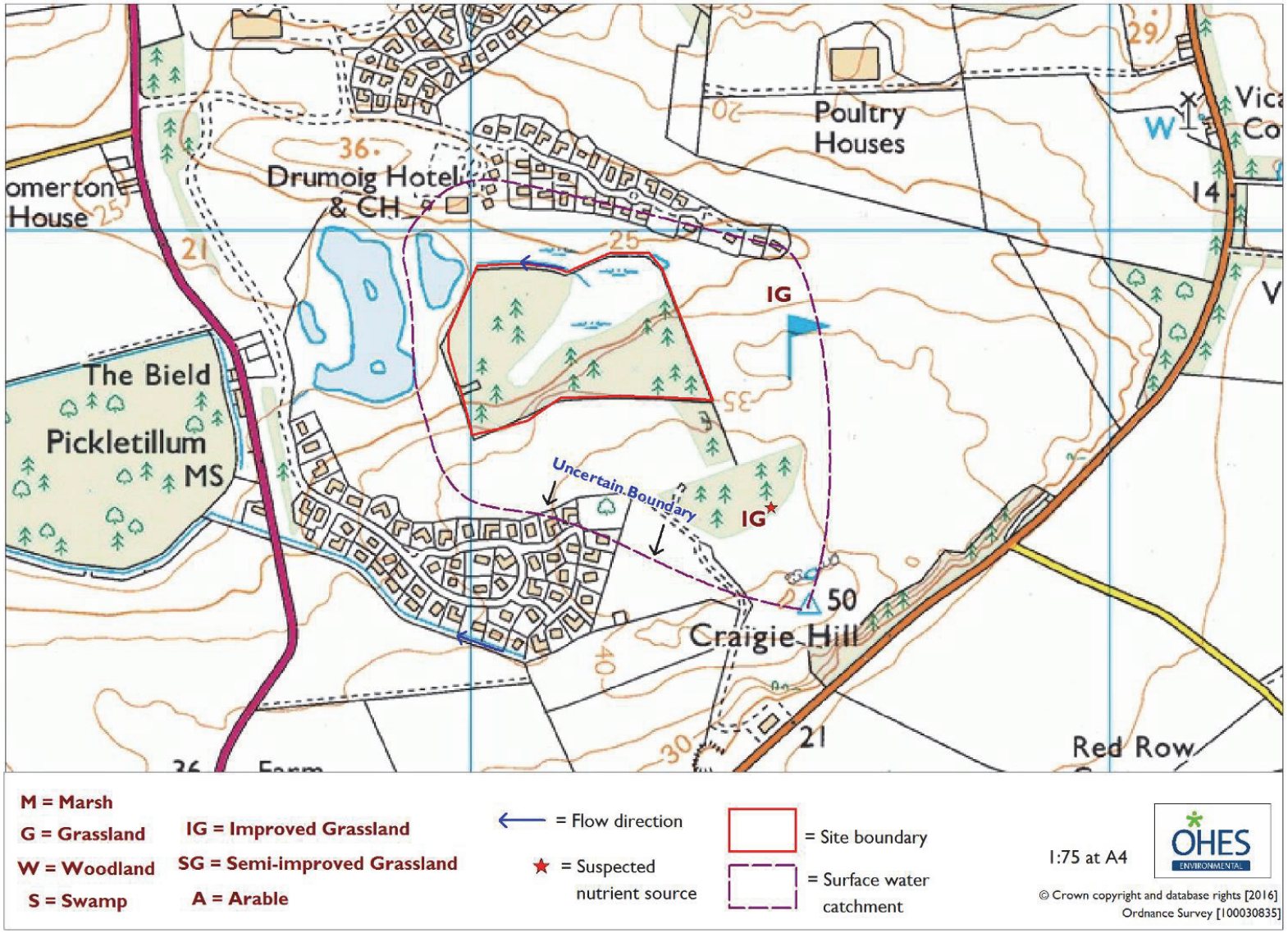

Figure 6. Land use and potential nutrient sources at Pickletillem Marsh

3.2 Assessment of vegetation data

Pickletillem Marsh SSSI contains a range of fen, marsh and swamp habitats. Observations on the vegetation have been recorded in 2002 and 2013. However NVC communities were only mapped for the whole site during 2002, with no quadrat data available. Figure 7 shows the NVC communities recorded in 2002.

The 2002 data suggests the continued presence of the following communities:

- MG1 *Arrhenatherum elatius* grassland
- U4 *Festuca ovina-Agrostis capillaris-Galium saxatile* grassland
- U20 *Pteridium aquilium-Galium saxatile* community
- W2 *Salix cinerea-Betula pubescens-Phragmites australis* woodland
- W18 *Pinus sylvestris-Hylocomium splendens* woodland
- W23 *Ulex europaeus-Rubus fruticosus* scrub
- W24 *Rubus fruticosus-Holcus lanatus* underscrub
- OV26 *Epilobium hirsutum* community
- OV27 *Epilobium angustifolium* community
- M23 *Juncus effusus/acutiflorus-Galium palustre* rush-pasture
- S3 *Carex paniculata* sedge-swamp
- S4 *Phragmites australis* swamp and reed-beds
- S10 *Equisetum fluviatile* swamp
- S14 *Sparganium erectum* swamp
- S28 *Phalaris arundinacea* fen

It is also noted that, during the collection of water samples in 2012, species such as *Sphagnum recurvum, Sphagnum palustre, Aulacomnium palustre, Carex lasiocarpa* and *Carex diandra* were made within the reedbed. Some of these species (such as the *Sphagnum sp.* can occur in low frequency within S4a, but in greater abundances could identify transitions towards either W2b woodland of the *Sphagnum* sub-community or mires such as M4 *Carex rostrata-Sphagnum recurvum* mire or M5 *Carex rostrata-Sphagnum squarrosum* mire. The vegetation descriptions currently available for the site would suggest the open marsh is not sufficiently mire-like to classify it as M4 or M5, but it does raise the question of whether such communities were present historically (when the site was presumably wetter and less enriched). Therefore, for the purposes of this study, the groundwater quality will not only be compared to existing swamp and reedbed communities but also to the guidelines for fen communities.

3.2.1 Historic evidence of community change

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

- During the 2013 SCM there was no apparent loss of extent of wetland in relation to the 2002 NVC and no loss in component habitat types.
- There was no encroachment of *Urtica dioica* (common nettle) into the wetland feature near sample 13 (location unknown) during the 2013 SCM but it was noted that management should be promoted to reduce the extent here.
- Examples of birch and pine within the W2b stands appeared to be dying during the 2013 SCM, which may be linked to higher water levels during the previous two years, resulting in the site target of a scattering of these species being met.

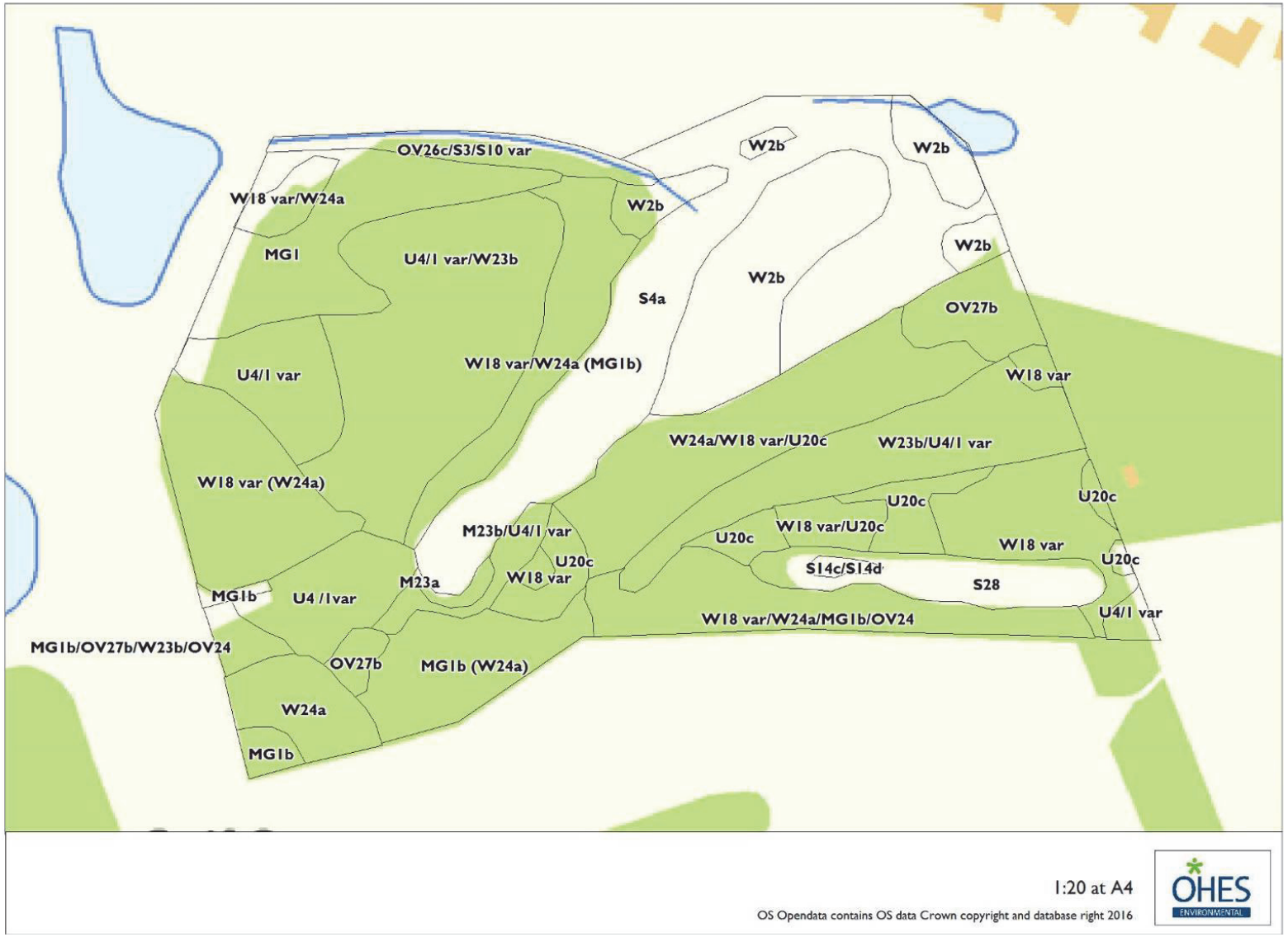

Figure 7. NVC communities recorded in 2002 (Source: SNH)

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 Pickletillum Marsh SSSI 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 communities contained within these types are considerable, but those relevant to Pickletillem Marsh SSSI include:

- M23 *Juncus effuses/acutiflorus – Galium palustre* rush-pasture - this community has a fairly widespread distribution across Scotland and can contain considerable plant diversity. The hydrology is typically one of a high water table close to the surface for most of the year (ER37), with periodic flooding

ER37 data and guidelines for Marshy grassland are presented in Table 2. Mean Nitrate results for wet grassland in good condition are given in UKTAG (2014) as 6 mg/l N. The UK

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

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

Table 2. Groundwater targets for Marshy Grassland in Good Condition (Source: ER37 – DRAFT)

	Marshy grassland			
Parameter	**1st Quartile**	**Median**	**3rd Quartile**	**Indicator/guideline**
pH (-)	6.3	6.6	7.1	5 to 8
Dissolved Oxygen (%)	32	35	40	
Electric Conductivity (mS/cm)	0.093	0.13	0.18	
Calcium (mg/l)	8	18	24	
Magnesium (mg/l)	2.5	4.5	8.7	
Sodium (mg/l)	6.2	9.2	12	
Phosphate (mg/l)	0.041	0.06	0.065	Indicator: 0.065
Nitrogen (total) (mg/l)	2.5	4	7	
Nitrate (mg/l N-NO_3)	0.25	0.25	0.25	Guideline: 6 (or 26 mg/l as N-NO_3) for <175 m 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).*

No NVC communities listed in ER37 were recorded at Pickletillem Marsh SSSI during the 2002 survey or subsequent SCM. However this wetland type has been included here for comparative purposes, based on the presence of mire species on site.

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

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

Table 3. 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 listed in WWF Consulting (2009) and which are found at Pickletillem Marsh SSSI are:

- S3 *Carex paniculata* sedge-swamp
- S10 *Equisetum fluviatile* swamp
- S14 *Sparganium erectum* swamp

S28 *Phalaris arundinacea* swamp is not directly mentioned within ER37 but, for the purposes of this report, has been included within Type 5 swamps.

ER37 data and guidelines for Swamps are presented in Table 4. Mean Nitrate levels for groundwater-fed swamp in good condition are reported in UKTAG 2012 as 4.9 and 3.5 mg/l N-NO_3 for mesotrophic and oligotrophic swamp respectively (ER37). Swamp groundwater sampled in Scotland was significantly lower than this (third quartile value of <0.25 mg/l N-$NO_{3)}$. This suggests that all sampled Scottish swamps are in good condition.

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

Table 4. 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)

3.2.2.4 Type 6 Reedbed

Equivalent NVC types covered:

- S4a *Phragmites australis* sub-community (present at Pickletillem Marsh 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 5. Nitrate guidelines under UKTAG for groundwater are 4.9 mg/l N-NO_3 for groundwater feeding mesotrophic swamp and reedbed in good condition, and 5.1 mg/l N-NO_3 for poor conditions, but this value is significantly higher than was observed in Scottish reedbeds. 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 5.0 mg/l N-NO_3 has been adopted by UKTAG (2012)". However, ER37 concludes values between observed 1mg/l and UKTAG threshold of 22 mg/l should be viewed as an increasing risk.

No threshold value is given in UKTAG (2012) or the ER37 report for Phosphate concentrations.

Table 5. 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 mg/l N-NO_3 (or 22 mg/l as NO_3)

3.3 Assessment of ground water samples

Groundwater samples taken at Pickletillem Marsh have been compared with the levels recorded in 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 and secondly that groundwater standards can often be more demanding than surface water standards.

Table 6 indicates that the groundwater currently found around the sample locations exceeds the 3rd quartile Phosphate concentrations recorded within the data for fens and reedbed in Scotland (ER37), with the exception of GW2. Total Nitrogen concentrations also exceed the 3rd quartile range for reedbed and fens, despite reedbed being able to tolerate eutrophic situations. Nitrate levels are within the threshold/guideline values but have not been analysed at sufficient detection levels to gauge whether they are within the ER37 inter-quartile range.

No samples were taken within / near to the marshy grassland or S28 *Phalaris arundinacea* swamp habitat present on site and therefore no comparison could be made with published guidelines for this wetland type. However, if the groundwater in the M23 present is at similar Phosphate levels to those sampled, only GW2 would be within the indicator value for marshy grassland.

Table 6. Groundwater samples at Pickletillem Marsh compared to Wetland Type for Scotland. Red text denotes sample exceeds 3rd quartile.

	Pickletillem Marsh	Pickletillem Marsh	Pickletillem Marsh	Pickletillem Marsh	Reedbed			Fen		
Sample	**GW1 (in S4)**	**GW2 (in S4)**	**GW3 (in S4)**	**GW4 (near S4)**	**1st Quartile**	**3rd Quartile**	**Threshold**	**1st Quartile**	**3rd Quartile**	**Threshold**
pH (-)					5.7	6.5		6.4	7.4	
Dissolved Oxygen (%)					18	22		18	28	
Conductivity (mS/cm)					0.13	0.28		0.37	0.69	
Calcium (mg/l)	33	17	19	11	36	59		12	55	
Magnesium (mg/l)	6.8	3.4	5.5	3.6	5.8	18		3.4	14	
Sodium (mg/l)	18	2.7	5.1	22	12	19		5.4	14	
Phosphate (mg/l)	0.32	0.032	2.1	0.18	0.043	0.1	None set	0.064	0.1	None set
Nitrogen (total) (mg/l)	9	12	15	11	1.1	6.9	None set	1	5.1	
Nitrate (mg/l N-NO_3)	<0.5	<0.5	<0.5	<0.5	0.25	0.25	Threshold: 5 mg/l N-NO_3 (or 22 mg/l as NO_3)	0.25	0.25	Threshold: Meso = 5 (or 22 mg/l as NO_3) Olig = 4.5 (or 20 mg/l as NO_3)

3.4 Assessment of surface water samples

3.4.1 Current surface water quality status

Five surface water samples were taken from Pickletillem Marsh. 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 7.

Table 7. Comparison of Surface water and Groundwater at Pickletillem Marsh

	SW1	GW2	GW3	SW2	GW1	GW4	SW3	SW4	SW5
Calcium (mg/l)	12	17	19	23	33	11	19	25	26
Magnesium (mg/l)	6	3.4	5.5	6.3	6.8	3.6	4.1	5.4	5.6
Sodium (mg/l)	8.5	2.7	5.1	13	18	22	4.4	10	9.4
Phosphate (mg/l)	0.02	0.032	2.1	0.02	0.32	0.18	0.023	0.038	0.033
Nitrogen (total) (mg/l)	6.5	12	15	5	9	11	5	4	4.5
Nitrate (mg/l N-NO_3)	<0.5	<0.5	<0.5	4.5	<0.5	<0.5	<0.5	<0.5	<0.5

SW1 was taken from a fallen tree pool and shows similar water quality to that of nearby GW2. The lower Calcium levels in this pool may indicate a greater proportion of the water is sourced from precipitation here. It is also noted that Iron concentrations were particularly high in SW1.

SW2 was taken from an open pool under trees and does not show the higher Phosphate levels recorded in the groundwater in this area. However it does show a marked increase in Nitrate levels. Surface water sampling points 3, 4 and 5 are all on the northern edge of the site and show reasonable water quality both in terms of Phosphates, Total Nitrogen and Nitrates.

The results in Table 7 suggest that Phosphate and Nitrogen enrichment is a groundwater issue within the open marsh, but that Nitrate enrichment via surface water run-off in the centre of the site is also a concern.

Surface water results were compared to SNIFFER data (ER37 report) for the reedbed and swamp vegetation at Pickletillem Marsh SSSI. Water chemistry guidelines generally refer to groundwater rather than surface water and therefore comparison can only typically be made between Pickletillem Marsh SSSI and the SNIFFER dataset for wetlands in Scotland. Table 8 indicates that surface water quality is generally at typical concentrations for reedbed and swamp within Scotland, but that Nitrogen and Nitrate levels reach the 3rd quartile within the central reedbed.

Table 8. Surface water samples at Pickletillem Marsh compared with Wetland Type for Scotland (ER37 Draft) Red text denotes sample exceeds 3rd quartile.

	Pickletillem	Pickletillem	Reedbed		Pickletillem	Pickletillem	Swamp	
Parameter	**SW1 (nr S4)**	**SW2 (in S4)**	**1st Quartile**	**3rd Quartile**	**SW4 (nr swamp)**	**SW5 (nr swamp)**	**1st Quartile**	**3rd Quartile**
pH (-)			6.6	6.8			7.2	7.8
Dissolved Oxygen (%)			63	81			65	90
Electric Conductivity (mS/cm)			0.23	0.26			0.2	0.56
Calcium (mg/l)	12	23	24	44	25	26	23	36
Magnesium (mg/l)	6	6.3	4	5.6	5.4	5.6	5.4	14
Sodium (mg/l)	8.5	13	6	20	10	9.4	7.2	14
Phosphate (mg/l)	0.02	0.02	0.01	0.055	0.038	0.033	0.01	0.061
Nitrogen (total) (mg/l)	6.5	5	1.8	6	4	4.5	1	6
Nitrate (mg/l N-NO_3)	<0.5	4.5	0.21	4.6	<0.5	<0.5	0.25	5.3

3.4.2 Summary of site vulnerability

The proportion of groundwater to surface water feeding Pickletillem Marsh SSSI is not clear. However both sources appear to have some issues with enrichment. Groundwater showed both high Phosphate and Total Nitrogen, while surface waters within the southern half of the site showed some localised Nitrate enrichment. The northern half of the SSSI appears to be less enriched and more groundwater fed.

An assessment of vulnerability of the site to enrichment is given in Table 9 below.

Table 9. Assessment of the vulnerability of Pickletillem Marsh SSSI to eutrophication from catchment sources and their relative importance. Negative factors are shown in black, positive factors in blue.

Source	Pickletillem Marsh	
	Vulnerability	**Details of Factors**
EXTERNAL SOURCES		
1. Agriculture/land use	High	- A significant proportion of the land surrounding the SSSI is used as improved grassland (i.e. golf course), some of which appears to be providing enriched waters into the site. - The effect of eutrophication is somewhat ameliorated by the presence of good water quality along the northern edge of the site.
2. Human Population	Low - Moderate	- Two residential areas are present within the surface water catchment (one to the north and one to the south). If these houses are serviced with septic tanks it is reasonable to assume enrichment from these sources will be reaching the SSSI.
3. Aerial deposition	Low	- Deposition rates within this part of the UK are lower than recorded in England. Thus atmospheric Total Phosphorus input into the catchment is small, although Total Nitrogen remains a contributor.
4. Regional Groundwater	Low-Moderate	- Regional groundwater may be contributing to the site's water balance and is understood to be of poor water quality.
INTERNAL SOURCES		
1. Wildlife	Low	- The site does not contain large numbers of bird species which would significantly contribute to the nutrient balance.
2. Site Management	Low	- There is some suggestion within SCM that water levels have been higher in recent years on the SSSI. If this possible increase in water levels is followed a period of general drying out, it is possible there may temporarily be a flush of nutrients released from within substrate stores on site. If this is the case, the flushing should abate relatively quickly.

3.5 Assessment of soil samples

Soil chemistry was sampled at four locations within Pickletillem Marsh (3 of which were in S4 Reedbed and 1 near to S4 Reedbed). 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 10 presents the soil chemistry data for Pickletillem Marsh samples against the ER37 data. It shows that levels of Magnesium, Total Nitrogen and Extractable Nitrogen are all at the lower end of the range observed in Scottish samples. Phosphate, Sodium and Total Organic Carbon are elevated in all four samples.

Samples 1 and 4 (GW1 and GW4) were taken from the northern half of the site in a humified coarse peat with a sandy layer at 70 to 80 cm. The soil moisture content was considerably higher at the root layer than below in GW1, with a recorded water table 15 cm above the marsh surface. This would suggest this part of the site is primarily surface water fed. GW4 showed a water table at only 5 cm below marsh surface, with reasonably high soil moisture in both the root layer and below.

Samples 2 and 3 were taken in the south of the site in unhumified moss peat and fibrous peat respectively. Both of these samples had relatively high moisture content both at the root layer and below, however the recorded water table varied from 0 to 15 cm below marsh surface.

Table 10. Soil samples at Pickletillem Marsh and soil chemistry recorded by Wetland Type in Scotland (ER37). Red text denotes sample exceeds typical range.

	Pickletillem Marsh		Pickletillem Marsh		Pickletillem Marsh		Pickletillem Marsh		Reedbed	
Sample	**Soil 1 Root (in S4)**	**Soil 1 below (in S4)**	**Soil 2 Root (in S4)**	**Soil 2 below (in S4)**	**Soil 3 Root (in S4)**	**Soil 3 below (in S4)**	**Soil 4 Root (near S4)**	**Soil 4 below (near S4)**	**1st Quartile**	**3rd Quartile**
Calcium (mg/kg)	19,000	7,500	14,000	13,000	3,800	16,000	4,300	3,200	1,700	13,000
Magnesium (mg/kg)	330	380	240	230	510	380	230	120	200	2,700
Sodium (mg/kg)	100	65	55	65	130	85	130	85	32	44
Phosphate (available) (mg/l)	8.5	11	7.6	6	22	9.5	20	7.9	1.1	6
Nitrogen (total) (%)	1.4	0.63	0.18	1.7	0.16	1.6	0.39	1.1	0.99	1.7
Nitrogen (extractable) (mg/kg)	0.22	0.31	0.13	0.13	0.11	0.15	0.11	<0.1	0.39	0.56
Total organic carbon (%)	44	10	50	49	51	49	52	50	5.5	22
Potassium (total)	37	75	55	24	580	70	290	35	-	-
Soil Moisture Content %	1,207	235	2,266	1,535	1,426	1,744	1,036	1,856	-	-

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, particularly the hydrological connectivity between the northern and southern halves of the site, and the surrounding land.
- Data was collected from a single sampling round which, though providing consistency of timing could be very misleading if weather conditions were atypical. Clearly a single sample round will also not reflect conditions experienced through the various seasons (such as those times of the year when 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.
- No NVC quadrat data were available for the site which would have enabled more in-depth analysis of the vegetation communities to be undertaken.

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 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 Pickletillem Marsh SSSI, based on a single sampling round, suggests enriched water is present on the SSSI, partly sourced from surface water run-off but also through groundwater enrichment. The cause of the enrichment is still unclear, with possible sources being the drying out of the site, and then subsequent rewetting releasing a flush of nutrient, localised groundwater enrichment from the residential properties in the area or run-off from fertiliser application on the golf course. These sources would need further confirmation via the following data requirements:

- Ideally, monthly surface water sampling within existing points SW1, GW3, GW4, SW2, SW3 and SW5 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 or a source for nutrients being flushed of 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 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. This would require the support of neighbouring landowners (particularly the golf course) who would need to be prepared to reduce the application of fertiliser to their land. 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.

- ***Installation of a control structure at the outflow of the site*** – This would increase the chances that the site remains suitably wet and that any flushing of stored nutrient within the substrate is only temporary. Higher water levels would discourage the growth of problematic species (such as nettles and thistle) and may even encourage the expansion of mire species known to be present here.

- ***Implementation of a grazing/cutting plan*** – a net loss of nutrient can be encouraged on wetland sites using grazing or cutting to remove biomass, as well as providing greater opportunities to increase plant diversity. Whether this is possible at a site such as Pickletillem Marsh SSSI (where it is surrounded by a golf course) is not clear, but the planned removal of scrub off-site will provide similar advantages.

- ***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 Pickletillem Marsh SSSI. Furthermore, the effectiveness of the buffer zone will be dependent on management, to ensure nutrients are removed via, for example, cutting and removal of vegetation.

  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 may not be effective within this catchment.

4. REFERENCES

Entec UK, 2009. A Functional Wetland Typology for Scotland. SNIFFER, Edinburgh.

Envirocentre, 2012. Wetland Soil and Water Samples: Summary report. SNH.

"ER37" EnviroCentre (draft February 2016).

Interagency Freshwater Group, 2015. Common Standards Monitoring Guidance for Freshwater Lakes. JNCC, Peterborough.

Moss, B. *et al*. 2003. The determination of ecological standards in shallow lakes – a tested system (ECOFRAME) for implementation of the European Water Framework Directive. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 13, 507-549.

Natural Scotland, 2009. The River Basin Management Plan for the Scotland River basin district 2009-2015.

Rodwell, J.S. 1995. British Plant Communities: Volume 4: Aquatic communities, swamps and tall-herb fens. Cambridge University Press: Cambridge.

Rodwell, J.S. 1991. British Plant Communities: Volume 2: Mires and heaths. Cambridge University Press: Cambridge.

The Water Framework Directive Directions (England and Wales) 2015.

UKTAG, 2008. UK Environmental Standards and Conditions (Phase 2).

UKTAG, 2014. Technical report on Groundwater Dependent Terrestrial Ecosystems (GWTDE) Threshold Values.

Wheeler, B.D., Gowing, D.J.G., Shaw, S.C., Mountford, J.O. & Money, R.P. 2004. Ecohydrological Guidelines for Lowland Wetland Plant Communities. Environment Agency, Anglian Region.

Wheeler, B.D., Shaw, S. & Tanner, K. 2009. A Wetland Framework for Impact Assessment at Statutory Sites in England and Wales. Environment Agency, Bristol.

WWT Consulting, 2007. Wetland Hydrogeomorphic Classification for Scotland. SNIFFER, Edinburgh.

ANNEX 1: WATER AND SOIL SAMPLES

Water samples

			Sample ID	GW1	GW2	GW3	GW4	SW1	SW2	SW3	SW4	SW5
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	22/02/2012
Phosphorus (total)	mg l-¹	0.2	Water	<0.2	<0.2	0.69	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ammonium	mg l-¹	0.01	Water	1.1	1	1.5	2.4	1.3	1	0.84	0.84	1.1
Nitrate	mg l-¹	0.5	Water	<0.5	<0.5	<0.5	<0.5	<0.5	4.5	<0.5	<0.5	<0.5
Phosphate Low Level	mg l-¹	0.02	Water	0.32	0.032	2.1	0.18	0.02	0.02	0.023	0.038	0.033
Nitrogen (total)	mg l-¹	1	Water	9	12	15	11	6.5	5	5	4	4.5
Calcium	mg l-¹	5	Water	33	17	19	11	12	23	19	25	26
Magnesium	mg l-¹	0.5	Water	6.8	3.4	5.5	3.6	6	6.3	4.1	5.4	5.6
Sodium	mg l-¹	0.5	Water	18	2.7	5.1	22	8.5	13	4.4	10	9.4
Iron (II)	µg l-¹	20	Water	320	400	650	300	<20	<20	<20	<20	240
Iron (III)	µg l-¹	20	Water	30	480	150	1200	8500	610	170	240	<20
Iron (total)	µg l-¹	20	Water	350	840	800	1500	8500	610	170	240	240

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	72.4	89.9	93.3	95.4	93.6	94.7	94.9	93.3
Stones content (>50mm)	%	0.02	Soil	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Phosphorus (available)	mg l-¹	10	Soil	11	8.5	6	7.6	9.5	22	7.9	20
Phosphorus (total)	mg kg-¹	-	Soil	2400	6100	3600	3800	3200	3200	9900	900
Nitrogen (total)	%	0.02	Soil	0.63	1.4	1.7	0.18	1.6	0.16	1.1	0.39
Nitrite (extractable)	mg kg-¹	0.1	Soil	0.31	0.22	0.13	0.13	0.15	0.11	<0.1	0.11
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	7500	19000	13000	14000	16000	3800	3200	4300
Potassium (total)	mg kg-¹	0.2	Soil	75	37	24	55	70	580	35	290
Sodium (total)	mg kg-¹	0.2	Soil	65	100	65	55	85	130	85	130
Magnesium (total)	mg kg-¹	0.5	Soil	380	330	230	240	380	510	120	230
Total Organic Carbon	%	0.2	Soil	10	44	49.00	50	49	51	50	52
Moisture content	%	-	Soil	235	1207	1535	2266	1744	1426	1856	1036
Bulk density	Mg/m3	-	Soil	1.17	1.03	1.01	0.92	1	0.94	0.97	1
Dry density	Mg/m3	-	Soil	0.35	0.08	0.06	0.04	0.05	0.06	0.05	0.09

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