Combe Fen
Restoration Report

David Morris

Oxford

2024

For further information please contact:

Freshwater Habitats Trust
Bury Knowle House
North Place
Headington
Oxford, OX3 9HY

This report should be cited as:

Morris, D. 2024. Combe Fen Restoration Report. Freshwater Habitats Trust, Oxford.

Summary

Combe Fen on the Blenheim Estate in West Oxfordshire is one of the most extraordinary fens in the county. The site is a tiny wetland on the floodplain of the River Evenlode formed around two springs rising from deep underground, creating two mounds of peat raised above their surroundings. Historically the site supported a rich flora of specialist fen plants, well-known to botanists in the 18th and 19th centuries. Sadly, much of this has been lost.

This report presents results of a study commissioned by the Blenheim Estate and carried out by Freshwater Habitats Trust to understand the past and present biodiversity of Combe Fen, how the site has changed, and how it functions as a wetland. Based on this integrated understanding, a recommended approach to restoring fen habitat at Combe Fen is set out.

A total of 57 fen species have been recorded from Combe Fen, but only 38 were found during fieldwork carried out as part of this study. Species recorded historically include Bog Pimpernel (*Lysimachia tenella*), Common Cottongrass (*Eriophorum angustifolium*), Knotted Pearlwort (*Sagina nodosa*), Marsh Helleborine (*Epipactis palustris*) and Star Sedge (*Carex echinata*). Knotted Pearlwort is now extinct in Oxfordshire. The threatened floodplain species Tubular Water-dropwort (*Oenanthe fistulosa*) was last seen in 2016. Populations of local and declining wetland species are still present, including the moss Curled Hookmoss (*Palustriella commutata*) and the flowering plants Devil's-bit Scabious (*Succisa pratensis*), Marsh Pennywort (*Hydrocotyle vulgaris*) and Marsh Valerian (*Valeriana dioica*).

It is likely that Combe Fen once supported alkaline fen, a habitat endangered throughout Europe and for which Oxfordshire is a UK hotspot. However, from the 1960s the site was colonised by scrub and trees, leading to the loss of approximately 75 % of Combe Fen's open wetland. The remaining area of open fen vegetation is unmanaged, species-poor, dominated by tall competitive plants, and gradually being invaded by scrub. The summits of both spring mounds, where spring water emerges, are covered in trees. Interaction between the springs and surrounding floodplain has been modified by artificial drainage.

To restore Combe Fen will require succession to be reversed and management to be put in place. Restoration of alkaline fen and other species-rich fen habitat should be the goal.

It is recommended that restoration of fen habitat be phased as follows:

- Phase 1 -
  - During autumn 2024, clear trees, scrub and coarse fen vegetation from the western spring mound, where most fen species have persisted, and tree cover is younger.
  - Mow the cleared area over spring and summer 2025.
  - Plan more intensive restoration works for autumn 2025.
- Phase 2 -
  - During autumn 2025, clear trees from the rest of the site, using forestry machinery to avoid damaging the wetland surface. Reverse artificial drainage around the site.
  - Mow restored areas area over spring and summer 2026
- Phase 3 –
  - From spring 2026, manage the cleared area, with a combination of cattle grazing and mowing, to maintain and build on the work of the initial phases.
  - Monitor progress, to feedback into management and wider scientific knowledge.

Vegetation clearance should be supervised by Freshwater Habitats Trust specialists.

The baseline presented in this report lacks data on Combe Fen's invertebrate fauna. These are likely to be diverse and could include threatened species sensitive to the proposed restoration work. It is therefore recommended that an invertebrate survey be carried out in 2025, and the results of this be considered in planning the second phase of restoration work.

Contents

1 Introduction

1.1 Oxfordshire Fens Project

Freshwater Habitats Trust runs the Oxfordshire Fens Project[1], a county-wide programme started in 2018 bringing together Oxfordshire-based experts, volunteers, land managers and landowners to protect the county's internationally important alkaline fen habitat for the future.

Freshwater Habitats Trust is currently active in the restoration of eight fen sites across the county, with several other sites in the pipeline. The project is carrying out research to assess the status of the fen resource in Oxfordshire and understand how sites respond to management and restoration across a range of ecosystem functions, including biology, hydrology, and nutrient and carbon cycling.

1.2 Combe Fen

Combe Fen is situated on the floodplain of the River Evenlode, south of Combe in West Oxfordshire (Ordnance Survey grid reference SP 408 149). It is designated as a Local Wildlife Site (LWS) for its lowland fen and wet woodland priority habitats. With an area of 0.29 ha, it is one of the smallest fen sites in the county (Freshwater Habitats Trust, unpublished data). A plan of Combe Fen is shown in Figure 1.

The site is owned by the Blenheim Estate. The Estate plans to restore the site's wetland habitats and enhance it for biodiversity, beginning work over autumn and winter 2024 / 25.

1.3 Purpose of this report

Freshwater Habitats Trust was commissioned by the Blenheim Estate to develop a plan to restore the site's fen habitat.

This report draws together results of desk and field investigations to understand the past and present biodiversity of Combe Fen, how the site has changed, and how it functions as a wetland. Based on this work, the report sets out an approach to restoring fen habitat at Combe Fen.

[1] https://freshwaterhabitats.org.uk/projects/oxfordshire-fens-project/

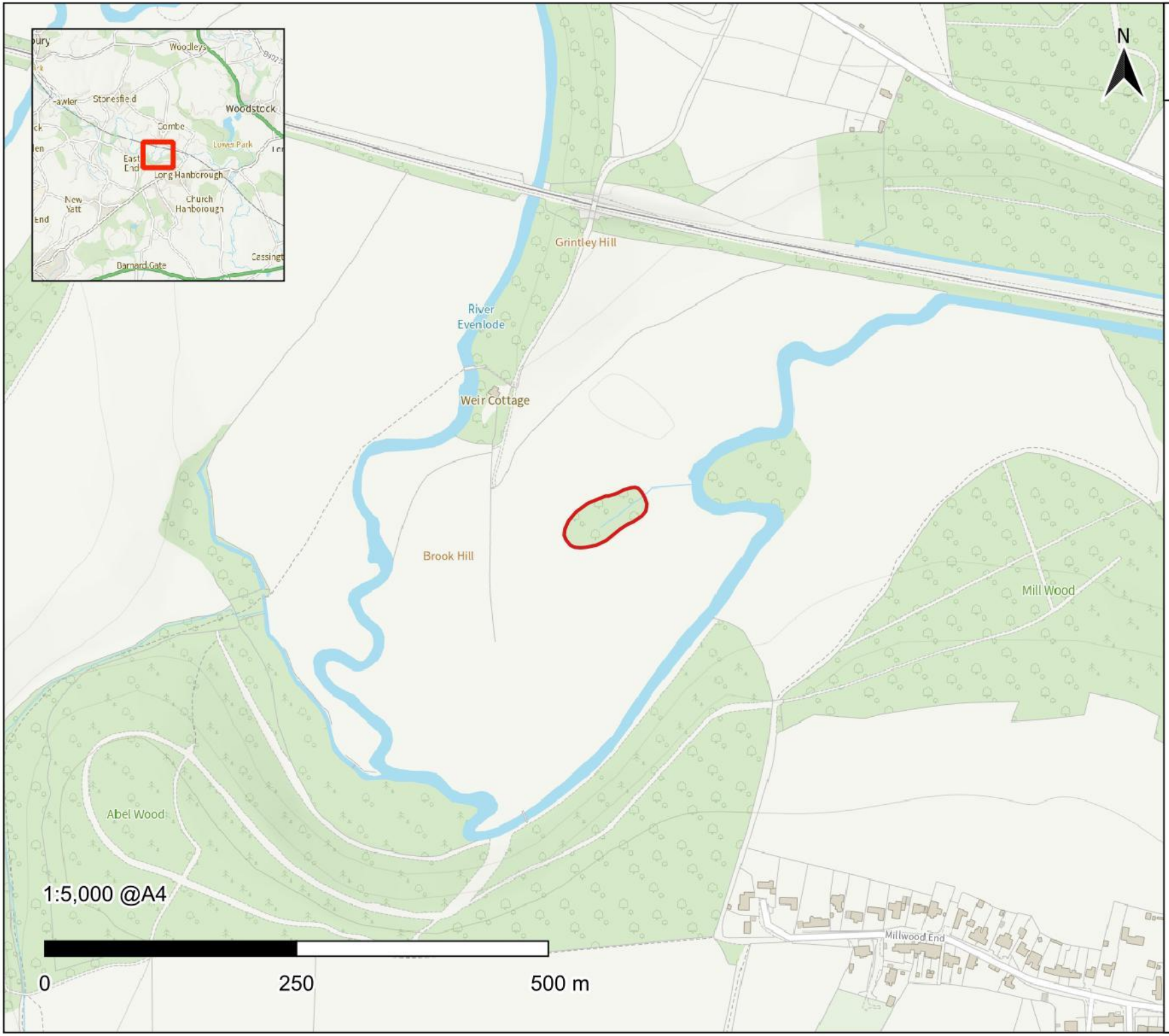


Figure 1. Combe Fen site plan

Legend

Combe Fen Local Wildlife Site

Freshwater Habitats Trust

2 Methods

2.1 Desk study

Historic sources of biological information about Combe Fen were downloaded from Freshwater Habitats Trust's fen database. This database includes biological records compiled from the Botanical Society of Britain and Ireland (BSBI), Thames Valley Environmental Records Centre (TVERC), and historic floras of the county (Sibthorp, 1794; Druce, 1927; Killick et al., 1998).

The LWS description was shared by TVERC and read for further site context. Priority habitat mapping published by Natural England[2] was reviewed.

To identify historic environmental changes around the site, including drainage, land use change and changes in vegetation cover, historic mapping and aerial photographs covering the site were searched for using National Library of Scotland[3], Oxfordshire County Council's History Centre archive[4], the National Collection of Aerial Photography[5] and Google Earth Pro software (Google, 2024).

Information about the physical environment around Combe Fen was gathered from Ordnance Survey mapping, LIDAR data published by the Environment Agency[6] and the British Geological Survey (BGS) GeoIndex website[7].

2.2 Botanical and vegetation survey

Site visits were carried out to gather information about the vegetation and botanical diversity of Combe Fen. The site was visited on 17th May and 16th August 2024 by David Morris MCIEEM, Senior Plant Ecologist at Freshwater Habitats Trust.

During the surveys, the following were carried out:

- To provide a photographic record of the site's vegetation before restoration, a DJI Mavic Mini 3 Pro drone was flown to capture vertical and oblique photographs. Images were processed using WebODM software (Toffanin et al., 2024) to produce an orthomosaic image and digital surface model (DSM).
- Vegetation within and around the site was classified and mapped using National Vegetation Classification (NVC) methodology (Rodwell, 2006). Mapping was carried out in the field using the drone orthomosaic image as a base map, at a scale of approximately 1:1,000. The map was digitised using QGIS (QGIS Development Team, 2024). Target notes describing vegetation were recorded and photographs taken.
- A list of all vascular plants and terrestrial bryophytes observed within the site was compiled. Historic records were used to relocate uncommon plant species. Nomenclature for vascular plants followed Stace (2019) and for bryophytes followed Pilkington, Hodgetts and Blockeel (2023).

[2] https://www.data.gov.uk/dataset/4b6ddab7-6c0f-4407-946e-d6499f19fcde/priority-habitats-inventory-england
[3] https://maps.nls.uk/geo/find/#zoom=14.5&lat=51.83253&lon=-1.40013&layers=101&b=1&z=0&point=51.83176,-1.40769&i=106016847
[4] https://www.oxfordshire.gov.uk/residents/museums-and-history/oxfordshire-history-centre/collections-archives-and-records/maps
[5] https://ncap.org.uk/search?view=map
[6] https://brightstripe.co.uk/dataset/01b3ee39-da3f-47b6-83da-dc98e73a461f/lidar-composite-digital-terrain-model-dtm-1m.html
[7] https://www.bgs.ac.uk/map-viewers/geoindex-onshore/

- For uncommon plant species found, populations were marked with bamboo canes in order that they could be relocated and protected during autumn / winter restoration works. The marked locations were photographed and recorded against the drone orthomosaic.

2.3 Hydrological investigations

During site visits, information was gathered to develop an understanding of how the site functions as a wetland. The following were carried out:

- Hydrological features around the site were mapped, including springs, standing water, flowing water, ditches and land drainage, and presence of peat or tufa[8]. Target notes describing features were recorded and photographs taken.
- The near-surface stratigraphy within and around the site was investigated using hand tools. Three hand augered cores were drilled into the site, two in peat deposits and one in mineral ground. The peat cores were augered using a Eijkelkamp Russian peat corer and the mineral core using a Eijkelkamp auger with combination auger head. The stratigraphy of each core was recorded and the cores were photographed. For peat deposits, the degree of decomposition was recorded using the von Post scale; small samples were removed to identify plant remains in the laboratory. For mineral strata, texture and redoximorphic properties were recorded following *Guidelines for Soil Description* published by the UN Food and Agriculture Organisation of the United Nations (2006). In addition to cores, the near-surface stratigraphy was investigated more rapidly by inserting a 2m plastic cabling rod into the ground, using differences in resistance to detect the presence and depth of peat / alluvium and depth to harder underlying mineral strata.

The field information gathered was integrated with desk data to produce a hydroecological conceptual model of Combe Fen, summarising the key elements and mechanisms in the site's water supply and other processes in the functioning of the wetland (Low et al., 2018). A diagrammatic cross section of the site was produced to summarise the main features of this conceptualisation.

[8] A calcium carbonate mineral formed by precipitation from water super-saturated with calcium carbonate, caused by factors such as degassing of carbon dioxide where water emerges from springs, or by biological processes.

3 Results

3.1 Ecology

3.1.1 Desk study

Biological records

Combe Fen appears to have been well known to 18th and 19th century botanists, assuming that localities given in Sibthorp (1794) and Druce (1927) for e.g. Marsh Helleborine (*Epipactis palustris*) can be identified with the site. This orchid was not seen at Combe in the twentieth century, but many other now rare species were, including the last known population of Knotted Pearlwort (*Sagina nodosa*) in Oxfordshire, recorded in 1984, one of the very few sites for Star Sedge (*Carex echinata*), and of other uncommon and declining fen species such as Bog Pimpernel (*Lysimachia tenella*), Common Butterwort (*Pinguicula vulgaris*) and Common Cottongrass (*Eriophorum angustifolium*), all last seen in 1984. A small number of commoner but local wetland plants have been recorded in the last ten years, including Devil's-bit Scabious (*Succisa pratensis*), Greater Tussock-sedge (*Carex paniculata*), Marsh Pennywort (*Hydrocotyle vulgaris*), Marsh Valerian (*Valeriana dioica*) and Tubular Water-dropwort (*Oenanthe fistulosa*). A list of plants recorded from the site, with year of last record, is given in Appendix 4.

Tubular Water-dropwort is a priority species. It was last seen at the site in 2016 during a LWS survey, but the record does not specify where. One of the surveyors, Dr Judy Webb, shared a photograph of the population taken during the survey (Figure 2).

There were few records of animals from the site. Except for a small number of snail records from 1999, records were of common species that can be recognised by non-specialists.

Figure 2. Population of Tubular Water-dropwort (white flowers in foreground) photographed during survey in 2016. J.A. Webb.

Habitat

The LWS description lists lowland fens and wet woodland priority habitats as features of the site, describing the site as '*a tiny area of marshland and alder carr in the middle of a floodplain field by the River Evenlode*'. The description refers to the presence of peat and to the wetland area being slightly raised above the level of the floodplain, with wet seepage areas, including iron-rich water.

Combe Fen was surveyed in 1990 as part of a survey of Oxfordshire fens (Fojt, 1991). The survey described the site as a '*[s]mall area of land surrounded by arable. Peripheral ditches dry at time of survey. Eastern end colonised by alder. Fen flat and colonised by C. paniculata, C. acutiformis and Juncus acutiflorus. Inter-tussock spaces bare, mossy or water. Water orange coloured. Arrhenatherum frequent [and] dominant along peripheries*.'

National priority habitat mapping does not show any priority habitat at Combe Fen.

Historic land cover changes

The first edition of the Ordnance Survey for the area (published 1876) shows the site as two areas of open wetland connected by a watercourse.

Changes in the vegetation in and around Combe Fen during the twentieth century are evidenced in aerial photographs from the RAF survey of 1944, Fairey survey of 1961, Astral survey of 1981, Geonex survey of 1991 and subsequent Google Earth satellite images:

- 1944 - The site is hardly visible in the photograph but trees appear to be absent.
- 1961 – Trees and scrub are largely absent. The wetland area appears as two connected regions on a west-south-west to east-north-east axis, with the western region larger. Areas of the floodplain to the north and west also appear to be wet. A connection to the Evenlode and ditches around the periphery of the site are apparent, as are ditches and possibly land drains in the surrounding field.
- 1981 – The eastern third of the site has scrubbed over. The surrounding land is arable.
- 1991 – The eastern half of the site has completely scrubbed over, and taller trees are present. The western half of the site is open. Surrounding land is arable.
- 2004 to present – Images show the expansion westward of scrub and trees to cover around three quarters of the site, and establishment of mature tree cover over the eastern half of the site.

The 1961, 1981 and 1991 images are included in Appendix 1, provided by Oxfordshire History Centre.

3.1.2 Vegetation survey

A plan showing the vegetation mapped and target note locations is shown in Figure 3. Target note descriptions and photographs are given in Appendix 3. A sample of drone photographs captured are provided in Appendix 2.

The vegetation was found to be organised in zones around two spring mounds elevated above the level of the floodplain, oriented on a west-south-west to east-north-east axis, and connected by watercourses and ditches draining east to the River Evenlode.

Alder (*Alnus glutinosa*) woodland dominated around three quarters of the site. The oldest trees occupied the eastern spring mound, becoming progressively younger to the west (target notes 30 and 11). An area of open fen vegetation was present around the western side of the site. The surrounding floodplain was improved grassland and was not mapped.

The mature Alder woodland over the eastern spring mound had a sparse field layer growing around pools on the top of the mound (target note 1) and cascades formed around its sides (target note 23), comprised of scattered tussocks of Greater Tussock-sedge, Broad Buckler-fern (*Dryopteris dilatata*) and other ferns, with mats of Curled Hookmoss (*Palustriella*

commutata) growing on the top of the mound and on debris within flowing water. Marsh Valerian was scattered around tree bases and growing through moss mats. The trees largely occupied a dry bank that encircled the mound on its eastern and southern sides, with a field layer of non-wetland species. A shrub layer was absent.

The field layer of the tree-covered part of the western mound (target note 8) was dominated by Greater Tussock-sedge and Lesser Pond-sedge (*Carex acutiformis*). Runnels flowing off to the east had an abundance of Curled Hookmoss and Maidenhair Pocketmoss (*Fissidens adianthoides*), with frequent Marsh Valerian (target note 5). On the south side of the mound was a very wet zone with more widely spaced, taller, buoyant tussocks of Greater Tussock-sedge growing in soft peat and standing water (target note 9). Lesser Pond-sedge was absent from this area.

In the area between the mounds, the field layer comprised sparsely vegetated mossy runnels (target note 3), with flanking vegetation with abundant Lesser Pond-sedge, Plicate Sweet-grass (*Glyceria notata*) and Sharp-flowered Rush (*Juncus acutiflorus*) (target note 4).

In terms of the NVC, this woodland vegetation is referable to W5 *Alnus glutinosa-Carex paniculata* woodland. There were no species preferential to any of the three sub-communities, likely because the woodland is of recent origin. This habitat qualifies as 'wet woodland' priority habitat.

Greater Tussock-sedge extended a short distance out of the tree cover into open fen to the west (target note 16), referred to S3 *Carex paniculata* swamp. Away from the top of the mound, the vegetation passed rapidly into rank, species-poor fen vegetation dominated by Lesser Pond-sedge (target notes 10 and 17), referred to S7 *Carex acutiformis* swamp. This vegetation extended onto the floodplain to the west and around the northern side of the site (target note 15). A small number of fen species were scattered through this area, such as Brown Sedge (*Carex disticha*), Ragged-Robin (*Silene flos-cuculi*) and Marsh Valerian. There was a richer area along the southern edge of the trees, with Devil's-bit Scabious, Fen Bedstraw (*Galium uliginosum*) and Marsh Pennywort (target notes 12-14).

These types of wetland vegetation qualify as 'lowland fens' priority habitat.

There was a small stand of Greater Pond-sedge (*C. riparia*) and larger stand of Plicate Sweet-grass along the northern edge of the woodland, in an area where water pools behind a ditch bank (target note 19).

Ditches around the site boundaries supported a range of wetland plants largely absent from the fen and woodland habitats. However, the ditches were mostly under the cover of trees and were therefore not mapped as separate types of vegetation. The ditch along the southern boundary was dominated by Lesser Pond-sedge and Soft-rush (*Juncus effusus*) (target notes 28 and 29). The ditch along the northern boundary was dominated by Creeping Bent (*Agrostis stolonifera*) and Plicate Sweet-grass (target note 22). Around the eastern boundary and the outfall into the Evenlode were species such as Brooklime (*Veronica beccabunga*), Common Spike-rush (*Eleocharis palustris*) and Fool's Watercress (*Helosciadium nodiflorum*) (target note 26).

There were stands of Common Nettle (*Urtica dioica*) along the north side of the site, referred to OV24 *Urtica dioica-Galium aparine* community. These indicate ground disturbance or enrichment by livestock.

3.1.3 Botanical survey

A total of 92 plant species were recorded, comprising two liverworts, 13 mosses and six ferns / horsetails and 71 flowering plants. The list of species is given in Appendix 4.

Four species recorded are of conservation concern, listed in Table 1. All four species are listed as Near Threatened on the England red list of vascular plants (Stroh et al., 2014). Marsh Pennywort is also scarce in Oxfordshire. A small population (fewer than 10 plants) of

Devil's-bit Scabious was found in the south-west of the site, along the edge of Alder trees (target notes 12-14). Marsh Pennywort was also found in small quantity in this area (target note 13), and in one place under trees to the north-east (target note 7). Locations of these populations were marked with canes. Marsh Valerian was present throughout most of the site, under trees and in the open western area of fen. Plants of Ragged-Robin were scattered through the open area of fen in the south-west of the site.

Tubular Water-dropwort was searched for but not found. Quaking Grass (*Briza media*), last recorded in 2016 and listed as Near Threatened on the England red list, was also not found. Orchid species such as Southern Marsh Orchid (*Dactylorhiza praetermissa*) seen in 2015 were not recorded.

The runnels draining off the western spring mound were rich in brown mosses[9], including Curled Hookmoss, Dull Starry Feathermoss (*Campylium protensum*) and Maidenhair Pocketmoss. This area was marked with a cane (target note 6).

Table 1. Plant species of conservation concern recorded.

Scientific name	Common name	Conservation status
Hydrocotyle vulgaris	Marsh Pennywort	England Near Threatened, Oxon Scarce
Silene flos-cuculi	Ragged-Robin	England Near Threatened
Succisa pratensis	Devil's-bit Scabious	England Near Threatened
Valeriana dioica	Marsh Valerian	England Near Threatened

[9] Ground-dwelling mosses from several taxonomic families, typically coloured shades of brown or orange. They form an important component of the vegetation of mineral-rich fens, especially of fens of high nature conservation value.

Figure 3.
Vegetation plan

Legend

- Target note
- Target note (photo direction)

Vegetation

- MG1b Arrhenatherum-elatius grassland, Urtica dioica sub-community
- OV24a Urtica dioica Galium aparine community, typical sub-community
- S3 Carex paniculata swamp
- S6 Carex riparia swamp
- S7 Carex acutiformis swamp
- Glyceria notata-dominated vegetation
- Scattered trees
- W5 Alnus glutinosa-Carex paniculata woodland

Freshwater Habitats Trust

3.2 Hydrology

3.2.1 Topography

The topographic relief around Combe Fen is shown in Figure 4, derived from 1 m resolution LIDAR data. The DSM generated from the drone imagery is shown in Figure A2.6, Appendix 2, and shows the relief of the combined ground and vegetation surface.

The site lies on relatively flat ground on the floodplain of the Evenlode valley, inside a meander loop with the river to the west, south and east, flowing west to east, with its closest approach approximately 50 m due east from the eastern boundary of the site. Brook Hill is a small hill projecting into the valley from the north, forming higher ground that rises from the floodplain approximately 70 m to the west of the site.

The floodplain around the site falls steadily in a south-west to north-east direction, more-or-less parallel to the direction of the river along the eastern side, from a highpoint of approximately 72 metres above Ordnance Datum (mAOD) along the river to the south, to a low point of around 70.5 mAOD along the northern edge of the valley, at the foot of the valley slope and railway embankment (see elevation section GH in Figure 4). As a result, the floodplain is approximately 0.3 m higher on the southern side of Combe Fen than on its northern side.

Combe Fen itself consists of a pair of spring mounds elevated above the level of the floodplain (see elevation section AB in Figure 4). According to LIDAR data, the highest point, located on top of the western mound, is approximately 0.7 m above the trend in height of the floodplain, with the eastern mound 0.35 m higher. These elevations may vary if the underlying peat swells and contracts (see subsection 3.3).

There is a low embankment around the western end of the site (marked ‘B’ in elevation section AB Figure 4), presumed to be spoil dumped against the slope of the mound from the excavation of a shallow ditch around the western side of the mound. There is also a low embankment on the inside of the ditch on the northern side of the site.

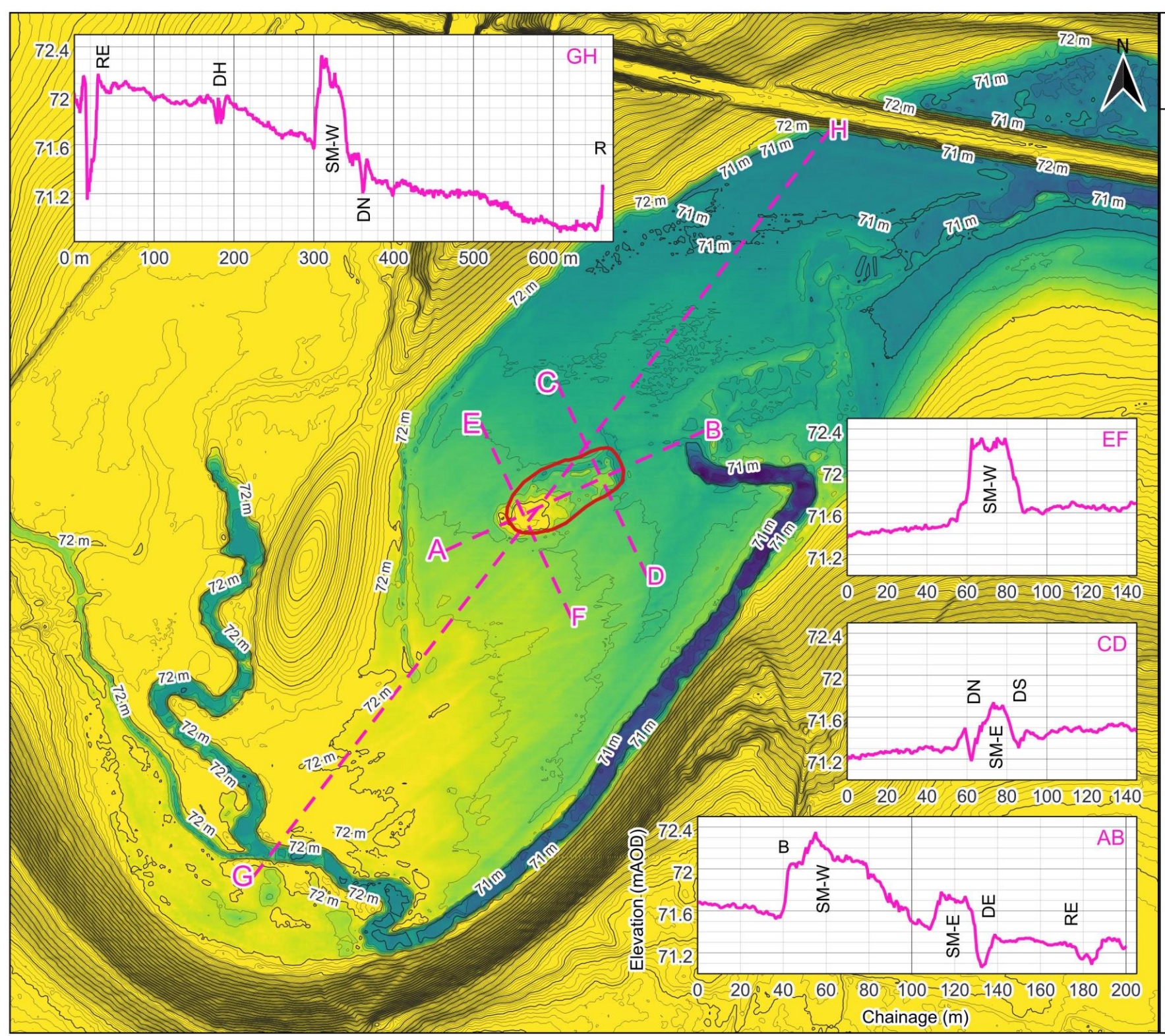


Figure 4.
Topography of Combe Fen

Legend

Combe Fen

Elevation contours at

0.2 m intervals

1 m intervals

Elevation

70 mAOD 72 mAOD

Elevation section
1 dash = 10 m

Key to annotations:

- SM-E - Eastern spring mound
- SM-W - Western spring mound
- RE - River Evenlode left bank
- B - Bank around west side
- DN - Ditch on northern boundary
- DE - Ditch on eastern boundary
- DS - Ditch on southern boundary
- DH - Ditch in hedgerow
- R - Railway embankment

1:3,500 @A4

0 20 40 60 80 100 m

Freshwater Habitats Trust

3.2.2 Hydrological features

The hydrological features and patterns of surface flow observed in August 2024 are shown in Figure 5.

The main natural features were the two spring mounds, consisting of lenses of peat raised above the surrounding floodplain (see subsection 3.2.3). Each mound appeared to be formed around areas of very localised groundwater discharge, each with different structure.

The western mound was a well-defined mound, consisting of peat from its apex (target note 8) with an asymmetrical shape, the longer slopes oriented approximately west-north-west to east-south-east. Through the mound's centre was a zone of very soft, unconsolidated organic deposits (target notes 5 and 9), through which groundwater appeared to discharge (shown as 'unconsolidated / buoyant peat surface' in Figure 5). This zone extended to the east (target note 3), forming a channel connected to the eastern spring mound, passing along its north side. There was abundant tufa in the runnels through this area. Some of this flow east diverted off to the south into a ditch (target note 4). Some flow was also observed off the north side of the mound. Compared to the eastern mound, flow from this mound appeared diffuse and was only evident where it ran over roots and down ditch banks.

The lower, eastern mound consisted of an elevated pool across its top (target note 1), with a strong flow of water to the north (target notes 23 and 24) and west (target note 2) over natural cascades formed of debris and moss. The pool appeared to occupy a void in the centre of the mound, with clear water and abundant iron ochre deposits, with the surface around its edges partly consolidated with coarse organic debris and mats of Curled Hookmoss. The bank around the eastern and southern sides was dry mineral ground.

Ditches enclosed the area of wetland within the site, intercepting water flowing off the two spring mounds onto the surrounding floodplain. The prevailing flow in the ditches was to the north-east corner, with flow captured by a culvert (target note 25) discharging to the River Evenlode (target note 31). The ditch connecting this corner to the river was dry during the survey (target note 30).

The ditches around the southern and eastern boundaries of the site were very shallow, filled with sediment and vegetation (target notes 27-29). There was abundant tufa in some areas. The southern ditch was fed by small runnels flowing off the ground between the mounds.

Due to the dense vegetation around the western side of the site it was difficult to make out a ditch, but there did appear to be a shallow channel; it didn't appear to be connected to the ditch along the southern boundary. The ditch became more well-defined on the north-side where it connected to the ditch along the northern boundary. The inside of the ditch had a low embankment, standing proud of the slope of the mound. This was more well-defined further to the north. The ditch and bank were not clear from the LIDAR but were discernible in the DSM generated from the drone imagery (Figure A2.6, Appendix 2).

Surface water along the north side of the site was more complex. The ditch along the north side had a low bank on its inside (south side), and in May surface water was pooling behind it, inside the site, presumed to be flow collected off the western spring mound. In the bank was a pipe, which in May appeared to have water flowing out of it into the ditch but in August water was draining into it from the east. The pipe could be a land drain. The current Bing satellite image shows what could be the routes of land drains, with three potential drains across the north side of site, converging on a single potential drain running north, following the gradient of the floodplain. These are shown in Figure 5.

As described above, some of the flow off western spring mound flows along a channel within the site, bypassing the northern ditch and running along the northern edge of the eastern spring mound. This may be the channel shown on the first edition of the Ordnance Survey and may be natural.

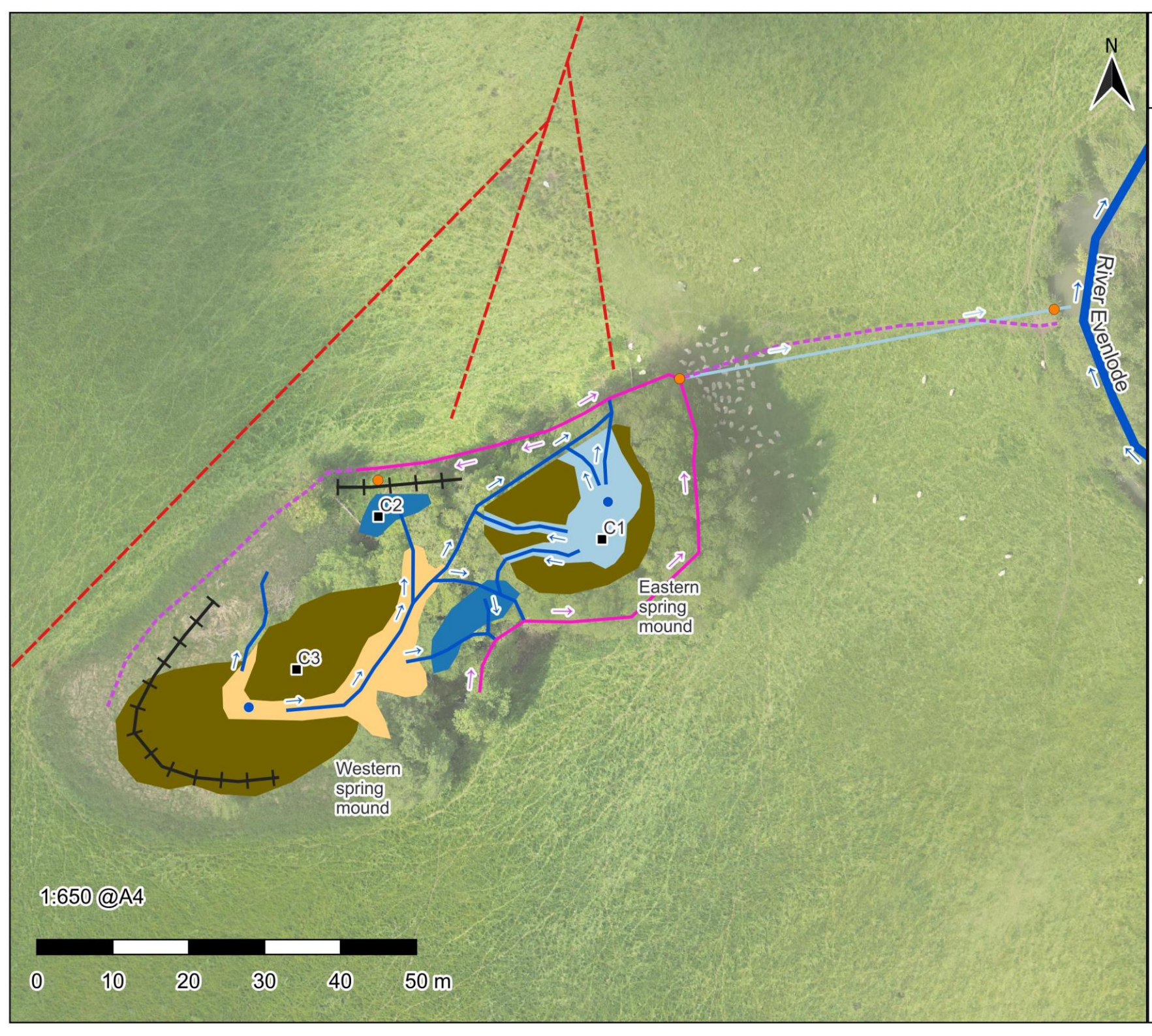


Figure 5.
Hydrological features of Combe Fen

Legend

- Hand-augered core
- Spring
- Land drain / pipe
- Embankment
- Land drain
- Ditch - dry
- Ditch - running
- Culvert
- Surface flow pathway
- River
- Spring-fed pools / cascades
- Consolidated peat surface
- Unconsolidated / buoyant peat surface
- Standing water (seasonal)

Freshwater Habitats Trust

3.2.3 Geology and hydrogeology

British Geological Survey (BGS) 1:50,000 bedrock geological mapping shows the valley around Combe Fen as being underlain by a series of limestones, with the oolitic limestone of the Taynton Limestone Formation under the site and most of the floodplain, and the Hampden and White Limestone Formations outcropping across the floodplain to the south and on the northern valley slopes. These rocks are part of the Great Oolite Group, a principal aquifer in which virtually all flow is through fractures and other discontinuities.

BGS 1:50,000 superficial geological mapping shows the floodplain as being underlain by alluvial clays, sands and gravels. These deposits are classified as a 'Secondary A' aquifer.

There is one borehole record near the site in the BGS GeoIndex, approximately 100 m to the south at SP 40840 14830, carried out in 1971. This recorded alluvium at 0-2.6 metres below ground level (mbgl); peat at 2.6 to 3.1 mbgl; river terrace sands and gravels at 3.1 to 5 mbgl; and limestone below 5 mbgl. Water was struck at 2.2 mbgl. This is similar to the log recorded in the borehole sunk by the Blenheim Estate in August 2024 approximately 50 m west of the site, though the alluvium was found only to 0.5 mbgl, peat was not recorded, and limestone was at 4 mbgl. In the recent borehole, water was struck in the gravels at 0.92 mbgl, in the limestone at 4.25 mbgl and rising to 1.6 mbgl. Copies of the borehole logs are given in Appendix 5.

To investigate the shallow stratigraphy within the site, three cores were augered by hand during the survey, in each of the spring mounds and in the area between them. Locations of the cores are shown in Figure 5 and descriptions and photographs are given in Appendix 5.

The spring mounds were underlain by peat deposits, but these differed in stratigraphy. In the core from the eastern mound (C1), peat was found to 0.87 mbgl, although the top 0.07 m comprised loose sediment and water and was not retrieved. The peat near the surface, to 0.24 mbgl, was fluid and strongly decomposed, while the peat below was firm and fibrous and less well decomposed. Near the base of the latter deposit were abundant, well-preserved remains of the brown mosses Intermediate Hookmoss (*Scorpidium cossonii*) and Hooked Scorpion-moss (*S. scorpioides*).

Peat from the core in the western spring mound (C3) consisted of a weakly decomposed upper portion to 0.56 mbgl, and a fluid, almost completely decomposed lower portion, to 1.2 mbgl. The latter was similar to the loose organic deposit in the zone of groundwater discharge within the spring mound (see Figure 5) and is presumably continuous with it.

The base of these cores comprised mineral substrates, sandy clay loam in the eastern spring mound and sand in the western. The former appeared to be a freshwater deposit.

The core from the middle of the site (C2) comprised a soft silty clay to 0.88 mbgl. This was strongly oxidised and showed some evidence of surface gleying but little groundwater gleying. This was interpreted as alluvium. Below this depth the substrate was too hard to core into, presumed to be river terrace gravels. There appeared to be a water level at the interface between these strata, but this did not rise.

The extent of organic and mineral substrates at the surface more widely was investigated by probing with a rod. The area of organic deposits identified is shown in Figure 5; unmapped areas consisted of soft alluvial clay like that identified in core C2.

The area through the western spring mound interpreted as a zone of groundwater discharge and surface flow (see Figure 5) was found to consist of a loose organic deposit with hard sand / gravel at around 0.6 m below the surface.

The eastern spring mound was found to be enclosed by a bank of mineral substrate around its eastern and southern sides. The peat around the sides of both spring mounds was found to thin rapidly onto alluvium. The configuration of the peat / alluvium contact was not investigated (e.g. whether peat deposits had been buried by alluvial deposition).

3.3 Hydroecological conceptual model

The results of the study were integrated to develop a conceptualisation of the main hydrological processes supporting wetland habitat at Combe Fen. This is presented as a diagrammatic cross section in Figure 6, which shows the main processes and relationships with vegetation, as well as uncertainties.

The two springs appear to be supplied by highly localised upwelling of artesian groundwater through ‘windows’ in the floodplain deposits. Neither borehole recorded near the site recorded groundwater near the surface in the limestone underlying the floodplain. The high-pressure water welling up through the two spring mounds must originate from deep groundwater flowing through a network of fractures in the bedrock under the site. Presumably this flow is transmitted through the overlying sands and gravels, found to extend to 4-5 mbgl in the two boreholes, but there is perhaps some discontinuity in this deposit directing flow to the springs, rather than artesian water flowing more widely through the sand and gravels and influencing the groundwater in that stratum. Alternatively, the bedrock may be very close to the surface under the site, with the surrounding area deeply buried by alluvial deposits.

Under the western spring mound, a hard mineral deposit appears to be closer to the surface under parts of the mound, including the zone of groundwater discharge. The mound appears to have a ‘core’ of fluid peat, with an outer ‘mantle’ of consolidated peat. This structure is likely to be dependent on the water pressure in the core, maintained by the artesian groundwater. As a result, the peat surface may rise and fall as groundwater level varies.

The vegetation of the western spring mound shows a clear zonation in relation to distance from the mound summit and zone of groundwater discharge. Around the top of the mound, Greater Tussock-sedge is abundant. This declines radially outwards from the top, with Lesser Pond-sedge rapidly assuming dominance and Greater Tussock-sedge disappearing. Greater Tussock-sedge is dependent on a stable water table, and likely on the chemistry of the groundwater, while Lesser Pond-sedge is tolerant of a fluctuating water table and will grow in summer dry mineral substrates. Greater Tussock-sedge can also grow over unstable surfaces, forming buoyant mats, as over parts of the mound.

The eastern mound appears to be simpler in structure, with groundwater upwelling through an open void. As it sits at a lower elevation, this may be because the head of groundwater is relatively higher, perhaps enough to prevent peat forming a consolidated surface.

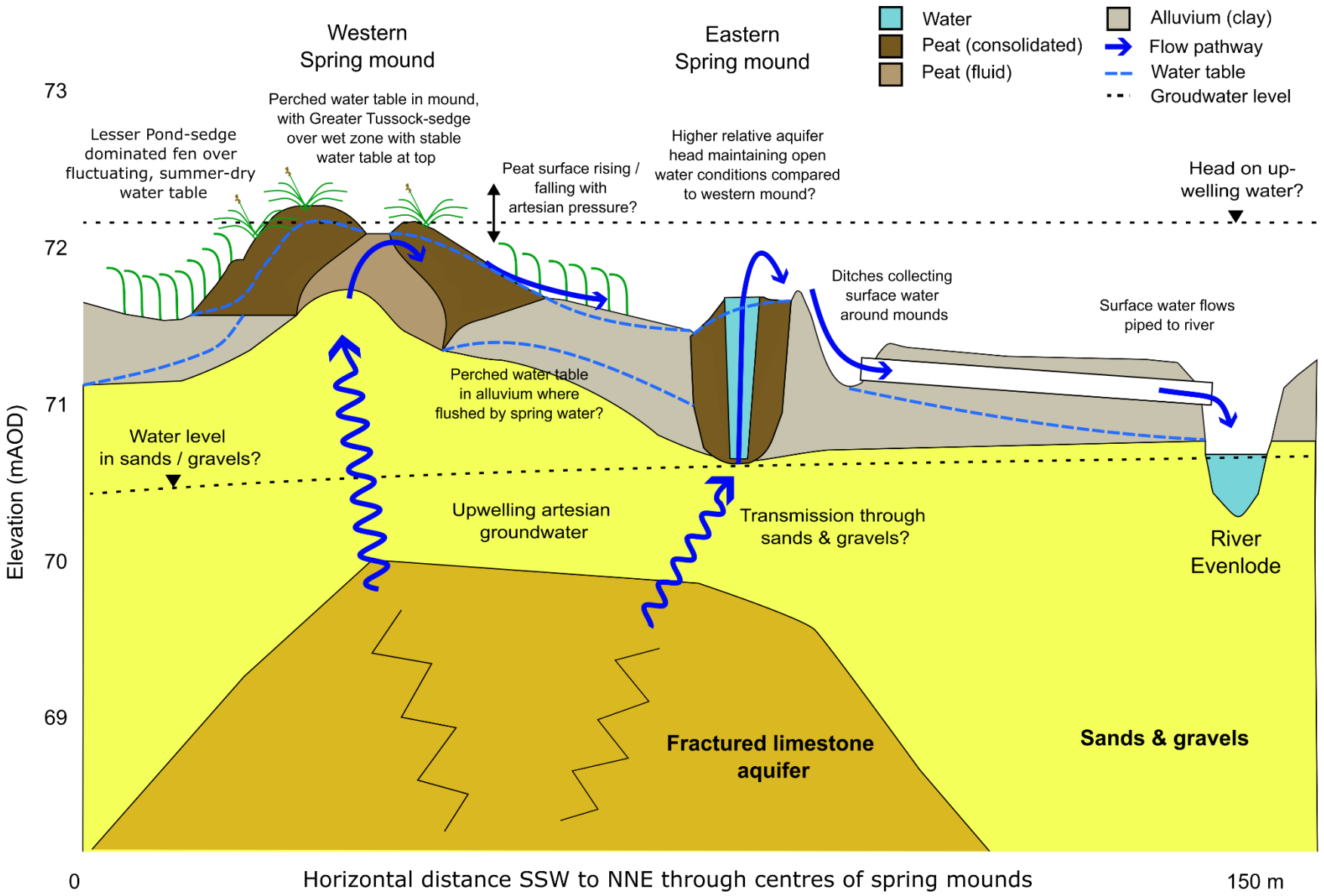
Across both mounds, brown moss communities were present in areas of surface flow, growing in shallow, mineral-rich water derived from the springs. Abundant tufa was found in these areas, indicating a calcium-rich groundwater source. Curled Hookmoss is a typical species of ‘petrifying’ springs, where calcium carbonate from spring water precipitates onto debris.

The surrounding floodplain appears to be largely uninfluenced by the springs. In the 2024 borehole, the groundwater in the sands and gravels was at approximately the level of the river, and below the base of the alluvium. During coring, no water was found in the alluvium, which was highly oxidised, though there seemed to be a water table at the top of the sands and gravels.

The summer dry condition is likely the natural state of the floodplain around Combe Fen, but this may be exaggerated by drainage. The ditches around the site appear to modify the interaction between the groundwater dominated system of the two spring mounds and the surface water system of the surrounding floodplain, preventing water from the springs from inundating the floodplain and forming a perched water table in the alluvium.

Artificial drainage around the sites does not appear to exert any influence on the spring mounds. It is miraculous that the mounds have remained intact, and that more intensive drainage appears not to have been attempted.

Figure 6. Hydroecological conceptual model of Combe Fen



4 Restoring Combe Fen

4.1 Nature conservation value

Even in a county with a rich wetland heritage, Combe Fen stands out as a special place. However, the site has changed greatly since the mid-twentieth century, with loss of around three quarters of open wetland habitat to scrub and trees (subsection 3.1.1). Although wet woodland is a priority habitat, the succession of fen habitat to wet woodland will have caused significant losses of plant and animal species.

Combe Fen was once very rich in wetland plants, despite its small size. Using B. Wheeler's list of fen plants published in Fojt (1993), a total of 57 fen species have been recorded, 38 in the present survey. Five of these are 'rare' fen species: Common Butterwort, Curled Hookmoss, Knotted Pearlwort, Marsh Helleborine and Slender Tufted-sedge (*Carex acuta*). Of these, only Curled Hookmoss is still present at the site. Knotted Pearlwort is now extinct in Oxfordshire. Other species once recorded include Bog Pimpernel, Common Cottongrass and Star Sedge, all rare in the county. The remaining populations of Marsh Pennywort and Devil's-bit Scabious are small and vulnerable to further successional changes.

These historic records indicate that Combe Fen was once much more open and that the vegetation was short and species-rich, likely maintained by light grazing. Species such as Common Butterwort, Common Cottongrass and Marsh Helleborine, together with the brown mosses Curled Hookmoss and Maindenhair Pocketmoss still present (as well as evidence of Intermediate Hookmoss and Hooked Scorpion-moss from peat deposits), suggest that Combe Fen likely once supported alkaline fen habitat, an Annex I habitat[10] endangered throughout Europe (European Commission: Directorate-General for Environment et al., 2016). Alkaline fen habitat would likely have occurred around the tops of the spring mounds, in areas of groundwater discharge and flow, with tufa deposition.

Alkaline fen habitat supports very rich invertebrate communities, including many rare and threatened species. Unfortunately, almost nothing is known about the past or present invertebrate diversity of Combe Fen. Many specialist fen invertebrates require open vegetation with sunny, mossy, shallow pools of water, and are likely to have been lost due to succession. However, some species of conservation concern are less dependent on botanically rich, open fen habitat, and might have persisted under scrub and trees.

In addition to fen species, a range of plants more typical of alluvial floodplain wetlands in Oxfordshire have been recorded, including the priority species Tubular Water-dropwort. Last recorded in 2016, the Combe Fen population was one of only two known from the Evenlode catchment (Botanical Society of Britain and Ireland, 2024). It was not found during the present survey, despite targeted searching. The photograph of the population from 2016 (Figure 2) suggests it was on the north side of the site. It may have died out as the tree canopy extended over this edge, although there remains favourable habitat in the ditch nearby.

Finally, although degraded ecologically, Combe Fen remains of outstanding interest for its unusual morphology and hydrology. Only one other fen site in the county is known to support spring mounds (Freshwater Habitats Trust, unpublished data) but the morphology and hydrogeology of the mounds at that site are different to Combe Fen. The occurrence of spring mounds in wetlands in the UK has not been systematically recorded, but they are rare, and little is known about their development (Wheeler et al., 2009). The occurrence of deep peat, more than one metre, is also of paleoenvironmental value in a region where peat is scarce.

[10] Annex I of the EC Habitats Directive, which lists natural habitats of European conservation concern.

4.2 Restoration

The main factors in the ecological condition of wetland habitat at Combe Fen are the lack of management and succession to woodland. Reversing these must be the priority for restoration.

Hydrologically, Combe Fen is largely intact: the artesian groundwater and associated morphological features that likely supported Combe Fen's most valuable wetland biodiversity in the past are remarkably undamaged. The artificial drainage around the boundaries of the site modifies the interaction between the groundwater-driven systems of the two spring mounds and surrounding surface water system, which has lower potential nature conservation value compared with the spring mounds.

The restoration of alkaline fen habitat should be the main goal of restoration. As an endangered habitat occurring naturally in small patches with very special hydrology, the value of this habitat is out of all proportion to the potential area that could be restored at Combe Fen (likely a few tens of square metres). This approach will also bring the greatest benefits to the rest of the site, creating a larger, more diverse area of fen habitat.

The approach to restoration recommended consists of three phases:

- **Phase 1** - The purpose of the first phase is to carry out the priority works, observe how the site responds and plan the second phase. Priority works involve vegetation clearance from the western spring mound, where most fen species and vegetation have persisted.
- **Phase 2** – Following the first phase, and with an enhanced understanding of the site and additional time for planning, the second phase involves more intensive works, including removing larger trees and reversing artificial drainage.
- **Phase 3** – The maintenance and monitoring period, when management work is carried out to maintain and build on the work of the initial phases, and monitor site development to feedback into management and wider scientific knowledge.

Proposed actions for each phase are described in Table 2. Monitoring is described in subsection 4.3.

To restore alkaline fen, it will be necessary to monitor the response of the seedbank and consider whether to reintroduce key species. Bog Pimpernel and Knotted Pearlwort may regenerate, but species such as Common Cottongrass are unlikely to reappear.

At the outset of restoration, it will be important to address the following challenges:

- **Waste management** – Cutting fen vegetation and clearing trees will generate a large volume of waste and will continue to do so until the site can be managed by grazing alone. Removing material (e.g. off site or to habitat piles in hedgerows) will require machinery to be committed to the restoration work. As the site has good access, trees could be taken off and used commercially. If material is kept in habitat piles near the site, it should be on the northern (downslope) side.
- **Tree regeneration** – Cut Alder trees regrow very quickly and in such a small area initial tree clearance work could be undone in five years. It will therefore be necessary to either 1) kill the trees at the outset by winching or poisoning stumps, or 2) committing to an annual coppicing regime until the trees are killed. Option 1 would be preferred.
- **Long-term resources** – Fen restoration is a long-term activity. Grazing by cattle is the most sustainable management method in the medium to long term, and securing this should be explored early on. This will involve acquiring suitable livestock, or working with a grazier invested in grazing wetlands for nature conservation, and installing the infrastructure to enable grazing. Secure funding will be needed to support this and other management activities; as landowner, Blenheim Estate can access Countryside Stewardship Higher Tier grants to support management of high value, complex habitats.

Table 2. Restoration phases and actions

	Timing	Actions
Phase 1	September 2024 - March 2025	• Clear western spring mound: ▪ Mow the fen vegetation around the western side of the site. Lesser Pond-sedge-dominated vegetation to the north and lower down on the spring mound can be cut with a flail mounted on a tractor. Areas with Greater Tussock-sedge and sensitive wetland plants (marked by canes) should be cut by hand, e.g. with a brush cutter. All material should be raked off by hand and removed from the site. ▪ Mowing should be supervised by Freshwater Habitats Trust staff, to guide site operatives and protect sensitive features. ▪ Clear all the young Alder trees and scrub off the spring mound. Woody material should be cut as close to the ground as possible. Some trees / bushes are growing out of Greater Tussock-sedge tussocks and should be removed carefully. Most of these trees are small enough that they can be cut, processed and removed from site by hand. ▪ There are some larger Alder trees to the south of the spring mound. These can be ring-barked to create standing deadwood habitat. • Investigate the potential land drainage along the north side of the site using an excavator. Verify the orientation of drains, their depth and design, and whether they function. • Work should be carried out early in autumn before the ground becomes too wet, especially if using machinery. • Following vegetation clearance work, observe how the site responds. Movement of water around the western spring mound will be easier to observe once vegetation has been removed, and the structure and function of the embankment and ditch around the western boundary will be clearer.
	March 2025 - September 2025	• In April, mow again the area mown previously and the regrowth in the area cleared of trees. Remove all material from site as before. Mowing under the area cleared of trees will need to be by hand, and under supervision to avoid sensitive features, such as old tussocks supporting important species. This early cut is especially important for reducing competitive species. • The same area should be cleared again in mid-summer, and again in August or September. Important plants should be identified and avoided, so that they can flower and set seed (e.g. Devil's-bit Scabious) • Carry out invertebrate survey – see subsection 4.3 • Plan phase 2 works. Apply for any permits needed for further felling work and drainage modifications.

	Timing	Actions
Phase 2	September 2025 - March 2024	• Clear central area: ▪ Trees are larger, requiring more intensive work, machinery would be needed to move cut material around or off site. As the site has good access, felling would be best carried out using forestry machinery, such as tree shears on a tractor-mounted arm, to make the work fast and effective and minimise ground disturbance in wet areas. ▪ This area of site is less sensitive and trees can be used to create a larger habitat mosaic. Fell and leave some trees across surface flow pathways to direct water onto the floodplain. Fell a selection of trees and winch the stumps to create pools, and ring-bark others to create standing deadwood. ▪ Choice of methods / trees should be determined by botanical sensitivities, under supervision. Trees growing along runnels supporting brown moss communities should have trees felled and the stumps treated to prevent regrowth. If necessary, terrestrial bryophytes can be translocated to preserve them. • Clear eastern spring mound: ▪ Fell the alders growing around the eastern spring mound and treat the stumps. Felling work should be careful to protect the mound banks, especially the northern and western banks with their fragile cascades. ▪ As above, clearance would be most effective using a machine with an arm to minimise ground disturbance. • Hydrological restoration: ▪ The objective of this work is to remove pipes and block ditches so that water from the springs finds its own way across the floodplain, wetting a larger area before draining away. The exact approach would be developed during Phase 1. ▪ Ditch blocking can be done using timber from felled trees and clay from the floodplain. Clay can be excavated near where needed, creating topographic complexity and temporary waterbodies. ▪ If land drains are found during Phase 2, then they should be dug out up to 10 m from the site and the trenches backfilled and packed with clay. The culvert draining the site into the Evenlode should be treated in the same way. ▪ Carefully remove the bank around the western spring mound, or break gaps into it to enable water from the spring to discharge more evenly across the mound and onto the floodplain.
	March 2025 - September 2025	• Continue cutting the western spring mound 2-3 times during the spring and summer, following the methods described above. • Continue to observe site development and plan any remedial work. • Carry out monitoring – see subsection 4.3.

	Timing	Actions
Phase 3	September 2025 onwards	• Management: ▪ During spring and summer, continue regular mowing of fen vegetation. Adjust the frequency and extent of cutting according to vegetation development in response to restoration. ▪ Over the winter of 2025 / 26, set the site up for grazing, to begin on a trial basis from spring or early summer 2026. • Monitoring: ▪ Monitor the response of fen plants to restoration. Assist some species to spread, e.g. Devil's-bit Scabious, Curled Hook-moss. ▪ Assess the site for species reintroductions, to be carried out by Freshwater Habitats Trust specialists. ▪ Carry out other monitoring – see subsection 4.3.

4.3 Monitoring

The aim of monitoring is to observe the site's biological response to restoration and management and determine whether this is toward the goals of the restoration, i.e. a larger, more diverse area of fen habitat, including alkaline fen habitat. Monitoring results should feed back into management and contribute to wider scientific knowledge.

This report provides a baseline against which changes can be assessed. However, there are almost no data on the site's invertebrate communities, so that the impact of restoration (positive or negative) cannot be assessed. It is therefore recommended that an invertebrate survey be carried out during 2025. The phasing of works will enable restoration work to be adapted to the findings of this survey.

Invertebrate survey should use a combination of malaise trapping and more active methods such as netting and hand searches. Malaise trapping is an effective method of sampling flying invertebrate communities, which can be very diverse in fens and include many species of conservation concern. The survey must be carried out by an expert in fen invertebrates.

The methods of the botanical and vegetation survey carried out for this report would be appropriate for monitoring going forward. This approach gives a site level survey of plant diversity, can identify locations of important species and changes in their distribution, and provides qualitative information that can be used to direct management. The survey should be carried out annually by Freshwater Habitats Trust specialists, or other suitably qualified wetland ecologist.

Methods designed to monitor changes in vegetation species abundance and structure, such as by recording fixed vegetation plots, are more time consuming and logistically challenging to implement around a restoration programme. The information is less useful for management, but the method is more structured and unbiased, appropriate for publication in scientific literature. In the short term, this approach is not recommended but could be instigated following the main vegetation clearance works.

Finally, surveillance monitoring could investigate the site's hydrology, consisting of measurement of water levels, flows and chemistry across the site through time. Without a baseline, only inferences could be made about the impact of restoration, but as a rare type of wetland, data on the hydrology of the spring mounds, and their interaction with the surrounding surface water system, would be of wider scientific value. There would be technical challenges to monitoring the spring mounds. For instance, given the probably highly localised nature of the upwelling, it may not be possible to monitor this without damaging the site. The design would also need to consider the likely mobile surfaces of the spring mounds. As such, the network would need to be carefully designed by an expert in wetland hydrology and hydrogeology.

5 Conclusion

Combe Fen is one of the most extraordinary fens in Oxfordshire, with its unique spring mounds and historically rich flora of specialist fen plants.

This report has investigated the past and present biodiversity of Combe Fen, how the site has changed, and how it functions as a wetland. While fen priority habitat and a diversity of wetland species are still present, much of the site's fen and many of its special plants have been lost. This is due to succession to woodland since the 1960s.

To restore rare, species-rich fen habitat to Combe Fen will require succession to be reversed and long-term resources for management to be invested. Restoration methods have been recommended, following three steps in the restoration process. Freshwater Habitats Trust is able to support restoration with specialist technical advice.

6 References

Botanical Society of Britain and Ireland, 2024. *Oenanthe fistulosa distribution map*. [online] Available at: <https://bsbi.org/maps?taxonid=2cd4p9h.xrf> [Accessed 21 September 2024].

Druce, G.C., 1927. *The Flora of Oxfordshire*. Oxford: Clarendon Press.

European Commission: Directorate-General for Environment, Tsiripidis, I., Piernik, A., Janssen, J., Tahvanainen, T., Molina, J., del Galdo, G., Gardfjell, H., Dimopoulos, P., Šumberová, K., Acosta, A., Biurrun, I., Poulin, B., Hájek, M., Bioret, F., Essl, F., Rodwell, J., García Criado, M., Schaminée, J., Arts, G., Capelo, J., Sanders, N., Attorre, F., Tzonev, R., Mickolajczak, A., Molnár, Z., Valderrabano, M., Dengler, J., Loidi, J., Tonteri, T., Paternoster, D., Renaux, B., Haynes, T., Nieto, A., Jansen, J., Jansen, F., Chytrý, M., Ssymank, A., Bergmeier, E., Gubbay, S., Valachovič, M., Calix, M., Biţă-Nicolae, C., Toivonen, H., Kapfer, J., Landucci, F., Čarni, A., Bijlsma, R., Aronsson, M. and Gigante, D., 2016. *European red list of habitats. Part 2, Terrestrial and freshwater habitats*. Publications Office. https://doi.org/doi/10.2779/091372.

Fojt, W., 1991. *Comparative survey of rich calcareous fens of Oxfordshire. English Nature Research Report No. 139*. Peterborough.

Fojt, W.J., 1993. *Update to quick reference to fens. No 21 - English Nature Research Reports*. Peterborough.

Food and Agriculture Organisation of the United Nations, 2006. *Guidelines for Soil Description*.

Google, 2024. *Google Earth Pro*.

Killick, John., Perry, Roy. and Woodell, S.R.J.., 1998. *The flora of Oxfordshire*. Pisces Publications.

Low, R., Farr, G., Clarke, D. and Mould, D., 2018. Hydrological Assessment and Monitoring of Wetlands. In: *The Wetland Book: I: Structure and Function, Management, and Methods*. [online] Springer, Dordrecht. pp.1741–1758. https://doi.org/10.1007/978-90-481-9659-3_294.

Pilkington, S.L., Hodgetts, N.G. and Blockeel, T.L., 2023. *Interim Census Catalogue 2023*.

QGIS Development Team, 2024. *QGIS Geographic Information System*.

Rodwell, J.S., 2006. National Vegetation Classification: Users ' handbook. *Jncc*.

Sibthorp, J., 1794. *Flora Oxoniensis, exhibens plantas in agro Oxoniensi sponte crescentes, secundum systema sexuale distributas*. [online] *Flora Oxoniensis, exhibens plantas in agro Oxoniensi sponte crescentes, secundum systema sexuale distributas*. Oxford: Fletcher and Hanwell. https://doi.org/10.5962/bhl.title.114892.

Stace, C.A., 2019. *New Flora of the British Isles*. 4th ed. C&M Floristics.

Stroh, P.A., Leach, S.J., August, T.A., Walker, K.J., Pearman, D.A., Rumsey, F.J., Harrower, C.A., Fay, M.F., Martin, J.P., Pankhurst, T., Preston, C.D. and Taylor, I., 2014. *A Vascular Plant Red Data List for England*.

Toffanin, P., Leo, L. Di, Chamo, N., Farell, K., arty-aeroai, Saijin-Naib, Mather, S., Barker, B., Davis, B., Kaluza, O., bot, pyup. io, Joseph, D., IZem, A., Acuña, D., Bateman, C., Islam, T., USPLM, POULAIN, S., Mahesh, A., Machado, R.W., Ves, N., Mumby, P., Pereira, P.J., Sarıçiçek, İ., kendallaeroai, vinsonliux, w-toguchi83, mateo3d and Fitzsimmons, S., 2024. *OpenDroneMap/WebODM: 2.5.5*. https://doi.org/10.5281/zenodo.13345963.

Wheeler, B.D., Shaw, S. and Tanner, K., 2009. *A wetland framework for impact assessment at statutory sites in England and Wales*.

Appendix 1 Historic aerial photographs

Figure A1.1. Extract at 1:3,000 scale from Fairey aerial survey of 1961. Copyright Oxfordshire History Centre.

Figure A1.2. Extract at 1:3,000 scale from Astral aerial survey of 1981. This frame of the survey does not cover the whole field around Combe Fen. Modern Google Satellite image shown in area not covered. Copyright Oxfordshire History Centre.

Figure A1.3. Extract at 1:3,000 scale from Geonex aerial survey of 1991. Copyright Oxfordshire History Centre.

Appendix 2 Drone images

Figure A2.1. View south, at 45 m above ground level.

Figure A2.2. View west, at 45 m above ground level.

Figure A2.3. View north, at 45 m above ground level.

Figure A2.4. View west, at 45 m above ground level.

Figure A2.5. Vertical drone photograph at 85 m above ground level.

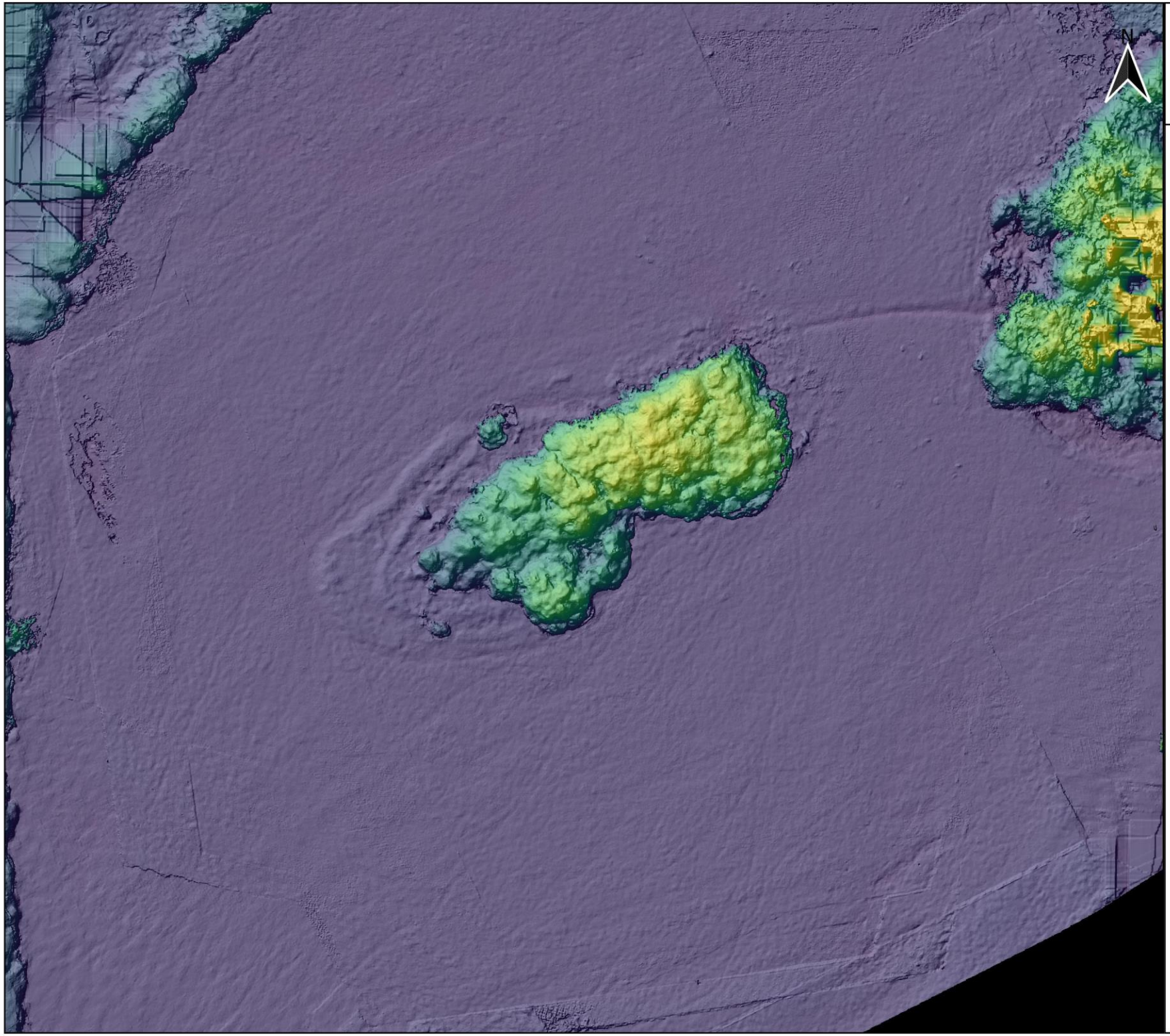


Figure A2.6.
Digital surface model generated from drone imagery

Legend

Shaded digital surface model

Elevation (m)
Datum WGS 84

90

65

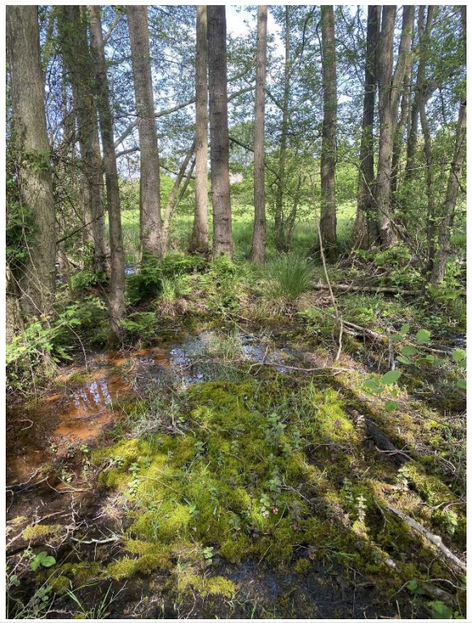
1:1,000 @A4

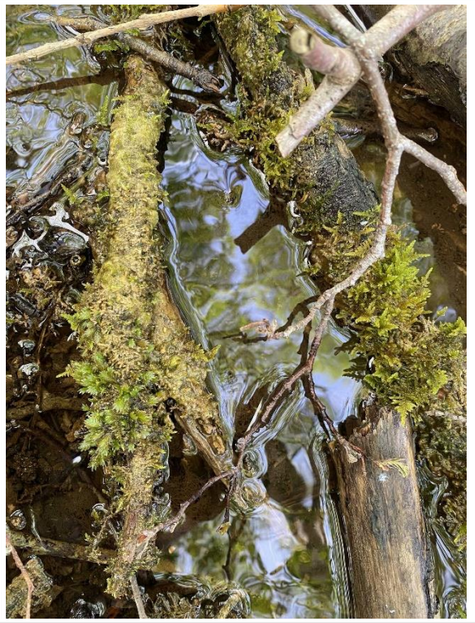
0 20 40 m

Freshwater Habitats Trust

Appendix 3 Target notes

Table A3.1 Target notes recorded. See Figure 2 for locations.

No.	Description	Photograph(s)
1	*Alnus glutinosa* woodland over top of eastern spring mound, with open field layer around pools and runnels, comprising scattered *Carex paniculata* and *Dryopteris dilatata* tussocks, and mats of *Palustriella commutata*. 17/05/2024	
2	Flow west from spring in shallow mossy runnels. Patches of *Valeriana dioica* frequent around tree bases and increasing west from here. 17/05/2024	 

No.	Description	Photograph(s)
3	Water flowing around north and south side of narrow central area of young *Alnus* trees, forming pools and runnels among roots, with abundant brown mosses and tufa. Second photo shows *Fissidens adianthoides* (left) and *Palustriella commutata* (right). 17/05/2024	 
4	Flow accumulation on south side of central area, dominated by *Glyceria notata*. 17/05/2024	

No.	Description	Photograph(s)
5	Wet ground around living and dead *Carex paniculata* tussocks supports flora with abundant brown mosses, *Valeriana dioica* and at least two colonies of *Hydrocotyle vulgaris* (second image). Canopy becomes lighter, with younger *Alnus* trees than to east. 17/05/2024	 
6	Abundant brown mosses growing over debris in runnels. Abundant *Fissidens adianthoides* and *Palustriella commutata*. One small patch of *Campylium protensum* found. Marked 16/08/2024.	

No.	Description	Photograph(s)
7	*Hydrocotyle vulgaris* growing on dead *Carex paniculata* tussocks. Marked 16/08/2024.	
8	Young stand of *Alnus* around western spring, with abundant *Carex paniculata.* 17/05/2024	

No.	Description	Photograph(s)
9	Area of deeper water accumulation and loose sediment, with unstable *Carex paniculata* tussocks. 17/05/2024	
10	*Carex acutiformis* dominated fen at open, western end of site. 17/05/2024	

No.	Description	Photograph(s)
11	Young stand of *Alnus* over western spring. 17/05/2024	
12	Compared to rest of site, small area of more species-rich fen, with *Carex panicea, Galium uliginosum, Succisa pratensis* and *Valeriana dioica*. Marked 16/08/2024.	

No.	Description	Photograph(s)
13	*Hydrocotyle vulgaris* growing on tree bases, old tussocks and dead wood at edge of trees. One plant of *Succisa pratensis.* Marked 16/08/2024.	
14	One plant of *Succisa pratensis* at edge of *Alnus* and *Rosa* scrub. Marked 16/08/2024.	

No.	Description	Photograph(s)
15	View from top of embankment. Abrupt transition from *Carex acutiformis* dominated fen to grassland, with scattered *Carex paniculata* tussocks behind. 17/05/2024	
16	*Carex paniculata* dominated fen behind embankment. 17/05/2024	

No.	Description	Photograph(s)
17	*Carex acutiformis* fen and pasture edge, along north side of site. 17/05/2024	
18	*Carex acutiformis* and *C. riparia* dominated fen along north side of site. Area in foreground where water accumulates dominated by *Glyceria notata.* 17/05/2024	

No.	Description	Photograph(s)
19	Area where water flowing off spring to south-west accumulates behind ditch bank, dominated by *Glyceria notata*. Stand of *Urtica dioica* in middle of view is on raised bank above ditch along northern boundary of site. 17/05/2024	
20	View along ditch. Bank to right of image has pipe draining water accumulating above bank into ditch. 17/05/2024	

No.	Description	Photograph(s)
21	Pipe under ditch bank, water seemed to be flowing out of this on 17/05/2024 (left). On 16/08/24 water was draining into it (right). 17/05/2024	 
22	Ditch along northern boundary of site, with abundant *Glyceria notata.* 17/05/2024	

No.	Description	Photograph(s)
23	Outflow of spring mound, with iron-rich water falling over series of low cascades and pools formed of twigs and *Palustriella commutata.* 17/05/2024	
24	Runnel off spring mound, with dipwell and gauge board. Some flow from the western spring mound flows along a channel to this point, from the right of the image. The ditch along the northern boundary of the site also flows to this point. 17/05/2024	

No.	Description	Photograph(s)
25	Area where boundary ditches meet and drain into pipe to the River Evenlode. 17/05/2024	
26	View along dry ditch channel toward the River Evenlode. 17/05/2024	

No.	Description	Photograph(s)
27	Bare ground under trees where sheep shelter. 17/05/2024	
28	Stand of *Carex acutiformis* extending from ditch into pasture. 17/05/2024	

No.	Description	Photograph(s)
29	Vegetation along ditch, dominated by *Juncus effusus*, *Juncus inflexus*, *Glyceria*, *Mentha* etc. 17/05/2024	
30	View along dry ditch toward site, with mature *Alnus* canopy over eastern spring mound. 17/05/2024	

No.	Description	Photograph(s)
31	Pipe discharging flow from site into River Evenlode. 17/05/2024	

Appendix 4 Botanical records

Table A4.1 Plants recorded from Combe Fen, historically and during visits in 2024.

Scientific name	Common name	Conservation status	Fen species	Present 2024	Year of last record
Liverworts					
Lophocolea bidentata	Bifid Crestwort	-	-	✓	-
Pellia endiviifolia	Endive Pellia	-	Principal	✓	2016
Mosses					
Brachythecium rivulare	River Feathermoss	-	-	✓	-
Brachythecium rutabulum	Rough-stalked Feathermoss	-	-	✓	-
Bryum pseudotriquetrum	Marsh Bryum	-	Principal	✓	-
Calliergonella cuspidata	Pointed Spearmoss	-	Principal	✓	2016
Campylium protensum	Dull Starry Feathermoss	-	Principal	✓	-
Cratoneuron filicinum	Fern-leaved Hookmoss	-	-	✓	-
Fissidens adianthoides	Maidenhair Pocketmoss	-	Principal	✓	2016
Kindbergia praelonga	Common Feathermoss	-	-	✓	-
Leptodictyum riparium	Kneiff's Feathermoss	-	-	✓	-
Mnium hornum	Swan's-neck Thyme-moss	-	-	✓	2016
Palustriella commutata	Curled Hookmoss	-	Rare	✓	2016
Rhizomnium punctatum	Dotted Thyme-moss	-	-	✓	-
Thuidium tamariscinum	Common Tamarisk-moss	-	-	✓	-
Ferns and horsetails					
Athyrium filix-femina	Lady-fern	-	-	✓	2016
Dryopteris dilatata	Broad Buckler-fern	-	-	✓	2016
Dryopteris filix-mas	Male Fern	-	-	✓	-
Equisetum arvense	Field Horsetail	-	-	✓	2016

Scientific name	Common name	Conservation status	Fen species	Present 2024	Year of last record
Equisetum fluviatile	Water Horsetail	-	Principal	✓	2016
Equisetum palustre	Marsh Horsetail	-	Principal	✓	2016
		Flowering plants			
Achillea millefolium	Yarrow	-	-	-	2015
Aegopodium podagraria	Ground-elder	-	-	-	1979
Agrostis stolonifera	Creeping Bent	-	-	✓	2016
Ajuga reptans	Bugle	-	-	✓	2016
Alnus glutinosa	Alder	-	-	✓	2016
Alopecurus geniculatus	Marsh Foxtail	-	-	-	2016
Alopecurus pratensis	Meadow Foxtail	-	-	-	2016
Angelica sylvestris	Wild Angelica	-	Principal	✓	2016
Anthriscus sylvestris	Cow Parsley	-	-	-	2015
Arrhenatherum elatius	False Oat-grass	-	-	-	2016
Bellis perennis	Daisy	-	-	-	1984
Berula erecta	Lesser Water-parsnip	-	-	✓	-
Brachypodium sylvaticum	False Brome	-	-	✓	-
Briza media	Quaking-grass	England Near Threatened	-	-	2016
Bromus hordeaceus	Soft-brome	-	-	-	2016
Bromus racemosus	Smooth Brome	-	-	✓	-
Caltha palustris	Marsh-marigold	-	Principal	✓	2016
Calystegia sepium	Hedge Bindweed	-	-	-	2016
Cardamine flexuosa	Wavy Bitter-cress	-	-	-	2016
Cardamine pratensis	Cuckooflower	-	-	-	2015
Carduus crispus	Welted Thistle	-	-	-	1984
Carex acuta	Slender Tufted-sedge	-	Rare	-	1983

Scientific name	Common name	Conservation status	Fen species	Present 2024	Year of last record
Carex acutiformis	Lesser Pond-sedge	-	Principal	✓	2016
Carex disticha	Brown Sedge	-	Principal	✓	2016
Carex echinata	Star Sedge	England Near Threatened, Oxon Rare	Principal	-	1984
Carex flacca	Glaucous Sedge	-	-	-	2015
Carex hirta	Hairy Sedge	-	-	✓	2016
Carex nigra	Common Sedge	-	Principal	✓	1984
Carex panicea	Carnation Sedge	-	Principal	✓	2015
Carex paniculata	Greater Tussock-sedge	-	Principal	✓	2016
Carex riparia	Greater Pond-sedge	-	Principal	✓	2016
Carex sylvatica	Wood-sedge	-	-	✓	2016
Cerastium fontanum	Common Mouse-ear	-	-	-	2016
Circaea lutetiana	Enchanter's-nightshade	-	-	✓	2016
Cirsium arvense	Creeping Thistle	-	-	-	2016
Cirsium palustre	Marsh Thistle	-	Principal	✓	2016
Cirsium vulgare	Spear Thistle	-	-	-	1984
Clematis vitalba	Traveller's-joy	-	-	-	2016
Crataegus monogyna	Hawthorn	-	-	✓	2015
Dactylis glomerata	Cock's-foot	-	-	✓	2016
Dactylorhiza fuchsii	Common Spotted-orchid	-	Principal	-	2016
Dactylorhiza fuchsii x praetermissa = D. x grandis	-	-	-	-	1983
Dactylorhiza incarnata x praetermissa = D. x wintoni	-	-	-	-	1983
Dactylorhiza incarnata	Early Marsh-orchid	-	Principal	-	1984
Dactylorhiza praetermissa	Southern Marsh-orchid	-	Principal	-	2015

Scientific name	Common name	Conservation status	Fen species	Present 2024	Year of last record
Deschampsia cespitosa	Tufted Hair-grass	-	-	✓	2016
Eleocharis palustris	Common Spike-rush	-	Principal	✓	2016
Epilobium hirsutum	Great Willowherb	-	Principal	✓	2016
Epilobium parviflorum	Hoary Willowherb	-	Principal	✓	2016
Epipactis palustris	Marsh Helleborine	England Near Threatened, Oxon Scarce	Rare	-	1833
Eriophorum angustifolium	Common Cottongrass	England Vulnerable, Oxon Scarce	Principal	-	1984
Euonymus europaeus	Spindle	-	-	-	2016
Eupatorium cannabinum	Hemp-agrimony	-	Principal	-	1984
Festuca rubra	Red Fescue	-	-	✓	2016
Ficaria verna	Lesser Celandine	-	-	✓	-
Filipendula ulmaria	Meadowsweet	-	Principal	✓	2016
Fraxinus excelsior	Ash	-	-	✓	2016
Galium album	Hedge Bedstraw	-	-	✓	-
Galium aparine	Cleavers	-	-	✓	2015
Galium palustre	Marsh-bedstraw	-	Principal	-	2016
Galium uliginosum	Fen Bedstraw	-	Principal	✓	2016
Geranium dissectum	Cut-leaved Crane's-bill	-	-	-	2016
Geum urbanum	Wood Avens	-	-	✓	2016
Glyceria fluitans	Floating Sweet-grass	-	-	-	2016
Glyceria maxima	Reed Sweet-grass	-	Principal	-	2015
Glyceria notata	Plicate Sweet-grass	-	Principal	✓	-
Helosciadium nodiflorum	Fool's-water-cress	-	-	-	2016
Heracleum sphondylium	Hogweed	-	-	-	2016
Holcus lanatus	Yorkshire-fog	-	-	✓	2016

Scientific name	Common name	Conservation status	Fen species	Present 2024	Year of last record
Hydrocotyle vulgaris	Marsh Pennywort	England Near Threatened, Oxon Scarce	Principal	✓	2016
Hypericum hirsutum	Hairy St John's-wort	-	-	-	2016
Hypericum tetrapterum	Square-stalked St John's-wort	-	Principal	✓	2016
Juncus acutiflorus	Sharp-flowered Rush	-	Principal	✓	1990
Juncus articulatus	Jointed Rush	-	Principal	✓	2016
Juncus effusus	Soft-rush	-	Principal	✓	2016
Juncus inflexus	Hard Rush	-	-	✓	2016
Lathyrus pratensis	Meadow Vetchling	-	-	✓	2016
Lotus pedunculatus	Greater Bird's-foot-trefoil	-	Principal	✓	2016
Lycopus europaeus	Gypsywort	-	Principal	✓	2016
Lysimachia nummularia	Creeping-Jenny	-	-	-	2016
Lysimachia tenella	Bog Pimpernel	Oxon Scarce	Principal	-	1984
Lysimachia vulgaris	Yellow Loosestrife	-	Principal	-	1984
Lythrum salicaria	Purple-loosestrife	-	Principal	✓	2016
Medicago lupulina	Black Medick	-	-	-	2016
Mentha aquatica	Water Mint	-	Principal	✓	2016
Myosotis laxa	Tufted Forget-me-not	-	Principal	-	2016
Myosotis scorpioides	Water Forget-me-not	-	Principal	-	2016
Myosoton aquaticum	Water Chickweed	-	-	-	1984
Oenanthe fistulosa	Tubular Water-dropwort	Section 41, England Vulnerable, Great Britain Vulnerable	Principal	-	2016
Phalaris arundinacea	Reed Canary-grass	-	Principal	✓	2016
Phleum bertolonii	Smaller Cat's-tail	-	-	-	2016
Phleum pratense	Timothy	-	-	-	2016

Scientific name	Common name	Conservation status	Fen species	Present 2024	Year of last record
Pinguicula vulgaris	Common Butterwort	England Vulnerable, Oxon Rare	Rare	-	1984
Plantago major	Greater Plantain	-	-	-	1984
Poa trivialis	Rough Meadow-grass	-	-	✓	2016
Potentilla anserina	Silverweed	-	-	-	1984
Potentilla reptans	Creeping Cinquefoil	-	-	✓	2016
Prunella vulgaris	Selfheal	-	-	-	2016
Prunus spinosa	Blackthorn	-	-	✓	-
Ranunculus acris	Meadow Buttercup	-	-	✓	2016
Ranunculus repens	Creeping Buttercup	-	-	-	2016
Rorippa nasturtium-aquaticum	Water-cress	-	-	-	2016
Rosa corymbifera	Hairy Dog-rose	-	-	✓	-
Rosa squarrosa	Glandular Dog-rose	-	-	✓	-
Rubus fruticosus agg.	Bramble	-	-	-	2016
Rubus idaeus	Raspberry	-	-	-	1979
Rubus ulmifolius	Elm-leaved Bramble	-	-	✓	-
Rubus vestitus	A Bramble	-	-	✓	-
Rumex acetosa	Common Sorrel	-	-	-	1984
Rumex conglomeratus	Clustered Dock	-	-	-	2015
Rumex crispus	Curled Dock	-	-	-	2016
Rumex obtusifolius	Broad-leaved Dock	-	-	-	2016
Rumex sanguineus	Wood Dock	-	-	✓	2016
Sagina nodosa	Knotted Pearlwort	England Vulnerable, Oxon Extinct	Rare	-	1984
Sambucus nigra	Elder	-	-	✓	2016
Sanguisorba officinalis	Great Burnet	-	-	-	1979

Scientific name	Common name	Conservation status	Fen species	Present 2024	Year of last record
Schedonorus giganteus	Giant Fescue	-	-	✓	-
Schoenoplectus lacustris	Common Club-rush	-	-	-	2016
Scrophularia auriculata	Water Figwort	-	Principal	✓	2016
Scutellaria galericulata	Skullcap	-	Principal	-	2016
Silene flos-cuculi	Ragged-Robin	England Near Threatened	Principal	✓	2016
Silene latifolia	White Campion	-	-	-	2016
Solanum dulcamara	Bittersweet	-	-	✓	2016
Sonchus oleraceus	Smooth Sow-thistle	-	-	-	2016
Sparganium erectum	Branched Bur-reed	-	Principal	✓	2016
Stachys palustris	Marsh Woundwort	-	-	✓	-
Stachys sylvatica	Hedge Woundwort	-	-	✓	2016
Stellaria graminea	Lesser Stitchwort	-	-	-	1984
Succisa pratensis	Devil's-bit Scabious	England Near Threatened	-	✓	2016
Symphytum asperum x officinale = S. x uplandicum	Russian Comfrey	-	-	✓	-
Symphytum officinale	Common Comfrey	-	Principal	-	2016
Taraxacum agg.	Dandelion	-	-	-	2016
Trifolium repens	White Clover	-	-	✓	2016
Triglochin palustris	Marsh Arrowgrass	England Near Threatened	Principal	-	1984
Urtica dioica	Common Nettle	-	-	✓	2016
Valeriana dioica	Marsh Valerian	England Near Threatened	Principal	✓	2016
Veronica anagallis-aquatica	Blue Water-Speedwell	-	-	-	2016
Veronica beccabunga	Brooklime	-	-	✓	2016
Viburnum opulus	Guelder-rose	-	-	✓	2016
Vicia cracca	Tufted Vetch	-	-	✓	2016

Appendix 5 Borehole logs

Figure A5.1. BGS borehole scan SP41SW21

SP 41 SW 21 4084 1483 Brook Hill Combe Block G

Surface level (+71.0 m) +236 ft
Water struck at +68.8 m
Shell and auger (modified) 6 in (152 mm) diameter
April 1971

Overburden 3.1 m (10.0 ft)
Mineral 1.9 m (6.0 ft)
Bedrock 0.2 m+ (0.5 ft+)

LOG

Geological Classification	Lithology	Thickness m	(ft)	Depth m	(ft)
	Soil, silty and clayey	0.2	(0.5)	0.2	(0.5)
Alluvium	Clay, silty, light brown, blue near base	2.4	(8.0)	2.6	(8.5)
	Peat, brownish black, with plant remains	0.5	(1.5)	3.1	(10.0)
First Terrace Deposits	Gravel Gravel: fine to coarse limestone with some quartz Sand: medium to coarse	1.9	(6.0)	5.0	(16.5)
Taynton Stone	Limestone, oolitic, buff	0.2+	(0.5+)	5.2	(17.0)

GRADING

Mean for Deposit

	%	mm	%
Gravel	64	+16	17
		-16 + 4	47
Sand	33	-4 + 1	21
		-1 + ¼	9
		-¼ + 1/16	3
Fines	3	-1/16	3

Bulk Samples

Depth below surface (m)	Percentages Fines	Sand	Gravel
3.1 - 4.1	1	28	71
4.1 - 5.0	5	39	56

64

Figure A5.2. Borehole log for groundwater monitoring well installed by Blenheim Estate August 2024.

Groundwater Monitoring and Drilling Ltd	**BOREHOLE LOG**	**BOREHOLE No** BP1 **Sheet** 1 of 2
Equipment & Methods Cable Percussion, u4 coring/bag samples		**Location** Horns Lane Combe Witney OX29
Water level Gravel aquifer struck at 0.92 m BGL Oolite aquifer struck at 4.25m BGL. Rose to 1.6m after gravel aquifer sealed of from casing. Rest wl 0.92m BGL		**Grid Ref** **Ground level** **Datum level**
Carried out for Dave Gasca	**Date** 20/8/24	**Ground level**

Description	Thickness (m)	Depth (m)	Reduced Level
Brown soft Clay	0.5	0.5	
Sandy Gravel	1.0	1.5	
Coarse Gravel and Sand	2.5	4.0	
Oolite Limestone	1.0	5.0	

Groundwater Monitoring and Drilling Ltd	**BOREHOLE LOG**	**BOREHOLE No** BP 1 **Sheet** 2 of 2

Completion (m)		
Bentonite	0.70	
Pack – 3 - 5 mm	2.0	
32 mm OD x 25 mm ID HDPE plain casing	1.0	
32 mm OD x 25 mm ID HDPE 0.3 mm slotted screen	4.0	

Appendix 6 Augering results

Core ref.	C1		
Date	16/08/2024		
Grid reference	SP 40924 14965	**Location**	Top of spring mound in woodland, under a mat of *Palustriella commutata*
Resting water level (cmbgl)	0		
Stratigraphy	0-7 cmbgl no recovery. 7-24 cmbgl PEAT H8 black, sloppy, abundant modern twigs. 24-87 cmbgl PEAT H6 abundant *Carex* rhizomes and fibres, a little wood toward bottom. 87-105 sandy clay LOAM with wood and *Equisetum* rhizomes, round medium flint gravel and angular flattened limestone coarse gravel, matrix a dark buff colour with plastic grainy texture. Well preserved brown moss remains toward base of peat column, with abundant, readily identifiable stems of *Scorpidium cossonii*, and few *S. scorpioides.*		

C1 Photo. no.	**Photo. (top of core to right)**
1	

C1 Photo. no.	Photo. (top of core to right)
2	
3	

C1 Photo. no.	Photo. (top of core to right)
4	
5	

Core ref.	C2		
Date	16/08/2024		
Grid **reference**	SP 40895 14969	**Location**	North side, on bank above ditch and pipe.
Resting water level (cmbgl)	NA		
Stratigraphy	0-19 cmbgl clay LOAM, dark. 19-88 cmbgl silty CLAY, orange-brown matrix colour, homogenous buttery highly plastic texture, few medium gravels, evidence of seasonal surface gleying at top, but no gley mottles below really. 88-90 cmbgl poor recovery, seems to be onto limestone gravels.		

C2 Photo. no.	**Photo (top of core to right)**
1	
2	

C2 Photo. no.	Photo (top of core to right)
3	

Core ref.	C3		
Date	16/08/2024		
Grid **reference**	SP 40884 14948	**Location**	Top of western spring mound.
Resting water level (cmbgl)	30		
Stratigraphy	0-56 cmbgl PEAT H4, firm but very coarse organic material, hardly decomposed. 56-120 cmbgl PEAT H9, sloppy. 120-130 cmbgl SAND grey-brown with abundant very fine whitish fragments, few medium limestone gravels. Couldn't penetrate further with Russian auger.		

C3 Photo. no.	**Photo. (top of core to right)**
1	
2	

C3 Photo. no.	Photo. (top of core to right)
3	
4	

C3 Photo. no.	Photo. (top of core to right)
5