Farm Ecological Score Protocol Master Copy

2022-23

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Introduction

This document sets out the chosen metrics, data sources, measurement protocol and the end-to-end process of generating an ecological farm score for the first pilot farms in the Phase 1 project. This information is intended for the Soil Association only, as a standalone document to provide a complete outline of the ecological farm score. In the following sections we set out the following:

- A summary of the metrics chosen for the ecological farm score
- A summary of the data sources for all metrics, and licensing where applicable.
- An overview of the step by step process to build an ecological farm score for a single farm
- A detailed description of each individual metric, including methods, data sources, scoring rules and reference to any relevant industry standards.
- A summary of stratification methods for sampling soils, water and biodiversity within a farm

SA Exchange Metrics: Summary

HEALTHY SOILS	
Soil structure	VESS test
Soil life	Earthworm count
Soil chemistry	pH test
Soil Physical Status	Bulk density
Soil Organic Matter	Dry combustion survey
WATER	
Surface Runoff Avoidance	Survey NCR modelling
Nutrient runoff & turbidity	Nitrate & Phosphate concentration in water bodies and turbidity
Nutrient balance	Farm gate nutrient balance - Farmscoper Tool
Water Usage	Survey NCR modelling
BIODIVERSITY	
Woodland Connectivity	NCR modelling
Landcover	NCR modelling
Birds	Bird count
Insect	Pan traps
Flora	Grassland & arable species count Hedgerow
Biodiversity Practice Score	Survey
CLIMATE CHANGE	
GHG Emissions	Farm Carbon Tool
GHG Stock and Sequestration	NCR modelling
SOCIAL	
Land access	Open source data

Summary data sources table

Table 1: Summary of datasets used to model metrics and those relevant for mapping. Datasets and literature used to establish benchmarks are given in the Protocol Mastercopy text.

Category	Usage	Datasource	Accessibility	URL
Metrics				
Carbon	Carbon storage and sequestration	NCR Natcap Map	Licensed from NCR	
Soil	Zonation – Parent material and soil texture	British Geological Survey	Publicly available	https://www.bgs.ac.uk/datasets/soil-parent-material-model/
	Zonation – Landcover	NCR Natcap Map	Licensed from NCR	
Water	Scoring – Water connectivity	NCR, derived from Open Source DEM	Licensed from NCR	
	Scoring – Resource availability	Environment Agency 2015 (England)	Publicly available	https://data.gov.uk/dataset/b1f5c467-ed41-4e8f-89d7-f79a76645fd6/water-resource-availability-and-abstraction-reliability-cycle-2#licence-info
		Natural Resources Wales 2015 (Wales)	Publicly available	http://lle.gov.wales/catalogue/item/WaterResourceReliabilityData
		SEPA Water Scarcity 2020 (Scotland)	Dataset will be handed over	https://www.crew.ac.uk/sites/www.crew.ac.uk/files/news/Water%20Scarcity%20-%20An%20Emerging%20Issue%20in%20Scotland%20%5BBLOG%5D.pdf
	Scoring – WFD status	Environment Agency (England)	Publicly available	https://data.gov.uk/dataset/2a74cf2e-560a-4408-a762-

				cad0e06c9d3f/wfd-groundwater-bodies-cycle-2
		Natural Resources Wales (Wales)	Publicly available	https://lle.gov.wales/catalogue/item/WaterFrameworkDirectiveWFDGroundwaterBodiesCycle2/?lang=en
Biodiversity	Woodland connectivity	NCR Natcap Map	Licensed from NCR	
	Grassland and arable flora - list of common species	UK Habitat Classification Working Group (2018)	Publicly available	https://ecountability.co.uk/wp-content/uploads/2018/05/UK-Habitat-Classification-Habitat-Definitions-V1.0-May-2018-1.pdf
Social	Land access	OpenStreetMap – Scotland Rights of Way (if not assuming public right of roam as per Land Reform Act 2003)	Publicly available	https://download.geofabrik.de/europe/great-britain/scotland.html
		Ordnance Survey – Public Rights of Way	Publicly available	https://www.rowmaps.com/kmls
Mapping				
Landcover		NCR Natcap Map	Licensed from NCR	
NRFA Catchment data		NRFA CEH	Publicly available	https://nrfa.ceh.ac.uk/data/search
Waterbodies		OS Surface water	Publicly available	https://www.ordnancesurvey.co.uk/business-government/products/open-map-rivers
Field boundaries (England)		RPA	Privately owned	https://environment.data.gov.uk/rpa

End-to-End process

The table below details the steps required to conduct a full survey for a single farm.

Steps	Details	Section	Data layer sources	Link
Pre-farm visit				
Send initial survey				
Receive shapefile of RPA boundaries				
Zonation				
Gather data	Farm boundaries – 'Land parcel' shapefile from RPA		Rural Payments Agency (**private**)	https://environment.data.gov.uk/rpa
	Landcover clipped to farm boundary		NCR Landcover (**licensed from NCR**)	
	Parent material and soil texture data downloaded		British Geological Survey (**public**)	https://www.bgs.ac.uk/datasets/soil-parent-material-model/
Zonation				
Create clusters	Step 1 in zonation procedure	6.1		
Data preparation - remove unnecessary land covers	All landcovers except for arable and grassland types are removed			
Run zonation plugin (Attribute Based Clustering) for each farm	Step 2 in zonation procedure		QGIS plugin (**public**)	https://github.com/eduard-kazakov/attributeBasedClustering
Post-zonation				
Removal of minor zones from sampling consideration	Any zone less than 2 hectares	6.1		
Select fields within remaining zones for sampling	Fields ranked by area; highest area = highest priority of sampling within that zone			
Send big survey				
Map-making				
Platform report (condensed)	This is the NCR NatCap Map, in a condensed form		NCR NatCap Map (**licensed from NCR**)	
Landcover map (all field IDs)	Using NCR Landcover layer (licensed from NCR)		NCR Landcover layer (**licensed from NCR**)	
Sampling fields map	What3words is provided for the sampling fields		What3words plugin (**public**)	https://developer.what3words.com/tools/gis-extensions/qgis
Fields for soil sampling	Fields ranked by area; Highest area = highest priority of sampling within that zone.			

		Fields for biodiversity sampling	Field selection based upon: (1) Presence of hedgerows; (2) Landcover type (as detected from open source data) – we sought to get samples from a spread of landcover types, including arable and grassland; (3) Location (situating all sampling areas within one section of the farm was avoided), (4) Prior sampling (maximise efficiency).	6.3		
	Woodlands sampling map		What3words is provided for the sampling woodlands		What3words (**public**)	
		Select woodlands for biodiversity sampling	Woodland selection based upon: (1) Size of woodlands – larger size is prioritised (2) A minimum of 2 woodland patches are chosen for sampling	6.3		
	Waterbodies map		What3words is provided for the sampling waterbodies		What3words (**public**)	
		Catchments identified	If waterbodies are in separate catchments, this is pointed out		Catchment layer from NRFA CEH (**public**)	https://nrfa.ceh.ac.uk/data/search
		Waterbodies identified	Waterbodies mapped		OS Surface water (**public**)	https://www.ordnancesurvey.co.uk/business-government/products/open-map-rivers
	Zone map (with all field IDs)		Field IDs are the 'parcel IDs' given in the SBI 'land parcels' shapefile			
Create farm-specific Data Collection spreadsheet						
Name farm-specific Supplementary Survey spreadsheet						
Farm visit						
Check zonation: ask management Qs						
Check waterbodies: ask management Qs				6.2		
Data collection (including farmscoper Qs)						
Survey (& Supplementary sheet) completed with farmer						
Carbon calculator completed with farmer						
Post-farm visit						
Data analysis						
	Soil					
		VESS	Data collected in field	1.1		
		Earthworms	Data collected in field	1.2		

		pH	Data collected in field, processed in lab	1.3		
		Bulk density	Data collected in field, processed in lab	1.4		
		SOM	Data collected in field, processed in lab	1.5		
		Carbon stock	Processing step Metric: Total and average carbon stock			
	Water		SRA = Surface Runoff Avoidance NB = Nutrient Balance WU = Water Usage			
		SRA – Connectivity index		2.1	**Licensed from NCR**	
		SRA – VESS	Data collected in the field			
		SRA – Flood mitigation survey	Data collected in survey			
		SRA – Combine scores & needs	Processing step - see scoring guidelines			
		NB – Water samples of nutrient concentration	Data collected in field	2.2		
		NB – Nutrient balance	Data from survey inputted into Farmscoper	2.3	Farmscoper (decision support tool) (**public**)	https://adas.co.uk/services/farmscoper/
		WU – Resource availability	Measure of resource availability	2.4	England – Environment Agency 2015 (**public**)	https://data.gov.uk/dataset/b1f5c467-ed41-4e8f-89d7-f79a76645fd6/water-resource-availability-and-abstraction-reliability-cycle-2#licence-info
					Wales – Natural Resources Wales 2015 (**public**)	http://lle.gov.wales/catalogue/item/WaterResourceReliabilityData
					Scotland – SEPA Water Scarcity 2020 (**public**)	https://www.crew.ac.uk/sites/www.crew.ac.uk/files/news/Water%20Scarcity%20-%20An%20Emerging%20Issue%20in%20Scotland%20%5BBLOG%5D.pdf
		WU – WFD status	WFD Groundwater quantitative status		England – Environment Agency (**public**)	https://data.gov.uk/dataset/2a74cf2e-560a-4408-a762-cad0e06c9d3f/wfd-groundwater-bodies-cycle-2
					Wales – Natural Resources Wales (**public**)	https://lle.gov.wales/catalogue/item/WaterFrameworkDirectiveWFDGroundwaterBodiesCycle2/?lang=en
		WU – Survey	Data from survey			

		WU – Combine score & need	Processing step - see scoring guidelines			
	Biodiversity					
		Connectivity	Connectivity map of native woodlands	3.1	NCR NatCap Map (**Licensed from NCR**)	
		Landcover - Farmed vs non-farmed ratio	Ratio of farmed to non-farmed land based on the NCR landcover map	3.2	NCR NatCap Map (**Licensed from NCR**)	
		Birds	Data collected in field	3.3		
		Insects	Data collected in field	3.4		
		Hedgerows	Data collected in field	3.5		
		Plants	Data collected in field			
		Biodiversity practice score	Data collected in field	3.6		
	Carbon					
		GHG emissions	Farm Carbon Toolkit – not scored	4.1		
		Carbon storage	Metrics: Total (tCO2e), Average (tCO2e/ha) Landcover: Trees in woodlands and forests; Trees and vegetation outside woodlands	4.2	NCR Natcap Map (**Licensed from NCR**)	
		Carbon sequestration	Metrics: Total (tCO2e), Average (tCO2e/ha/yr) Landcover: Trees in woodlands and forests; Trees and vegetation outside woodlands		NCR Natcap Map (**Licensed from NCR**)	
	Social					
		Publicly accessible paths on land		5.1	Scotland – OpenStreetMap Rights of Way (**public**)	https://download.geofabrik.de/europe/great-britain/scotland.html
					England – Ordnance Survey Public Rights of Way (**public**)	https://www.rowmaps.com/kmls
Presentation of data						

SA Exchange Metrics: Measurement protocol

1. Healthy Soils

1.1 Soil Structure – VESS

<table>
<tr><th>Data source</th><th>Literature</th></tr>
<tr><td>Field collected – VESS test</td><td>

Soil function: Soil structure regulates flow of air and water into the soil which are essential for plant growth, root penetration, drainage and to reduce soil erosion and surface run-off.
Assessment: Soil structure is usually assessed by visual evaluation (VESS) for structure quality, aggregate size and appearance of crumb.
Scoring (AHDB, 2018a)

<table>
<tr><th>Assessment</th><th>Score</th></tr>
<tr><td>Crumbly (aggregates readily crumble with fingers)</td><td>5</td></tr>
<tr><td>Intact (aggregates easily break apart)</td><td>4</td></tr>
<tr><td>Firm (most aggregates break down)</td><td>3</td></tr>
<tr><td>Compact (effort needed to break down aggregates)</td><td>2</td></tr>
<tr><td>Very compact (aggregates are compact, difficult to pull apart and platy)</td><td>1</td></tr>
</table>
(The VESS score chart gives reverse scoring – i.e. Score of 1 for ‘Crumbly’. However, to maintain consistency with other metrics’ scoring systems, this has been reversed. Data will still be collected in alignment with VESS Scoring chart, and reversed during data processing).
VESS scores for zones within a farm were assigned from the representative fields sampled within each of these zones.
</td></tr>
</table>

1.2 Soil Life – Earthworms

Data source	Literature
Field collected – Earthworm count	***Soil function***: Earthworms help drainage, improve soil structure, redistribute organic materials, increase nutrient availability and increase soil penetrability. A healthy population of earthworms is a good indicator of optimum soil conditions for plant growth. ***Assessment***: Dig a soil pit of 20 cm x 20 cm x 20 and place the soil on the mat. Collect the earthworms by sorting through the soil. Once the soil has been sorted, count and record the total number of earthworms by species: epigeic (surface/litter dwelling), endogeic (shallow, mineral soil dwelling) or anecic (dwelling in deep vertical soil burrows) (AHDB, 2018b; Stroud, 2019). If individual species can not be identified, please just provide the total worm count. ***Scoring***: AHDB (2018) report proposed two sets of scores ranging from 1 to 3 based on land use (arable and grassland). Score range was modified as 1 to 5 by creating subcategories for score 1 and 3 by calculating the difference in score categories of 1 to 2 and 2 to 3 of AHDB scores. For grass, earthworm species counts were also considered in scoring (AHDB, 2018d).

Score	Arable	Grassland
5	>12	>45 (3 or more species)
4	9-12	31-45 (3 or more species)
3	5-8	16-30 (1-2 species)
2	4-2	<15 (1 species)
1	<2	<5 (1 species)

Earthworm scores for zones within a farm were assigned from the representative fields sampled within each of these zones.

1.3 Soil Chemistry – pH

Data source	Literature
Field collected (and by laboratory analysis)	***Soil function*:** Soil pH measures acidic, neutral or alkaline nature of the soil. pH also determines the forms and availability of essential nutrients (phosphorus) for plant growth and degree of toxicity of some trace elements (zinc, copper) for some plants. ***Measurement*:** Soil pH is measured by soil sampling (see sampling and stratification for more details) and analysis of the samples at the laboratory (AHDB, 2019). Measurements undergoing laboratory analysis (pH, bulk density, and SOM) are derived from a 30cm depth of soil sample for ease of collection. There is no considerable difference in pH within the rooting or tillage zones. Variability in pH in surface soils depends on how ‘surface soil’ is interpreted (0-15cm or 0-30 cm), land use, land cover, and land management. For annual grasslands, 0-15cm is often recommended; for croplands and woodlands, 0-30cm is acceptable; however for other kinds of management (especially when root crops are included in the rotation) 0-15cm may not be reliable (Reeves and Liebig, 2016; Zhang et al., 2017). For pragmatism, a single depth for all land management types is used in this method.
	***Laboratory Analysis*:** Soil pH is measured in water (1: 2.5 soil to water) (PAAG, 2008) ***Scoring*:** AHDB (2018) report proposed six sets of scores ranging from 1 to 3 based on region (England & Wales and Scotland), land use (arable and grassland) and soil type (mineral and peat soils). This score range was extended from 1 to 5 by creating subcategories for score 1 and 3 by calculating the difference in score categories of 1 to 2 and 2 to 3 of AHDB scores (AHDB, 2018d). Mineral soils are classified as <10% organic matter, whereas peaty soils are >20% organic matter (AHDB, 2019).

Arable crops						
Score		**5**	**4**	**3**	**2**	**1**
England, Wales	Mineral soils	7-7.5	6.5-7.0	5.5-6.5 & 7.5-8.0	5.0-5.5 & 8.0-8.5	<5.0 & >8.5
	Peat soils	6.3-6.8	5.8-6.3	4.8-5.8 & 6.8-7.3	4.3-4.8 & 7.3-7.8	<4.3 & >7.8
Scotland	Mineral soils	6.6-7.1	6.1-6.6	5.1-6.1 & 7.1-7.6	4.6-5.1 & 7.6-8.1	<4.6 & >8.1
	Peat soils	6.3-6.8	5.8-6.3	4.8-5.8 & 6.8-7.3	4.3-4.8 & 7.3-7.8	<4.3 & >7.8
Grassland						
Score		**5**	**4**	**3**	**2**	**1**
England, Wales	Mineral soils	6.5-7.0	6.0-6.5	5.0-6.0 & 7.0-7.5	4.5-5.0 & 7.5-8.0	<4.5 & >8.0
	Peat soils	5.8-6.3	5.3-5.8	4.3-5.3 & 6.3-6.8	3.8-4.3 & 6.8-7.3	<3.8 & >7.3

Scotland	Mineral soils	6.5-7.0	6.0-6.5	5.0-6.0 & 7.0-7.5	4.5-5.0 & 7.5-8.0	<4.5 & >8.0
	Peat soils	5.9-6.4	5.4-5.9	4.4-5.4 & 6.4-6.9	3.9-4.4 & 6.9-7.4	<3.9 & >7.4

pH scores for zones within a farm were assigned from the representative fields sampled within each of these zones.

1.4 Soil Physical Status – Bulk density

Data source	Literature
Field collected (and by laboratory analysis)	**Soil function:** Soil bulk density (BD) directly affects several soil physical and biological processes such as water infiltration rate, gaseous exchange, root penetration and soil faunal activity (Environment Agency, 2008). Since BD will be readily modified by soil management practices such as tillage, manure application, etc., any changes in bulk density can be related to soil management changes and thus helps to infer any soil degradation.
	Measurement: Disturbed bulk density method. Disturbed soil cores of (100 cm3) are extracted from the soil at three different depths (0-10 cm, 10-20 and 20-30) and transferred to a bag to submit to the lab. (Walter et al., 2016; Schierholz, 2020). In personal communication, regarding the use of disturbed samples over undisturbed, NRM have reported that 'a small trial on a range of soil samples found a good correlation between methods', indicating their confidence in analysis (NRM, 2021). ***Laboratory Analysis***: Samples are weighed after drying overnight at < 30°C to calculate the soil bulk density on dry matter basis for the sampled volume. ***Scoring***: AHDB (2018d) report proposed scores ranging from 1 to 3 based on SOM (%), and land-use (arable and grassland). This score range was modified to 1 to 5 by creating subcategories for score 1 and 3 by calculating the difference in score categories of 1 to 2 and 2 to 3 of AHDB scores (AHDB, 2018d).

SOM (%)	Score				
	5	**4**	**3**	**2**	**1**
	Arable				
<2	<1.28	1.28-1.44	1.45-1.6	1.61-1.68	>1.68
2-3	<1.20	1.20-1.35	1.36-1.5	1.51-1.58	>1.58
3-4	<1.12	1.12-1.26	1.27-1.4	1.41-1.47	>1.47
4-5	<1.04	1.04-1.17	1.18-1.30	1.31-1.37	>1.37
5-6	<0.96	0.96-1.13	1.14-1.30	1.31-1.39	>1.39
6-8	<0.96	0.96-1.08	1.09-1.20	1.21-1.26	>1.26
>8	<0.80	0.80-0.90	0.91-1.0	1.01-1.05	>1.05
	Grassland				
<2	<1.20	1.2-1.35	1.36-1.5	1.51-1.58	>1.58
2-3	<1.12	1.12-1.26	1.27-1.4	1.41-1.47	>1.47
3-4	<1.04	1.04-1.22	1.23-1.4	1.41-1.49	>1.49
4-5	<0.96	0.96-1.13	1.14-1.3	1.31-1.39	>1.39
5-6	<0.96	0.96-1.08	1.09-1.2	1.21-1.26	>1.26
6-8	<0.88	0.88-1.04	1.05-1.2	1.21-1.28	>1.28

>8	<0.80	0.80-0.90	0.91-1.0	1.01-1.05	>1.05

BD scores for zones within a farm were assigned from the representative fields sampled within each of these zones.

1.5 Soil Organic Matter – Dry combustion

Data source	Literature
Field collected (and by laboratory analysis)	***Soil function***: Soil organic matter (SOM) plays an important role in many physical, chemical and biological processes through its influence on soil structure, aeration, soil water holding capacity, cation exchange capacity, its ability to form complexes with metal ions and as a nutrient (nitrogen and phosphorus) source and store. ***Measurement***: SOM is measured by soil sampling (see sampling and stratification for more details) and analysis of the samples at the laboratory. Soil organic carbon values will be converted to SOM by standard conversion ratio of 1.72 and is used for SOM scoring.
	Laboratory Analysis: Dry combustion method to measure total and inorganic carbon with pre-acid treatment (NRM). ***Scoring***: AHDB (2018) report proposed scores ranging from 1 to 3 based on soil type (light, medium and heavy), climate (low, medium and high rainfall) and land use (arable and grassland). To determine the soil type soil texture data from BGS is used. Mean average annual rainfall for the farm is extracted from the MetOffice climate data for 30 years (1980-2010). This score range was extended from 1 to 5 by creating subcategories for score 1 and 3 by calculating the difference in score categories of 1 to 2 and 2 to 3 of AHDB scores (AHDB, 2018d).

Soil type	**Score**					**Score**				
	5	**4**	**3**	**2**	**1**	**5**	**4**	**3**	**2**	**1**
	Low rainfall (<650 mm)					**Mid rainfall (650-800 mm)**				
Light (<18% clay)	>4.4	3.3-4.4	2.2-3.2	1.1-2.1	<1.1	>5.7	4.2-5.7	2.7-4.1	1.1-2.6	<1.1
medium (18-35% clay)	>6.8	5.1-6.8	3.4-5.0	1.8-3.3	<1.8	>8.1	6.1-8.0	4.1-6.0	2.0-4.0	<2
Heavy (>35% clay)	>8.7	6.6-8.7	4.5-6.5	2.3-4.4	<2.3	>10.1	7.7-10.0	5.3-7.6	2.8-5.2	<2.8
	High rainfall (800-1100 mm)					**Permanent pasture (all climates)**				
Light (<18% clay)	>8.6	6.2-8.6	3.8-6.1	1.4-3.7	<1.4	>10.8	7.9-10.8	5.0-7.8	2.2-4.9	<2.2
Medium (18-35% clay)	>10.1	7.6-10.0	5.1-7.5	2.6-5.0	<2.6	>12.2	9.3-12.2	6.4-9.2	3.5-6.3	<3.5
Heavy	>11.5	8.9-	6.3-	3.7-	<3.7	>13.4	10.5-	7.6-	4.7-	<4.7

(>35% clay)		11.5	8.9	6.2			13.4	10.4	7.5	

SOM scores for zones within a farm were assigned from the representative fields sampled within each of these zones.

We also estimated soil organic carbon stock (tonnes/ha) for the whole farm ($SOC_{stock,f}$) with a number of zones (n).

$$SOC_{stock,f} = \sum_{i}^{n} SOC_{conc,i} \times BD_i \times D \times 10 \times area_i$$

where $SOC_{conc,i}$ is the soil organic carbon concentration (g/kg), BD_i is the bulk density (kg/m3) and $area_i$ is the area of the *i* th zone. D is the sampling depth (0.3 m) and 10 is the conversion factor from kg m^2 to tonnes/ha.

The conversion from SOC to SOM is:

$$SOM = SOC \div 0.58$$

2. Water

2.1 Surface runoff avoidance

Data sources	Literature
Condition (soil): field collected – VESS test	VESS gives general information about the soil structure and condition, in particular porosity/compaction of the soil and therefore provides an indication of how well water will infiltrate into the soil. Improving soil structure will aid infiltration (AHDB, 2018c). For details on the procedure, see soil section. We chose VESS as an indicator of the soil condition in relation to flood risk, rather than measuring infiltration directly, as it is less sensitive to the timing of sampling and antecedent conditions than taking a direct infiltration measurement of the soil. Infiltration measurements would also have been needed at multiple times in the year to gain a reasonable representation of condition. In addition, this methodology has the benefit of not creating an additional sampling method and aiding in streamlining farm visits. Moncada et al. (2014) show the relationship between visual examinations and values of soil physical and hydraulic properties. An extensive summary of soil structure and flood risk also using VESS as indicator can be found in Hallett et al. (2016). Palmers and Smith (2013) present evidence on soil structure degradation leading to flooding.
Condition (flood risk): remote sensing and NCR modelling – Connectivity Index	**Connectivity map estimate based on**: A network-index-based version of TOPMODEL for use with high-resolution digital topographic data (Lane et al., 2004) The connectivity of a location in the landscape to the river network gives an indication of how likely runoff from that location will reach the river network and thus contribute to potential flood risk. By measuring the average connectivity index of a farm an indication of the farm's contribution to flood risk can be made: a low connectivity index indicates low contribution to flood risk, whilst a high connectivity index indicates high contribution to flood risk. The practical method used for estimating the hydrological connectivity to river network is based on a digital elevation model and constant rainfall pattern and land cover risk. It derives slope, catchment area, channels network, channel routing and therefore calculates the hydrological connectivity to the river network. The resulting connectivity index depends on the selected area, so in order to be consistent across all GB, the connectivity map has been estimated for the whole GB. For each farm, the connectivity index is given by finding the average value from the connectivity map within the farm boundary. This is then converted to an index 1-5 according to the following rule:

<table>
<tr>
<td></td>
<td>
<table>
<tr><th colspan="2">Connectivity index as indicator of flood risk area</th></tr>
<tr><td>Very low risk (v. low connectivity)</td><td>< 0.5</td></tr>
<tr><td>Low risk (low connectivity)</td><td>0.6 - 0.5</td></tr>
<tr><td>Moderate risk (moderate connectivity)</td><td>0.6.- 0.75</td></tr>
<tr><td>High risk (high connectivity)</td><td>0.85 - 0.75</td></tr>
<tr><td>Very high risk (v. high connectivity)</td><td>> 0.85</td></tr>
</table>

Benchmark decided based on: Quantile of connectivity values across all of GB.
</td>
</tr>
<tr>
<td>Actions: survey responses – ELMS</td>
<td>Flood mitigation measures survey questions adapted from the ELM tools section on flood mitigation measures, based on Newell Price et al. (2011). Evidence for some of the approaches is outlined here in Basche & DeLonge (2019). Scoring will be implemented according to rules we devise (see ‘Scoring Rules List’ document). Changes to the benchmark can be made if the data collected indicates this is necessary.</td>
</tr>
</table>

Surface runoff avoidance **condition** scores are obtained as an average (rounded down) between the 'connectivity index as indicator of flood risk area' (GIS modelling) and 'VESS score' (collected in-field). Action scores are obtained from survey questions, according to the rules supplied in the 'Scoring Rules List' document. The ultimate SRA score takes into account both condition and action (average) scores using the below rules:

COMBINING condition & action		
	Condition	Action
5 Very Good	Score 1-2 (very high or high risk)	Score 4-5 (high/very high degree of action)
4 Good	Score 3-5 (very low-low risk/moderate risk)	Score 4-5 (high/very high degree of action)
4 Good	Score 1-2 (very high or high risk)	Score 3 (moderate degree of action)
3 Moderate	Score 3-5 (moderate/low risk)	Score 3 (moderate degree of action)
3 Moderate	Score 4-5 (very low-low risk)	Score 1-2 (very low/low degree of action)
2 Bad	Score 3 (moderate risk)	Score 1-2 (very low/low degree of action)
1 Very bad	Score 1-2 (very high to high risk)	Score 1-2 (very low/low degree of action)

Alignment with industry standard: Most survey questions are derived from ELMS questions spreadsheet provided by the Soil Association.

2.2 Nutrient runoff – Nitrate and Phosphate concentration and turbidity

Data sources	Literature
Field collected	Nutrient concentration (nitrate and phosphate) is directly dependent on some farming practices such as fertilising practices, manure spreading, and irrigation practices. Turbidity that reflects the presence of sediments in water can be affected by cultivation/tillage/ploughing/deforestation/pond drainage during harvesting (Mateo-Sagasta et al., 2017; Zia et al., 2013). Following FreshWater Watch analysis protocol, wherein nitrate and phosphate concentration and turbidity data are collected in the field. Nitrate and phosphate measurements are on a 6 scores scale as colours on the test scorecard. In order to be conservative, the first four colours/measurements correspond to a 5-2 score and the last two colours/measurements are grouped in the worse class. Turbidity is in NTU (Nephelometric Turbidity unit), measured using a Secchi tube. Final score is the average of the nitrate, phosphate and turbidity scores (rounding down). Benchmarking based on Freshwater Watch reported values and quote: a common guideline for ecologically impacted surface waters is 1.0 mg NO3-N/L (Nitrates Directive (91/676/EEC) and a common guideline for ecologically impacted surface waters is 0.10 mg PO4-P/L. As a general indicator, a turbidity measurement of 46 NTU is used as a threshold in the FWW platform, following typical thresholds of biological impairment of 22 and 69 NTU.

Nitrate measurements		NO3-N mg/L
	Very good	0.2
	Good	0.5
	Moderate	1
	Bad	2
	Very bad	>5
Phosphate measurements		PO4-P mg/L
	Very good	0.02
	Good	0.05
	Moderate	0.1
	Bad	0.2
	Very bad	>0.5
Turbidity		NTU
	Very good	<=15
	Good	>15 and <25
	Moderate	>=25 and >=40
	Bad	>40 and <100
	Very bad	>=100

Alignment with industry standard: FreshWater Watch. The legislative values for nitrate are referring only to the maximum limit (50 mg/l of nitrate which corresponds to 11.3 No3/N mg/l) (Nitrates Directive (91/676/EEC)). FreshWater Watch aligns with the guide value of 5.6 No3/N mg/l (EEA, 2020) and the common guideline mentioned above.

2.3 Nitrate and Phosphorus farm balance

Data sources	Literature
Farmscoper nutrient tool	Farmscoper is a widely used tool to assess a farm's nutrient budget in the UK, built upon some of the most robust data currently available for the UK. It is used within the water industry and also is being used as part of Natural England's nutrient neutrality assessments (Hughes, 2022). Benchmarking from ELMS tool guidance on NPK balance and associated scoring. From ELMS tool, on NPK Farm Budget: Data for N, P, K values are taken from the Guide to Nutrient Budgeting on Organic Farms (Watson et al., 2010), PLANET (ADAS, 2008), and the Managing Manure on Organic Farms booklet (ADAS and ORC, 2002).

Nutrient calculator

Nitrogen balance	
	kg/ha
Very good	0-50
Good	50-70
Moderate	70-90
Bad	90-110
Very bad	110-130 plus

Phosphorus and Potassium balance	
	kg/ha
Very good	<5
Good	5-6
Moderate	6-9
Bad	9-10
Very bad	>10

Alignment with industry standard: Farmscoper is widely used to assess farm nutrient balance in the UK.

2.4 Water usage

<table>
<tr><th>Data source</th><th>Literature</th></tr>
<tr><td>Condition (surface water): Open source GIS data – Resource availability dataset</td><td>

Resource availability dataset with consumptive abstraction available: Dataset available for all UK from Environment Agency 2015, variable to consider: [Resource reliability](#) (Percentage of the time additional consumptive resource may be available). For Scotland a similar dataset is not available. However, a water scarcity map from SEPA reports the overall Risk of Water Scarcity. This can be used as a similar indicator, but, since it is a different index and the estimate is based on different methods, direct comparison between Scotland and England/Wales can not be done. Overall, water availability in Scotland is less of an issue compared to England and Wales according to maps produced by the European Environment Agency. (https://www.eea.europa.eu/data-and-maps/figures/precipitation-deficit-in-summer-jja-1/water-stress-indicator-wei-for).

<table>
<tr><td>Condition</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Resource availability dataset with consumptive abstraction available</td><td></td><td>Resource availability dataset for SCOTLAND</td><td></td></tr>
<tr><td></td><td></td><td>% of time</td><td></td><td>Status</td></tr>
<tr><td>5</td><td>Very low risk</td><td>≥95</td><td>Very low risk</td><td>Normal condition</td></tr>
<tr><td>4</td><td>Low risk</td><td>70 - <95</td><td>Low risk</td><td>Early warning</td></tr>
<tr><td>3</td><td>Moderate risk</td><td>50 - <70</td><td>Moderate risk</td><td>Alert</td></tr>
<tr><td>2</td><td>High risk</td><td>30 - <50</td><td>High risk</td><td>Moderate Scarcity</td></tr>
<tr><td>1</td><td>Very high risk</td><td><30</td><td>Very high risk</td><td>Significant Scarisity (no area with that class)</td></tr>
</table>

</td></tr>
<tr><td>Condition (groundwater): Open source data – WFD Groundwater Quantitative status</td><td>

WFD Groundwater Quantitative status: Dataset available from Environment Agency, variable: [quantitative class](#).
Scotland has data about WFD Groundwater quantitative status that are available only for online consultation. (https://www.sepa.org.uk/data-visualisation/water-classification-hub/). However, since only ~3% of the total area of Scotland has Groundwater status classified as Poor, we would assume that groundwater quantitative status is good everywhere in Scotland.

<table>
<tr><td></td><td>If borehole abstraction, WFD Groundwater Quantitative status (quant_class):</td><td></td></tr>
<tr><td></td><td></td><td>Risk</td></tr>
<tr><td>5</td><td>Very low risk</td><td>Very low</td></tr>
<tr><td>4</td><td>Low risk</td><td>Low</td></tr>
<tr><td>3</td><td>Moderate risk</td><td>Moderate</td></tr>
<tr><td>2</td><td>High risk</td><td>High</td></tr>
<tr><td>1</td><td>Very high risk</td><td>Very high</td></tr>
</table>

Condition score depends on the % of water source: resource availability and groundwater status are combined with relative proportions (e.g. % of mains and abstraction apply to the resource availability score and % of groundwater applies to the groundwater quantitative status score).

</td></tr>
<tr><td>Condition score – combining groundwater and surface</td><td>If water is taken from mains or abstracted surface water calculate the resource availability score.</td></tr>
</table>

water	If water is taken from **groundwater,** calculate the **groundwater quantitative status score**. To combine them use the relative proportions. For example, a farmer uses: **4% mains**, **5% surface water abstracted**, **81% groundwater** and **10% recycled**. Of the relevant classes (mains, surface water abstracted, groundwater = 90%), 10% of the score is mains or abstracted, and thus applies to the resource availability score, and 90% is from groundwater, and thus applies to the groundwater quantitative status score. If the resource availability score is 5 and the groundwater quantitative status score is 2, then the overall score is 5*0.1 + 2*0.9 = 2.3 (rounded to 2).
Action: Survey responses – ELMS	Water abstraction and irrigation: benchmarking and scoring rules from ELMs tool. Action score for water abstraction is based on the mean of the rainwater & recycling water score (>4% = score 5 -> 0% = score 1). Crop irrigation score is based on different points for each of the survey questions.

Conditions and actions are combined in one score according to the following rule:

COMBINING condition & action		
	Condition	Action
5 Very Good	Score 1-2 (very high or high risk)	Score 4-5 (high/very high degree of action)
4 Good	Score 3-5 (very low-low risk/moderate risk)	Score 4-5 (high/very high degree of action)
4 Good	Score 1-2 (very high or high risk)	Score 3 (moderate degree of action)
3 Moderate	Score 3-5 (moderate/low risk)	Score 3 (moderate degree of action)
3 Moderate	Score 4-5 (very low-low risk)	Score 1-2 (very low/low degree of action)
2 Bad	Score 3 (moderate risk)	Score 1-2 (very low/low degree of action)
1 Very bad	Score 1-2 (very high to high risk)	Score 1-2 (very low/low degree of action)

Alignment with industry standard: Most survey questions are derived from ELMS questions spreadsheet provided by the Soil Association.

3. Biodiversity

3.1 Woodland Connectivity

Data source	Literature
Landcover map (see below)	Connectivity across a landscape is essential for ecological functioning and supporting healthy populations of species. **The NCR connectivity map of native woodlands is based on** a model that identifies patches of native woodland, calculates their area and then uses graph theory models (Saura and Pascual Hortal, 2007; Saura and Rubio, 2010) to work out the overall connectivity of the landscape, as well as identifying the most important patches that act as stepping stones for species between other patches, using the Makurhini R package (Godínez-Gómez and Correa Ayram, 2020). Each patch is scored according to its relative value in the surrounding landscape. The patches are scored as 'high' importance, 'medium' importance, and 'low' importance. The output is a score of the importance of each forest patch to overall connectivity, from low to high. Scores are calculated for 100km x 100km tiles, with a moving window. **Connectivity of native woodlands** (Relative contribution to landscape connectivity, high to low) 5 High 3 Medium 1 Low Where more than one woodland patch is present, the maximum connectivity score is calculated to give a farm score. **Benchmark decided based on**: Quantiles of connectivity values across the landscape (landscape is defined as the OS tile in which the farm is located).

3.2 Landcover – Farmed: Non-farmed

<table>
<tr><th>Data source</th><th>Literature</th></tr>
<tr><td>Open source landcover products</td><td>Ratio of farmed to non-farmed land based on the NCR landcover map. The NCR landcover map is generated from the best available open-source data layers.
All input datasets are harmonised using the UK Hab classification (Butcher et al., 2018) to generate a landcover map with more than 200 unique classes.
In each location, multiple estimates of landcover may be available; sources will be prioritised based on their resolution (higher spatial resolution is prioritised) and collection date (more recent prioritised over older data). Hedgerows and trees outside of woodlands are extremely important features within UK landscapes but there are no complete, reliable, and freely available maps of single trees and hedgerows. NCR has applied their unique algorithm to data on canopy height to delineate hedgerows and trees outside of woodlands and include these in the landcover map. The dataset is a geotiff map at 5m resolution, and is available to UK hab level 5 where source data allow.

Note that these data could also be collected or updated using farm surveys provided that landcovers align with UK hab classes.</td></tr>
<tr><td>Habitat classification</td><td>Landcovers are split into productive and non-productive according to UK Hab. Landcovers classified as productive are shown in the table below. All other landcover classes are considered to be non-productive.
<table>
<tr><th>Detailed NCR landcover classification</th><th>Broad grouping (used in NCR maps)</th></tr>
<tr><td>Semi-improved acid grassland</td><td>Acid grassland</td></tr>
<tr><td>Semi-improved calcareous grassland</td><td>Calcareous grassland</td></tr>
<tr><td>Semi-improved neutral grassland</td><td>Neutral grassland</td></tr>
<tr><td>Hay meadows</td><td>Neutral grassland</td></tr>
<tr><td>Pasture or meadow</td><td>Neutral grassland</td></tr>
<tr><td>Modified grassland</td><td>Modified grassland</td></tr>
<tr><td>Intensive orchards</td><td>Arable and horticulture</td></tr>
<tr><td>Traditional orchards</td><td>Arable and horticulture</td></tr>
<tr><td>Vineyards</td><td>Arable and horticulture</td></tr>
<tr><td>Olive groves</td><td>Arable and horticulture</td></tr>
<tr><td>Arable field margins</td><td>Arable and horticulture</td></tr>
<tr><td>Cropland
Including fallow land, ruderal/ephemeral, short rotation coppice, cereal crops</td><td>Arable and horticulture</td></tr>
<tr><td>Arable and horticulture
Including permanently irrigated land, annual crops associated with permanent crops, nursery crops, land principally occupied by agriculture with significant areas of</td><td>Arable and horticulture</td></tr>
</table>
</td></tr>
</table>

	natural vegetation, non-irrigated arable land, perennial crops and isolated trees, complex cultivation patterns. | Non-vegetated or sparsely-vegetated land (from Defra crop map) | Arable and horticulture

natural vegetation, non-irrigated arable land, perennial crops and isolated trees, complex cultivation patterns.	
Non-vegetated or sparsely-vegetated land (from Defra crop map)	Arable and horticulture

The output is a percentage of non-farmed land.

5 - Very good	10%+ is non-productive land
4 - Good	7.5 - 9.9%
3 - Moderate	5 - 7.4%
2 - Poor	2.5 - 4.9%
1 - Very poor	Less than 2.5% is non-productive land

Alignment with industry standard:

The RSPB's Fair to Nature standard includes the requirement for farmers to create wildlife habitats on at least 10% of their land. The biodiversity benefits of this threshold is supported by the scientific literature. 10% of land as non-farmed habitats would have beneficial impacts on the population stability and growth of farmland birds (Sharps et al., 2019 unpublished/forthcoming; Traba and Morales, 2019), and pollinating insects (Cole et al., 2020).

3.3 Birds

Data source	Literature
Field collected	**Survey**: monitor birds using the BirdNET and Merlin apps. BirdNET is a research platform that identifies birds by their song (Kahl et al., 2021). It is a citizen science platform as well as an analysis software for extremely large collections of bird audio recordings. BirdNET can identify more bird species than any other similar programmes available and had an overall accuracy of 91.5% from a study with 189 recordings (Kahl et al., 2021, Arif et al., 2020). For birds that are not calling but are visible, the Merlin Bird ID app should be used to identify the species. Many larger scale bird surveys involve recording all birds seen or heard. Bird surveys are performed in early April to cover the early part of the breeding season (BTO). Spring would be the optimal time for birds and grassland habitats. However, bird surveys are completed throughout the year - the timing will impact the types of birds you are likely to record (wintering birds, breeding birds or migrant birds). It is important to record the weather conditions and time of day of survey to recognise this seasonality. This methodology aims to achieve a snapshot of bird presence, however if alternative types of recording devices are employed to achieve a more comprehensive bird survey (i.e. over a greater period of time and on more than one occasion), best practice guidelines should be followed - see Bird Bioacoustic Surveys – Developing a Standard Protocol. On farmed land, bird surveys are completed at the beginning of the 'W' walk and at the fourth apex of the 'W', to create a transect across the field. On non-farmed land, bird surveys are completed at the beginning of the 'W' walk and the third apex, to obtain data from the edge and middle of the non-farmed land. Birds are identified visually or acoustically over a 10 minute period – two surveys of 5 minutes each. A more comprehensive bird survey may include the use of distance bands (e.g. <25m, 25-200m, >100m) to calculate simple bird density (sum of individuals within distance band divided by area sampled within that distance band across study area) (Calladine et al., 2008). Moreover, distance bands provide an indication of bird detectability within the habitat (Gregory et al., 2004). However, for the sake of simplicity in data collection, distance bands are not utilised in this methodology. Nonetheless, point-count methods are a widely used methodology for the census and monitoring of bird diversity and abundance (Kulaga and Budka, 2019, Hvenegaard, 2011). **Scoring**: Benchmark values have been decided based upon expert opinion, however these values will be refined upon collection of more data. The Game & Wildlife Conservation Trust Big Farmland Bird Count 2022 recorded 130 different species of bird across farmland in the UK. Other surveys (such as Gillings et al., 2008) have identified 25-30 bird species that use UK farmland in large numbers, and have focused survey efforts on these as indicators of the wider distribution and abundance of wild farmland birds. Our benchmark takes the numbers from other surveys into account and adjusts the scoring to account for differences in the survey/sample time. Alternatives to BirdNet should be explored for greater data accuracy.

5 (Very good)	20 or more species
4 (Good)	15 to 19
3 (Moderate)	10 to 14
2 (Bad)	5 to 9
1 (Very bad)	Below 5

Scores are given for each sample site and the average of these is taken to give a final score across the whole farm. Although here we use the average number of bird species, reporting the total number[1] is also an option, particularly for the current survey methods.

Highlighting Red/Amber list birds: Rare or protected bird species could also be highlighted in the reports. All wild birds are protected in the UK, some species (known as Schedule 1 birds) have extra legal protection during the breeding season under the Wildlife & Countryside Act. For the full list of Schedule 1 birds, see https://www.legislation.gov.uk/ukpga/1981/69/schedule/1.
Threatened bird species are regularly monitored and reported in the Birds of Conservation Concern reports, which are published every six years. Birds of Conservation Concern is compiled by leading conservation and monitoring organisations. It reviews the status of all regularly occurring birds in the UK, assesses them against a set of objective criteria and places them on the Green, Amber or Red lists to indicate the level of conservation concern. The latest assessment was published in 2021. Birds can be added to the Red list if they are threatened with extinction globally, have undergone severe population declines in the UK or have seen a fall in breeding numbers or range in the UK (Stanbury et al., 2021). See Birds of Conservation Concern 5 for the full Red and Amber lists.

Alignment with industry standard: Bird counts are common in citizen science and other research projects. Distance bands used in this survey align with the BTO/JNCC/RSPB Breeding Bird Survey, which is the main scheme for monitoring the population changes of the UK's common and widespread breeding birds.

[1] Scoring would need adjustment accordingly

3.4 Insects

<table>
<tr><th>Data source</th><th>Literature</th></tr>
<tr><td>Field collected</td><td>

Survey: Insect sampling using pan traps placed at specified locations. Pan traps are brightly coloured trays filled with soapy water. Several colours are used to attract a range of insects - in this survey we will use blue, yellow and white. The colours attract insects who fall into the water and are trapped by the low surface tension. Pan traps should be left in place for 6–7 hours, and then samples collected. Fields and non-farmed land of less than 10 hectares use 2 pan trap stations, whereas those with >10 hectares use three pan trap stations, creating a transect across the field/non-farm land (Montgomery et al., 2021; McCravy, 2018; Droege et al., 2017).

Several studies have shown that wild insects are the most prominent providers of crop pollination services, and the majority of services are provided by a small handful of common species, including non-bee insects (Carvell et al., 2016; Garibaldi et al., 2013; Rader et al., 2015). Pan traps have been commonly used to estimate abundance & diversity of insects across landscape types (Clair et al., 2020; O'Connor et al., 2019) Pan traps captures the greatest information of pollinator communities in agricultural fields compared to other sampling methods such as sticky traps and sweep netting (Wheelock and O'Neal, 2016; Nuttman et al., 2011). Pan traps are deployed on both agricultural fields and woodlands (Alison et al., 2021).

Scoring: Insect scoring is based on the use of indicator insect groups. Higher-level taxonomic groupings can be used in recognition of the challenges of species identification. Further possibilities should be explored with NatureMetrics.

<table>
<tr><th></th><th># Of different functional groups across farm</th><th></th><th>Insect functional groups:</th></tr>
<tr><td>5 (Very good)</td><td>5 functional groups</td><td></td><td rowspan="5">Pollinators;
Predators of pests;
Parasitoids;
Herbivores;
Decomposers</td></tr>
<tr><td>4 (Good)</td><td>4 functional groups</td><td></td></tr>
<tr><td>3 (Moderate)</td><td>3 functional groups</td><td></td></tr>
<tr><td>2 (Bad)</td><td>2 functional groups</td><td></td></tr>
<tr><td>1 (Very bad)</td><td>1 functional groups</td><td></td></tr>
</table>

</td></tr>
<tr><td>Lab analysed</td><td>Analysis of insects will likely be performed through NatureMetrics lab analysis. Insects will be grouped into five categories: pollinators, predators of pests, parasitoids, herbivores, and decomposers – as these groups are commonly represented in studies on ecosystem services within agricultural environments (González and Correa, 2020; Noriega et al., 2018; Zhao et al., 2018; Noordijk et al., 2010) and perform beneficial functions including nutrient recycling, plant and animal waste decomposition, aeration of soils, pollination, prevention of crop pests, and provisioning of food sources (Hopwood et al., 2016).</td></tr>
</table>

Alignment with industry standard:

The UK Pollinator Monitoring Scheme (PoMS) 1 km square protocol involves a set of five pan trap stations (each hosting 3 coloured bowls filled with water) being set out along a diagonal of each 1 km square and left for 6 hours. This methodology thus deploys 1 pan trap station per 20 hectares (Carvell et al., 2016). Our methodology incorporates 2 pan trap stations at < 10 hectares, and 3 stations at > 10 hectares.

3.5 Flora – Grassland & arable flora and Hedgerows

<table>
<tr><th>Data source</th><th>Literature</th></tr>
<tr><td>Field collected – Grassland & arable species count</td><td>
Survey: Grassland & arable survey methodology is based on the Natural England's Common Standards Monitoring, and employed in the Wild Service Habitat Survey and Assessment (2019). Three grassland & arable flora surveys are conducted per field regardless of field size, creating a transect across the field. Grassland and arable plant species are identified using the "Picture This" application that identifies plants through user-submitted photos using a user-friendly interface.
Lists of common plant species associated with different habitat types can be found in the UKHab habitat definitions documentation (UK Habitat Classification Working Group, 2018).
Scoring:
<table>
<tr><td>5 (Very good)</td><td>25 and above</td></tr>
<tr><td>4 (Good)</td><td>9 to 24 species</td></tr>
<tr><td>3 (Moderate)</td><td>6 to 8 species</td></tr>
<tr><td>2 (Bad)</td><td>3 to 5 species</td></tr>
<tr><td>1 (Very bad)</td><td>1 or 2 species</td></tr>
</table>
Scores are given for each sample site (each 1m² quadrat) and the average of these is taken to give a final score across the whole farm.
Benchmark decided based on guidance for assessing grassland condition from the Defra biodiversity metric 3.0 (see Panks et al. (2021) Annex 1: Condition Sheets for Grassland - Low Distinctiveness and Grassland – Medium, High & Very High Distinctiveness).
</td></tr>
<tr><td>Field collected – Healthy Hedgerows Survey</td><td>
Survey: The PTES Healthy Hedgerows survey is a rapid survey for assessing the health of a hedgerow. This survey requires the user to collect information on hedge structure (using the Healthy Hedgerows hedge structure key), average height, average width, number of hedgerow trees, hedge gaps and average base canopy (average height of this canopy from the floor).
Scoring:
To achieve good condition, the following criteria must be met:

The structure of the hedgerow is dense and well-managed according to the Healthy Hedgerows hedge structure key.
The hedgerow has >1.5 m average height along its length
The hedgerow has 1.5 m - 5m average width along the length
The gap between ground and base of the canopy must be less than 0.5 m.

<table>
<tr><td>5 (Good)</td><td>All criteria for meeting good condition (see above) are met.</td></tr>
<tr><td>3 (Moderate)</td><td>At least 2 of the criteria for good condition met.</td></tr>
<tr><td>1 (Bad)</td><td>One or none of the criteria for good condition are met.</td></tr>
</table>
</td></tr>
</table>

	Scores are calculated for each hedgerow and then the average is calculated to provide a score for the farm as a whole. **Benchmark decided based on** guidance from the Healthy Hedgerows key and Defra Biodiversity metric 3.0 Hedgerows and Lines of Trees habitat condition scoring (see Panks et al. (2021) TABLE TS1-4: Hedgerow attributes and criteria for meeting ‘favourable condition’), which also align with the Defra Hedgerow Survey Handbook criteria.

Alignment with industry standard: The PTES Healthy hedgerows survey is derived from the standard procedure but simplified. The proposed methodology for assessing hedgerows or grasslands does not include all the information required to assess the condition of these habitats for biodiversity net gain (BNG) through the Defra metric 3.0. The more detailed surveys required for BNG are designed to be undertaken by practising ecologists and require the collection of some information outside the scope of this work (such as tree age and health, invasive and neophyte species and evidence of damage from pollution for hedgerows, and coverage of bracken, bare ground, invasive species and sward height for grasslands).

3.6 Biodiversity Practice Score

Data source	Literature
Survey responses – ELMS	**Survey:** Survey of wildlife friendly farming practices and measures have been adapted from questions from ELMS questions spreadsheet provided by the Soil Association and the Cool Farm Tool (Cool Farm Alliance, 2016). This measure quantifies how well farm management supports biodiversity, at the farm scale. The score is based on the number of activities that support biodiversity that are being undertaken at the farm level. This relates to the percentage of total possible points that could be gained from the survey.

Scoring (Very good = 5; Very bad = 1):

		Livestock and Crop Diversity			Wildlife habitat & measures	
		Livestock & Crop	Livestock	Crops		
Very good	≥ 80 %	≥ 18	≥ 10	≥ 10	≥ 80 %	≥ 31.6 < 39.5
Good	≥ 60 < 80 %	≥ 14 < 18	≥ 7 < 10	≥ 7 < 10	≥ 60 < 80 %	≥ 23.7 < 31.6
Moderate	≥ 40 < 60 %	≥ 9 < 14	≥ 5 < 7	≥ 5 < 7	≥ 40 < 60 %	≥ 15.8 < 23.7
Bad	≥ 20 < 40 %	≥ 5 < 9	≥ 2 < 5	≥ 2 < 5	≥ 20 < 40 %	≥ 7.9 < 15.8
Very bad	> 0 < 20 %	< 5	< 2	< 2	> 0 < 20 %	< 7.9

There are 4 biodiversity practice-related sections within the broader farmer survey: Livestock variety, crop variety, wildlife-friendly habitat, and wildlife-friendly measures. The points of each section are summed, with the exception of the 'wildlife friendly measures' section, wherein the sum of wildlife friendly measures across all habitats is divided by the number of habitat groups present on the farm (maximum number of groups is 7). These habitat groups are: cereal fields, grass fields, watercourses/ponds, hedgerows, nesting resources, perennial grass, pools/ponds. This is to prevent farmers from missing out on points due to the absence of a particular habitat, e.g. grass fields.
Points from the 'livestock variety' and 'crop variety' section are summed, as are the points from 'wildlife habitat' and 'wildlife measures' section, to create two separate categories. Within 'Livestock and Crop Diversity', point thresholds refer to the total possible points obtainable based on whether a farm does or does not have livestock and crops, so as to avoid penalising farmers for not having one or the other.

Please note: There are some recommended changes to the 'Wildlife-Friendly Habitat' questions that lead to a change in the scoring thresholds for that section. The given scoring thresholds reflect those changes, and are not therefore applicable to the 15 pilot farms.

Alignment with industry standard: Most survey questions are derived from ELMS questions spreadsheet provided by the Soil Association. However, we do not apply the different weightings to the various biodiversity friendly measures, as done in the Cool Farm Tool, to maintain simplicity in the calculation. Instead, certain scoring thresholds can only be obtained by acquiring a minimum percentage of points from the categories, to ensure that high or very high biodiversity scores cannot be achieved with a large number of points in just one or two categories (e.g. livestock and crop diversity).

4. Climate Change

4.1 GHG Emissions

Data source	Literature
Farm Carbon Toolkit	The Farm Carbon Toolkit has been selected as it provides a farm carbon balance with consideration of carbon sequestration and accounts for different production systems (Abram, 2021; Leinonen et al., 2019; Bokhoree et al., 2021).

4.2 GHG Stock and Sequestration

Data source	Literature
Remote sensing	**Carbon Storage** Carbon storage is estimated using a machine learning algorithm (Zellweger *et al*., 2022). We relate a set of predictor variables to stand-level carbon storage estimates from the National Forest Estate (R^2 = 0.86, RMSE = 70 tCO_2e ha^{-1}). Estimates of carbon storage in the National Forest Estate were calculated from forest inventory data (2019) and methods from the Woodland Carbon Code (2020). Predictor variables used include canopy height estimates from the National Tree Map, Sentinel NDVI data for summer and winter, stand age and yield class, together with climate and soil properties. This model is then applied across the entire study area. Trees in hedgerows and parklands with height >2m are included in the model. Carbon storage for non-woodland landcovers, such as heathland, grassland, and hedgerows (<2m height), are included by using published values for UK habitats (Gregg et al., 2021). Belowground living biomass (roots) are included in the estimates. Soil carbon is captured in the soil metrics. **Carbon sequestration** Current rates of annual sequestration into trees and woodlands are predicted using estimates of forest age and yield class, as detailed above for carbon storage. Using published growth curves for key forest species, the expected rate of carbon draw down each year can be estimated. Forests are assumed to be managed to give a conservative estimate of sequestration rates. Newly planted woodlands may not be detected by the National Tree Map immediately. Updates are available every 2-5 years. **Scoring**

Rank	Meaning	Range
1	Very Poor	0-22 tCO2eha-1
2	Poor	22-44 tCO2eha-1
3	Average	44-66 tCO2eha-1
4	Good	66-88 tCO2eha-1
5	Very Good	>88 tCO2eha-1

The mean carbon storage (per ha) across vegetated landscapes was computed for the UK (Zellweger et al., 2022). Mean carbon storage acts as the centre point for the 'average' class. All other classes are placed equidistant. The highest class represents a landscape with more than ~30% canopy cover of mature trees. The lowest class represents landscapes with less than ~5% canopy cover of mature trees.

5. Social

5.1 Land access

Data source	Literature
England and Wales Public Rights of Way	Length of paths (footpaths, bridleways, and byways) in kilometres is determined remotely using publicly available Public Rights of Way shapefiles. Properties in Scotland are not given a value as the right to roam is assumed. There is no benchmark or scoring system for this metric. This metric is only calculated for the field parcels obtained from RPA (or equivalent), and therefore may not cover other areas that the farm may own. There is no benchmark for this metric, it is purely descriptive.

6. Sampling by stratification

6.1 Soil stratification

The farms are stratified to identify homogeneous zones of variation across the farm. The following method was developed to balance a need to align with international carbon standards while also allowing soil sampling to be conducted within a single day for most farms. Some compromises were therefore made to reduce the number of zones to allow for fewer overall samples.

Stratification at farm level is done by intersecting three different datasets: soil parent material (PM), soil texture and landcover maps (aligning with international standards for soil carbon estimation: VERRA, 2012). For parent material and soil texture, open source data available at 1 km resolution from British Geological Survey (BGS, 2012) are used. Land cover data is extracted from the NCR platform (NATCAP Map, https://www.natcapresearch.com/latest-tools). These maps were extracted for the extent of SBI number land polygons and units with unique combinations of these data were identified in GIS software. These units were classified into 'zones' using an attribute-based clustering (ABC) algorithm. ABC algorithm is a category based clustering algorithm, which is available as a QGIS plugin (Kazakov, 2021). We used euclidean distance based criteria with non-weighted inputs and choosing unknown number of cluster options available from the ABC model.

Following zone identification, zones of less than 2 hectares are removed. Within each remaining zone, a field is selected for sampling (which may be refined later with farmer input). This initial field is chosen based on area. The largest field is selected to represent the greatest portion of that zone. If the largest field cannot be sampled, the second-largest field should be selected (and so on).

Stratification steps:

1. Process maps
    - Extract shapefiles of parent material, soil texture and landcover for the farm using the SBI number land polygons (shape file)
    - Intersect different spatial layers (parent material, soil texture, DEM and landcover) by field boundary map (shapefile)
        - DEM is not used unless the number of zones (and thus fields to be sampled) is manageable when including DEM. As of yet, DEM has not been included as it led to too many sampling zones being generated.
    - Check the layers created in terms of their categories/classes. LC classes of non-agricultural land are removed, as soil sampling is only intended for production land at this stage, to keep costs manageable.
    - Join these layers to create a single shapefile of unique units, with an associated attribute table of required variables (PM, soil texture, and LC)..
2. Attribute based clustering
    - To create homogeneous zones within each farm, ABC algorithm (available as a QGIS plugin) was used. This clustering algorithm has a graphical user interface to choose the model setting and options (Figure 1) for clustering.

- We used the ‘Hierarchical-2’ clustering algorithm which creates unsupervised clusters without normalising the data.
- ABC creates clusters (as a new field ‘class’ in the attribute table of the input vector) and assign cluster number for all the subunits of the farm to which it belongs
- In the final step, ‘dissolve’ the clusters (QGIS: dissolve) by their unique class IDs to create ‘zones’ within a farm.
- Remove zones with marginal (small and scattered) areas (with a total area of <2 ha) and revise the zones manually.

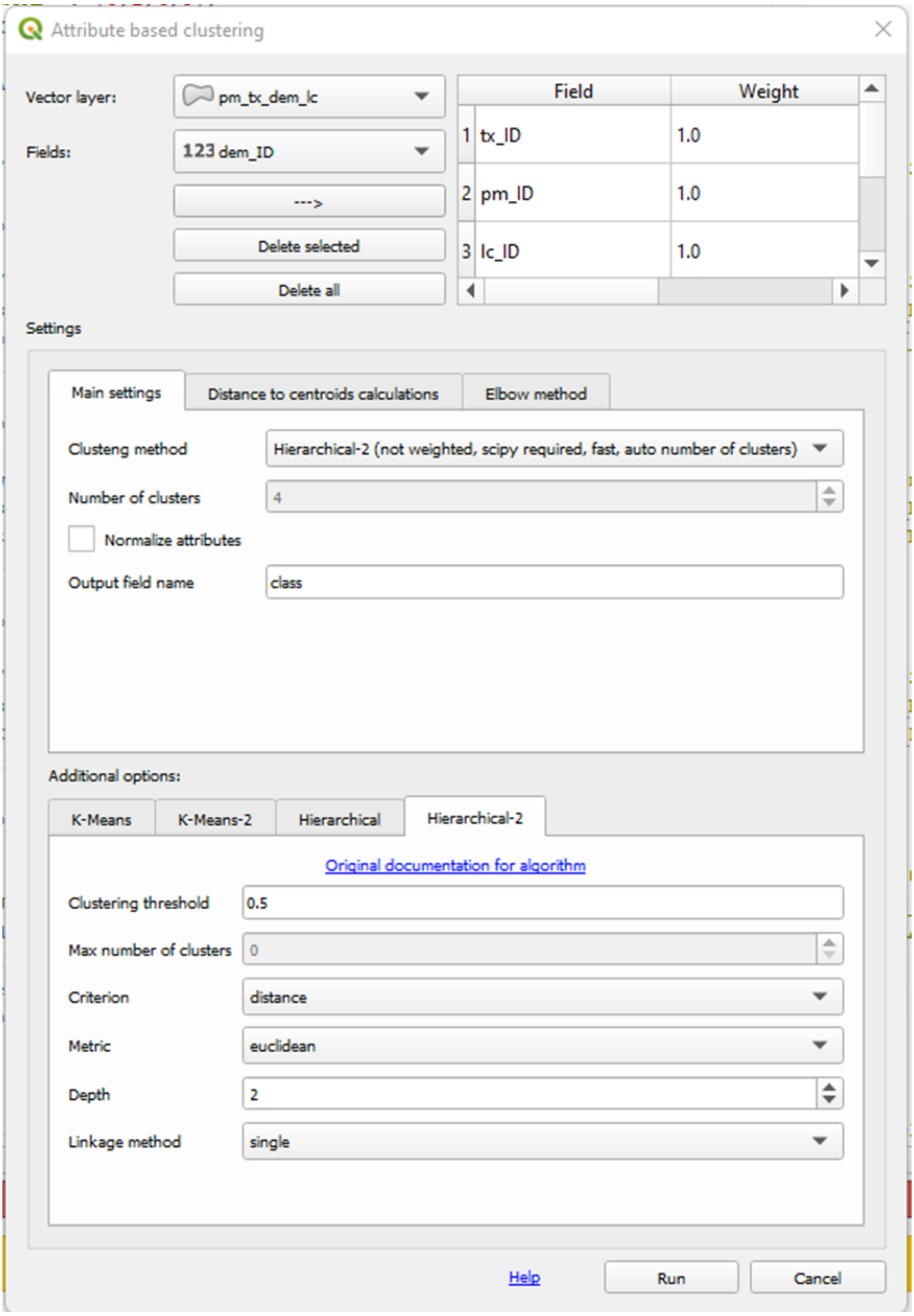
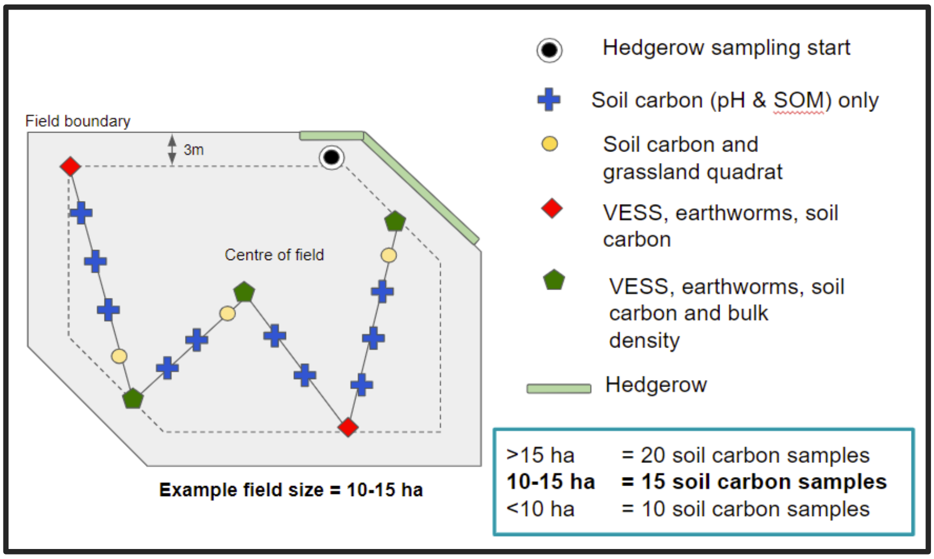
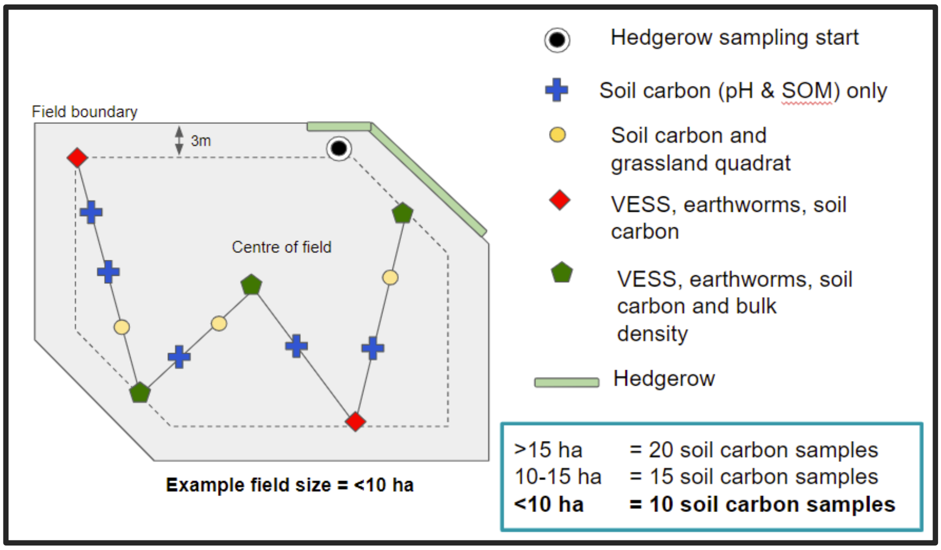


Figure 1. Graphical user interface for Attribute based clustering algorithm in QGIS showing the model settings and options. Note, in the current iteration DEM is excluded.

Soil sampling: Actual soil sampling is done at the zone level (from a representative field based on the stratification process above and refinement using the farmer's knowledge on their farm's spatial variability and productivity). A composite sample will be collected from each sampling field by traversing 'W' across the field. 10-25 cores will be collected from a field depending on its size. Three samples collected for earthworm, VESS, and bulk density per field.





In order to have greater alignment with VERRA sampling standards, the selection of sampling fields representative of 'zones' within the farm should be guided by information on (1) crop rotations, (2) land-use changes in the last 5 years, and (3) soil preparation.

The following is asked of farmers to refine the selection of fields:

> Given the map showing the zones across the farm, within each zone please identify any fields (using field ID) that have different (1) crop rotations; (2) land-use changes in last 5 years – i.e. conversion of arable land to permanent pasture or meadow, conversion of arable/grassland to permanent woodlands/biomass cropping, or conversion of grassland/woodland to arable; and/or (3) soil preparation (tillage/no-tillage); compared to the rest of fields within that zone. If identified, each of these fields

will constitute new 'zones' within these existing zones and therefore should be additionally sampled.

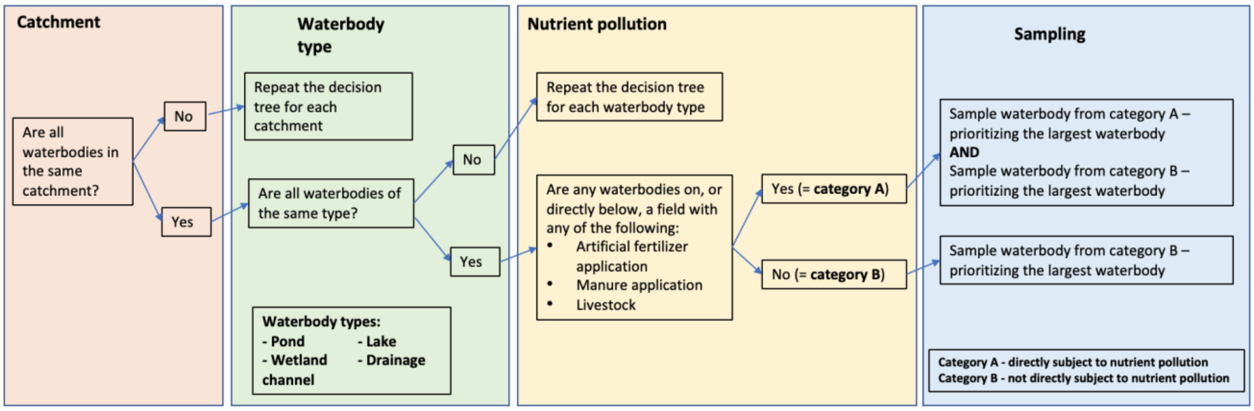
Selected fields should not be changed unless good reason is given.

6.2 Water stratification

Stratification process for water body sampling:

In order to devise a nutrient sampling methodology for waterbodies within the farm boundary, the waterbodies were divided up into groups. Waterbodies were then ranked based on the importance of them being sampled, with a number being essential to sample and the remaining being desirable to sample in order of importance. The waterbodies were divide up as follows:

- By catchment – Different catchments may have different hydrological regimes and this may affect how nutrients are transported through the landscape, in order to understand the overall farm's impact at least one waterbody sample should be taken from each catchment within the farm boundary (O'Grady et al., 2020).
- By waterbody type – Different waterbody types may represent different accumulation patterns of nutrients within the landscape (Kalkhajeh et al., 2019). Within each catchment, each waterbody type present should be sampled (Pond, Lake, Drainage Channel, Wetlands).
    - Rivers have not been included as standard because they are unlikely to reflect source pollution from the farm itself, more likely reflecting upstream pollution sources. In addition, being a moving waterbody they can have highly temporally variable nutrient concentrations and would require more consistent sampling in order to build up a representative picture of nutrient concentrations. HOWEVER, where a river passes through a farm for more than 1 km, a sample should be taken at the most downstream location of the river within the farm.
- By pollution risk – Waterbodies which fall within, or directly below, fields used for agriculture purposes and subject to livestock/poultry grazing or fertiliser application, will have higher risks of nutrient pollution (Sanderson et al., 2010). In order to understand this risk and assess the impact this may have for aquatic flora and fauna, for each waterbody type (where applicable), it is useful to sample both waterbodies directly subject to nutrient pollution (category A) and those not directly subject to nutrient pollution (category B).

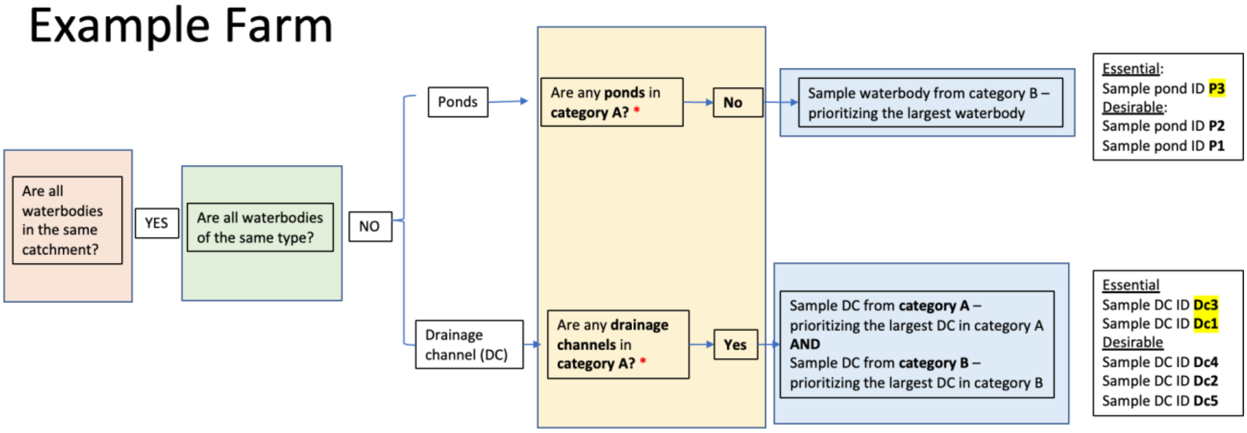


Sampling requirements:

- Catchment – each catchment should have at least one waterbody sample
- Waterbody type – within each catchment, each waterbody type present should be sampled (Pond, Lake, Drainage Channel, Wetlands)
- Pollution – within each waterbody type, one of each nutrient pollution category should be sampled (category A – directly subject to nutrient pollution ; category B – not directly subject to nutrient pollution)

Below is an example application of this decision tree to an anonymous farm.

Example Farm



ALL Pond IDs	Area (m)	Pollution enrichment category (A or B)*	Rank	Drainage channel	Area (m)	Pollution enrichment category (A or B)*	Rank
P3	813	B	1	Dc3	964	B	1
P2	579	B	2	Dc1	739	A	2
P1	478	B	3	Dc4	623	B	3
				Dc2	594	A	4
				Dc5	425	A	5

* **Category A**: Waterbodies are on, or directly below, a field with any of the following:
- Artificial fertilizer application
- Manure application
- Livestock

Category B: Waterbodies are **NOT** on, or directly below, a field with any of the following:
- Artificial fertilizer application
- Manure application
- Livestock

6.3 Biodiversity stratification

Biodiversity

Stratification process for biodiversity sampling on non-farmed land:

- Broad landcover groupings from the NCR landcover map were used to identify areas of non-farmed land (e.g. woodlands) within the farm boundaries.
- The prioritisation of non-farmed land was decided based upon: (1) Size (larger areas have higher priority, <2 ha are disregarded) and (2) location (situating all sampling areas within one section of the farm was avoided). Maximum of 5 woodlands are selected for sampling.

Stratification process for biodiversity sampling on farmed land:

- A minimum of three fields are selected for all farms. More fields may be required in order to satisfy the factors listed below.
- Field sampling selection was not based upon the zonation process from Soils. Rather, prioritisation of biodiversity sampling on farmed land was decided based upon: (1) Presence of hedgerows; (2) Landcover type (as detected from open-source data in NCR landcover product) – we sought to get samples from a spread of landcover types, including arable and grassland; (3) Location (situating all sampling areas within one section of the farm was avoided), (4) Soil sampling – fields already sampled for soil are preferred to limit amount of travel. This is why biodiversity field sampling may reflect sampling priorities from soil zonation.
- Biodiversity stratification could be improved by including other factors – including the variables that inform soil zonation – however this would result in many additional sampling points.

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