Botley West Solar Farm

Environmental Statement

Volume 3

Appendix: Surface Water Modelling Report

November 2024

PINS Ref: EN010147

Document Ref: EN010147/APP/6.5

Revision P0

APFP Regulation 5(2)(a); Planning Act 2008; and Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations

Approval for issue

Jonathan Alsop	15 November 2024

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Glossary

Term	Meaning
The Applicant	SolarFive Ltd
The Project	The Botley West Solar Farm (Botley West) Project
Hydraulic Modelling	A Hydraulic model can be defined as a computational representation a river or coastal system -so basically using a computer to do calculations to represent a watercourse.
1D MODELLING	1D models represent a river system using cross sections and in some software packages storage areas (e.g. reservoir units in FMP/ISIS). 1D models can also represent structures e.g. bridges, weirs and culverts.
2D MODELLING	2D models represent a river system using a grid. The grid represents the floodplain topography and channel geometry. 2D model grids can be manipulated to represent some structures.
Manning’s ‘n’	The Manning's n is a coefficient which represents the roughness or friction applied to the flow by the channel.
Downstream boundary	The 1D downstream boundary assumes a normal depth condition based on the local channel bed gradient of 1:1000

Abbreviations

Abbreviation	Meaning
AOD	Above Ordnance Datum
CC	Climate Change
DTM	Digital Terrain Model
EA	Environment Agency
ES	Environmental Statement
NFM	Natural Flood Management
LiDAR	Light Detection and Ranging
TUFLOW	Two-dimensional Unsteady FLOW Finite Volume
1D	1-Dimensional
2D	2-Dimensional

Units

Unit	Description
%	Percentage
km^2	Square kilometres
m	Meter
m/s	Meter per second

1 Introduction

1.1 Overview

1.1.1 This Appendix of the Environmental Statement (ES) has been prepared by RPS on behalf of Photovolt Development Partners GmbH. (PVDP) for the Applicant, SolarFive Ltd. (SolarFive). This Appendix supports Environmental Statement Volume 1 Chapter 10: Hydrology and Flood Risk of the ES.

1.1.2 PVDP is proposing to build and operate a new ground mounted solar farm in Oxfordshire. Botley West Solar Farm (the Project) covers approximately 1400 ha (excluding connecting cable routes), within the administrative areas of Cherwell, West Oxfordshire and The Vale of White Horse Districts.

1.1.3 The Project is formed by three separate but related sites, referred hereafter as the Northern, Central and South solar photovoltaic (PV) array land parcels. The parcels are to be connected to the national grid via underground interconnecting cables. The interconnecting cable route will largely follow the public highway, but some parts will cross land controlled by the Applicant. Overall, proposals involve the delivery of approximately 840MWe of power to the National Grid via a new National Grid 400 Kilovolt (kV) substation. As the Project will generate over 50MW it is recognised as a Nationally Significant Infrastructure Project (NSIP), and therefore requires a Development Consent Order (DCO) under the Planning Act 2008.

1.1.4 The surface water modelling of the site has taken place in support of the proposed Botley West Solar farm, which is to be located within the agricultural fields of the catchment. The impact of the proposed solar farm development on flood risk is negligible with appropriate flood risk mitigation and SuDS designed within the proposal of the scheme. However, where feasible the client wishes to provide a betterment to flood risk within Cassington village due to the historical flood issues at the village.

1.1.5 This modelling report describes the catchment characteristics, modelling approach, presents the baseline model results, and subsequently proposes Natural Flood Management (NFM) options for the site.

Background

1.1.6 The catchment area studied includes Cassington village and agricultural fields to the north of the site and comprises of a total area of 348ha. Most of the catchment area is rural as the area is predominantly arable land. Cassington village is located at the downstream extent of the catchment and comprises primarily of residential properties. The upstream extent of the catchment is proposed as part of the wider Botley West Solar Farm.

1.1.7 Atkins have previously undertaken a study for the Cassington site (Cassington NFM, 2021) which was based on existing Environment Agency (EA) Surface Water Modelling to explore natural flood management options within the agricultural fields to reduce the risk to Cassington. This report is included in Annex A. Findings and site visit information detailed within this report have been used to provide additional information to catchment characteristics and informs the planned modelling of proposed options which will be explored within the next stage of the modelling.

2 Catchment Characteristics

2.1 Hydrology

2.1.1 Surface water flow pathways exist from agricultural fields to the north. These fields are formally drained through numerous field drains and ditches.

2.1.2 Flow from the fields enters a small, flashy stream referred to as 'Cassington Stream' at Yarnton Road which then flows through the village. There are both open and culverted sections of the stream through the gardens of residential properties.

2.1.3 Cassington Stream continues to the south of the model extent and eventually discharges to the River Thames approximately 500m south of the village.

2.1.4 West Oxfordshire District Council Strategic Flood Risk Assessment (2016) provides further details regarding surface water flooding in the district:

- The updated Flood Map for Surface Water (uFMfSW) identifies a higher risk of surface water flooding in the natural topographic low points in the sub-area. Flow pathways follow the natural drainage of the local area, ponding in lower lying areas adjacent to the watercourses. The data shows three major flow pathways in the southern half of the sub-area. One of which is to the west of Cassington.
- Oxfordshire County Council doesn't have any historical flood events recorded within Cassington.

2.1.5 West Oxfordshire District Council have produced a Parish Report for Cassington (2008) this identified areas which have flooded, the cause and opportunities to manage risk. The following areas are subject to flooding:

- At Elms Road and Sports Field periodic flooding of low-lying properties from a combination of surface water, overland flow and water escaping Elm Road Drain (enmained watercourse).
- At Foxwell Court, Foxwell End, St. Peters Close, Horsemere Lane, Reynold Farm and Jericho Farm the residential areas periodically inundated by surface water run-off from Elms Road area, or from highway drainage system. Additionally, water surcharges from Cassington stream due to inadequate channel capacity and culverts.
- Explored opportunities to manage risk are discussed these include increased maintenance, flood defence improvement, increasing culverts and regrading the sports field and/or adding balancing ponds.

2.2 EA Surface Water Risk

2.2.1 The EA Updated Flood Map for Surface Water (**Figure 2.1**) illustrates that flow pathways exist in and around the site, with pooling seen within Cassington Village. There are areas of low-high risk within the village.

- Very low risk; has a chance of flooding of less than 0.1% each year.
- Low risk; has a chance of flooding between 0.1% and 1% each year.
- Medium risk; has a chance of flooding of between 1% and 3.3% each year.
- High risk; has a chance of flooding of greater than 3.3% each year.

2.2.2 The primary flow route is from the field drains in the centre of the catchment area, flowing south through Cassington via a stream, with numerous properties identified at risk. The flow running of the upstream agricultural fields appears to overtop the banks stream within the village.

2.2.3 A further flow pathway is noted to the east of the village, from agricultural fields, pooling is noted southeast of Cassington village. However, this does not impact properties within Cassington.

2.2.4 The EA Risk of Flooding from Surface Water (RoFSW) map is derived from a national model with varying resolution. As such it is not able to capture site-specific conditions.

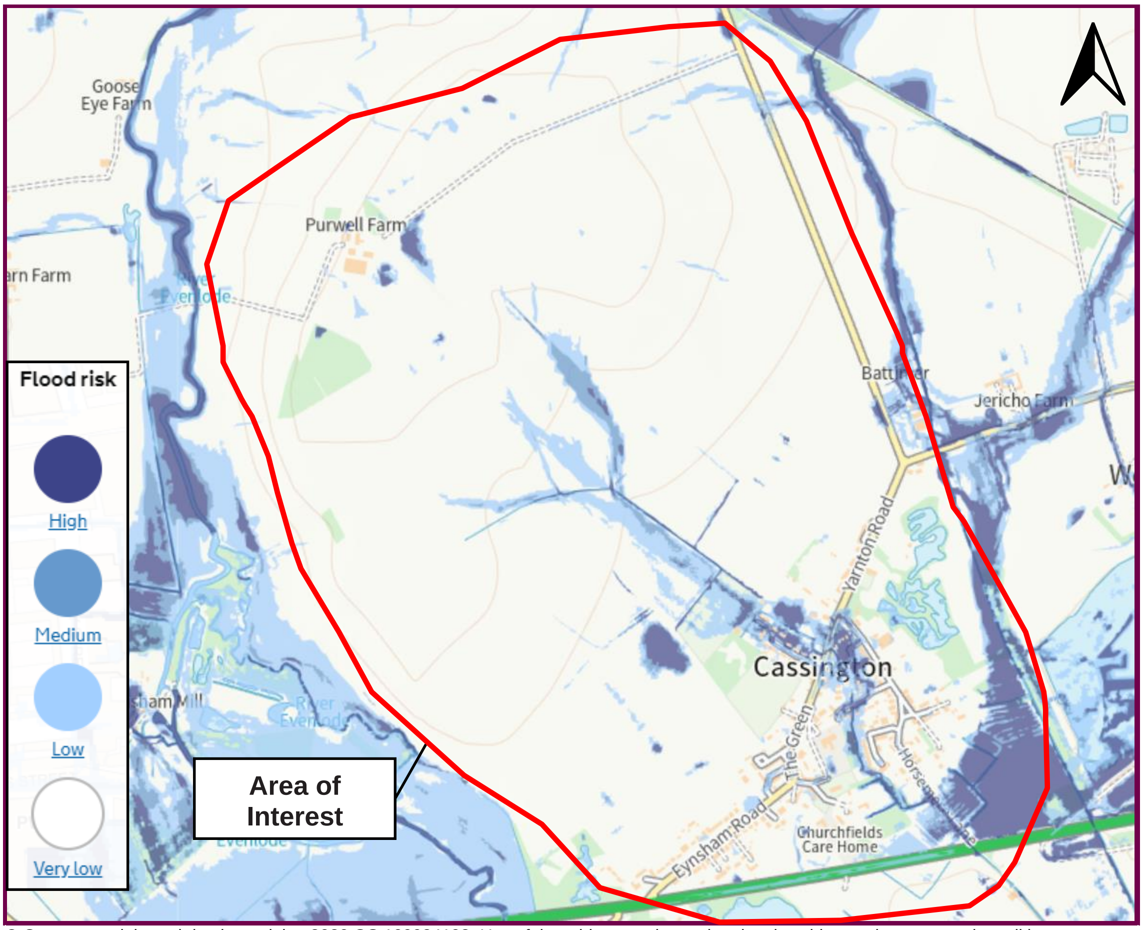

Figure 2.1: Updated Flood Map for Surface Water

2.3 Geology and Groundwater

2.3.1 BGS bedrock geology online mapping (1:50,000 scale) indicates the bedrock strata within the catchment area is Oxford Clay Formation and West Walton formation (undifferentiated). This comprises of mudstone, and silty mudstone with subsidiary calcilutite, limestone, sandstone and siltstone.

2.3.2 BGS superficial deposits online mapping (1:50,000 scale) indicates an area in the south comprises of Summertown-Radley Sand and Gravel Member superficial deposits, with an area in the north comprising Hanborough Gravel Member.

2.3.3 The Multi-Agency Geographic Information for the Countryside (MAGIC) online mapping (1:50,000 scale) identifies no bedrock aquifers within the study area. Cassington village and the north of the catchment are classified as Secondary A aquifers. Secondary A aquifers comprise of formations of permeable layers capable of supporting water supplies at a local scale, in some cases forming an important source of base flow to rivers.

2.3.4 Springs are noted in the north of the catchment, the site is underlain by local gravel deposits which act as local aquifers. As such groundwater is likely to be an important hydrological influencer of floodwater in the upstream of the catchment. Atkins site visit identified a spring upstream which is piped into the local ditch system within the agricultural fields.

2.3.5 Downstream within the catchment groundwater is considered to have less of a risk with runoff from surface water being the primary flow mechanism.

Soils

2.3.6 Soil information for the catchment has been obtained from the Soilscapes online viewer. The catchment extends across a number of the terrace deposits of the River Thames. Soils vary across the site and comprise the following:

- Deep loam to clay
- Seasonally wet deep clay
- Loam over gravel
- Seasonally wet loam over gravel

2.3.7 Loamy soils in the north and south are described as freely drainage, whereas loamy and clayey soils in the centre of the catchment are described as having impeded drainage.

3 Modelling Approach

3.1.1 A 2D rain on grid model has been developed in TUFLOW software (version: 2020-01-AA-iDP-w64).

3.2 Model Extent

3.2.1 The catchment boundary was defined using 'watershed' analysis of the local area based on the LIDAR-derived digital terrain model (1m resolution). This analysis identifies the area which drains to a specific location based on the ground topography. A 400m buffer was added to the derived catchment to provide a conservative approach and ensure any additional surface water pathways with the potential to impact Cassington were considered in the model.

3.2.2 It's noted that a surface water flow pathway is identified to the east of Cassington village (see Figure 1), generated from an area to the northeast of the village, but this passes to the east of the properties and therefore, is not anticipated to cause significant impact to the properties. Therefore, it was not included within the catchment boundary. Along the northwestern boundary the buffered catchment picks up an area that flows to the River Evenlode to the west as opposed to towards Cassington village.

3.2.3 The derived catchment boundary is presented in **Figure 3.1**.

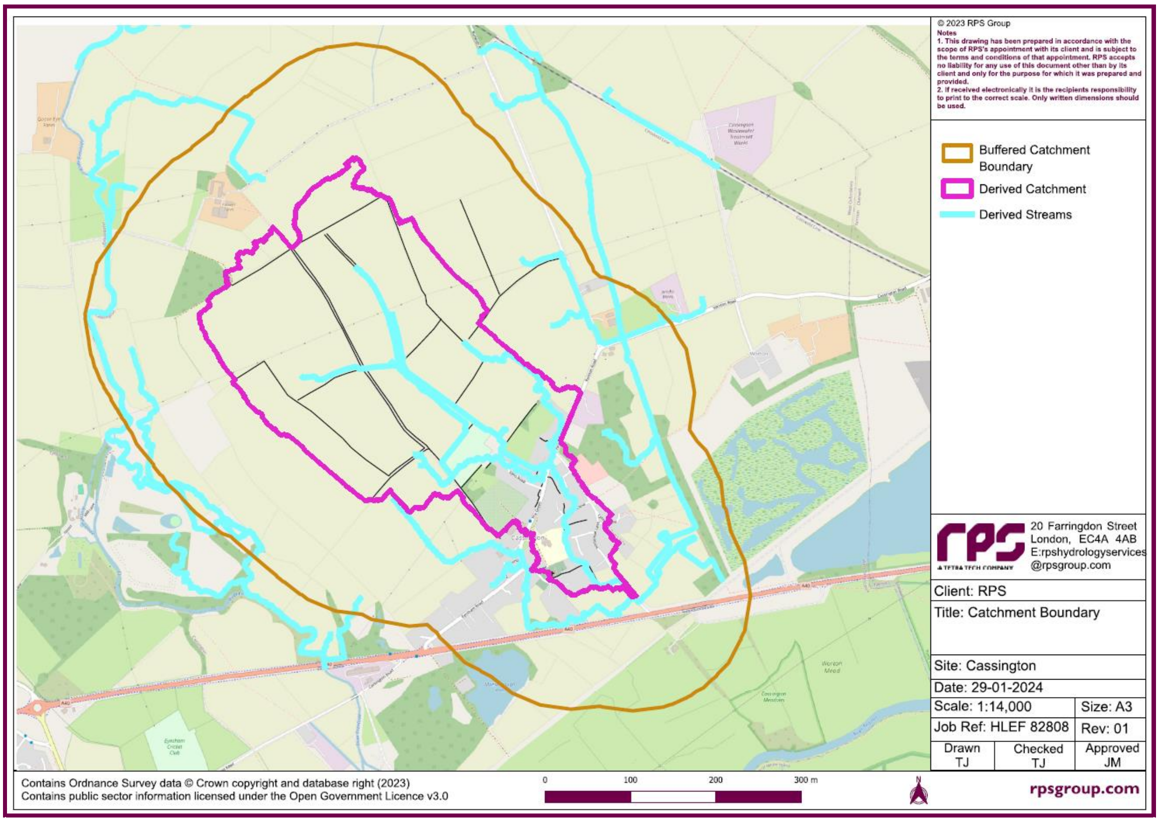

Figure 3.1: Model Extent

3.3 Inflows

2D Inflows Rainfall

3.3.1 The inflows into the model were derived rainfall hyetographs applied to the whole catchment area. These hyetographs were determined for the 30, 100, and 100-year rainfall using REFH 2. The 100-year rainfall was then multiplied by 1.3 to achieve the appropriate climate change inflow of 100-year+30% climate change.

3.3.2 Using REFH2, the critical duration was calculated in the software as being 6-hour 45-minute duration.

3.3.3 To test this within the model the hydraulic model was used to model a range of storm duration events; the 3-hour 15-minutes, 6-hour 15 minutes, and 9-hour 15-minutes durations. In all instances the derived critical duration of 6 hour 45 minutes produced the most significant depths.

3.3.4 The rainfall has been applied across the full model extent and represents the total rainfall for the catchment.

3.4 Outflows

2D Outflow

3.4.1 2D outflows were applied to the model where flow was ponding against the edge of the 2D domain. A HQ boundary was applied based on the slope of the ground in that location. In all locations a gradient of 0.1 was applied based on review of the elevation change.

3.5 1D- Structures

Culverts

3.5.1 Culverts have been modelled in 1D and has been defined using OS Mastermapping, Aerial Imagery and the Atkins (2021) report.

3.5.2 The inclusion of culverts is largely in the downstream urban section of the model. In the fields where watercourses cross tracks, these have been represented as a culvert. However, where there are culverted sections in the locations of vacant fields a cut in the LiDAR has been used. This is detailed in the topography section.

3.5.3 The culverts have been applied using a 300mm pipe diameter within the fields, and a 600mm pipe in the downstream. Although the Atkins (2021) report provided some imagery the exact locations of the features could not be determined. Therefore, in the absence of this it was assumed from the provided imagery that the pipe size of upstream field locations was smaller (300mm) and within the town dimensions of pipes are larger (600mm).

3.5.4 The culvert locations and details are presented in **Table 3.1** and **Figure 3.2** below. General images of culverts are presented in the Atkins (2021) report.

3.5.5 As there was a lack of survey information for the culverts two sensitivity scenarios were modelled. The first with the culverts at 0.5 times diameter (Sens 1) and the second with the culverts at 2 times diameter (Sens 2).

Table 3.1: Culvert Details

ID	Length (m)	Upstream Invert (m AOD)	Downstream Invert (m AOD)	Width or Diameter (m)		
				Baseline	Sens 1	Sens 2
CULV1	18.752	65.137	64.984	0.6	0.3	1.2
CULV2	18.752	65.27	65.205	0.6	0.3	1.2
CULV3	18.015	64.186	63.412	0.6	0.3	1.2

ID	Length (m)	Upstream Invert (m AOD)	Downstream Invert (m AOD)	Width or Diameter (m)		
				Baseline	Sens 1	Sens 2
CULV4	37.993	63.753	62.727	0.6	0.3	1.2
CULV5	9.981	63.308	62.961	0.6	0.3	1.2
CULV6	8.15	62.972	62.984	0.6	0.3	1.2
CULV7	18.46	74.573	74.017	0.3	0.15	0.6
CULV8	19.815	93.703	93.331	0.3	0.15	0.6
CULV9	13.335	64.518	64.278	0.6	0.15	0.6

3.5.6 Culverts are applied using the ‘1D_nwke’ layer with a ‘1d_bc’ layer connecting the 1D to 2D domain. All culverts are assumed to be circular in dimension.

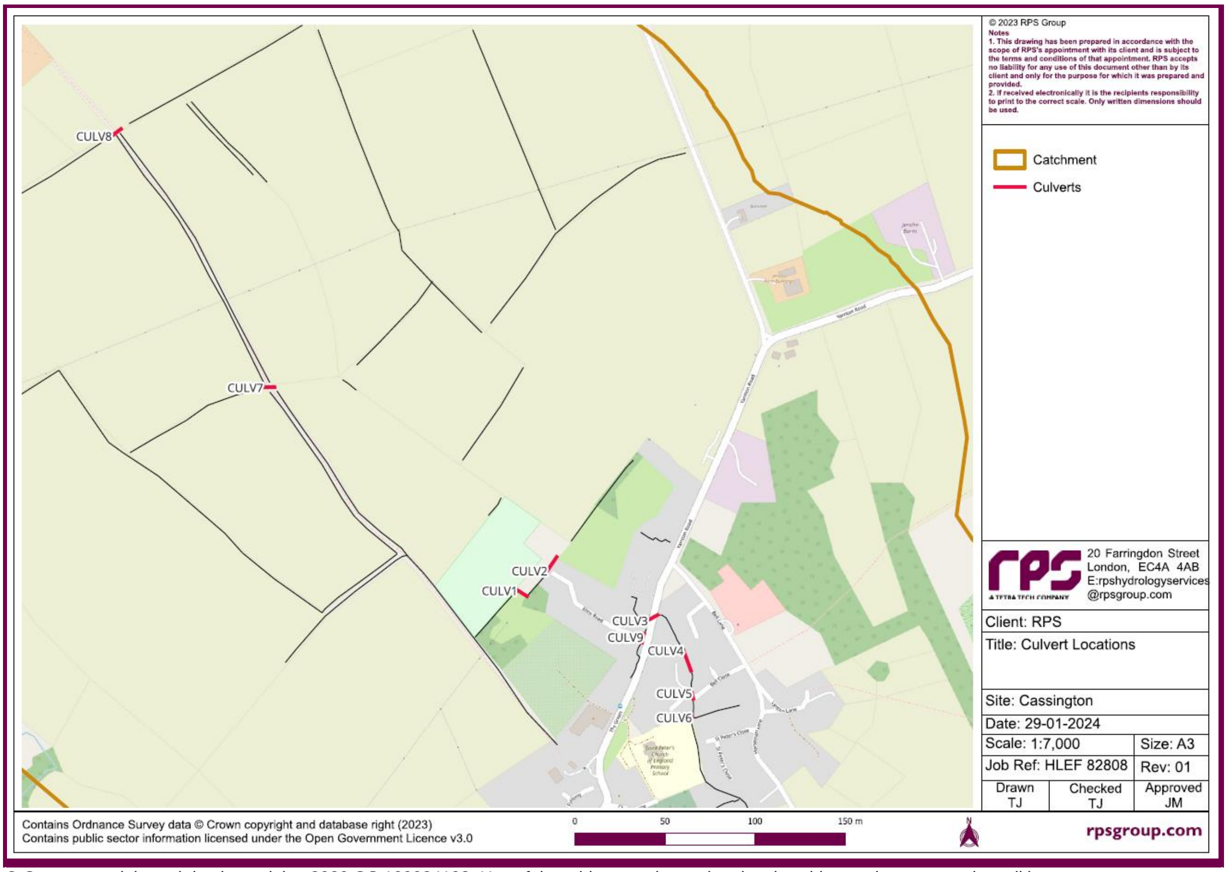

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Figure 3.2: Culverts included in the Model

3.6 Overland Flow

Roads

3.6.1 The roads in the model extent have been lowered by 125mm to ensure that the roads are the preferential flow paths. This is in line with EA surface water modelling guidance (National Scale Surface Water Flood Mapping Methodology, 2019). This reflects the fact that road design incorporates local-scale topographic features e.g. cambers and kerbs/raised pavements which encourage water to remain within the linear footprint of the road.

Buildings

3.6.2 The buildings have been abstracted from the OS MasterMap dataset.

3.6.3 Buildings have been represented in the model by applying stub heights to model topography to represent finished floor levels (FFL's) and to ensure surrounding roads are the preferential flow routes. The stub height applied to the buildings is 300mm. The height has been applied to the mean height of the building taken from the LIDAR to ensure a flat FFL.

3.6.4 A higher roughness value has been applied to the buildings detailed within the Manning's roughness section.

3.6.5 The modelling has included consideration for the drainage system within urban areas. This is discussed and detailed in the soil section of the model report.

3.7 Manning's Roughness

2D Roughness

3.7.1 The varying layers for the roughness values have been taken from the OS MasterMap layer. The values assigned are detailed below in **Table 3.2**.

Table 3.2: Manning's Roughness Values

Feature Code	Descriptive Group	Manning's Roughness (n)
10021	Buildings	0.500
10053	General Surface (Multi-surface)	0.04
10054	General Surface (Step)	0.025
10056	General Surface (Grass, parkland)	0.03
10062	Buildings (Glasshouse)	0.5
10089	Water (Inland)	0.035
10096	Dense vegetation, natural land form, working slopes or cliff	0.1
10099	Land Natural	0.1
10111	Natural Environment (Heavy woodland and forest)	0.1
10119	Roads, Tracks and Paths (manmade)	0.02
10123	Paths (tarmac and dirt tracks)	0.025
10167	Railway lines	0.05
10172	Roads Tracks And Paths (Tarmac)	0.02
10183	Roads Tracks And Paths (Roadside)	0.02
10185	Structures (Roadside)	0.03

Feature Code	Descriptive Group	Manning's Roughness (n)
10193	Structures (New)	0.03
10217	Land (Industrial yards, car parks)	0.035

3.8 Infiltration

3.8.1 Infiltration losses are applied to permeable surfaces based on the underlying soil textural class. TUFLOW uses the hydraulic properties (hydraulic conductivity, suction and porosity) corresponding to each textural class, as well as the initial moisture content, to vary the rate of infiltration over time.

3.8.2 The entirety of the model extent is assumed to be unsaturated at the start of the simulation. Throughout the simulation, TUFLOW monitors the amount of water infiltrated, such that once the soil is saturated, no further infiltration occurs.

3.8.3 A 2d_soil layer was created to represent the soils present in the study area based on the Soilscapes Viewer from Cranfield University's National Soil Resources Institute (NSRI), this is supported by Defra.

3.8.4 Polygons have been obtained from the site to represent the different soil types in the study area (shown in **Figure 3.3**). These polygons were then allocated a unique code according to textural class. The soil textural classes and corresponding TUFLOW codes are defined in the TUFLOW manual and shown in **Table 3.3**. Lakes or Waterbodies were attributed a Soil Type number of '99' with a value of NONE applied. A value of NONE means no water is infiltrated within waterbodies to account for the fact these already have water present at the start of the simulation.

3.8.5 An additional soil layer was created to account for the drainage capacity of the urban network. infiltration within the urban areas. shows this layer where an urban drainage rate was applied. In line with EA RoFSW methodology, a standard 'drainage rate' of 12mm/hr was applied at this built-up location. This is to account for the drainage capacity of the sewer system within urban areas.

3.8.6 An additional impermeable layer has also been defined taking the roads and buildings present in the model. A Soil Type number of '99' has been applied to this layer and a value of NONE (shown in **Figure 3.4**). This represents the fact buildings and roads have no infiltration.

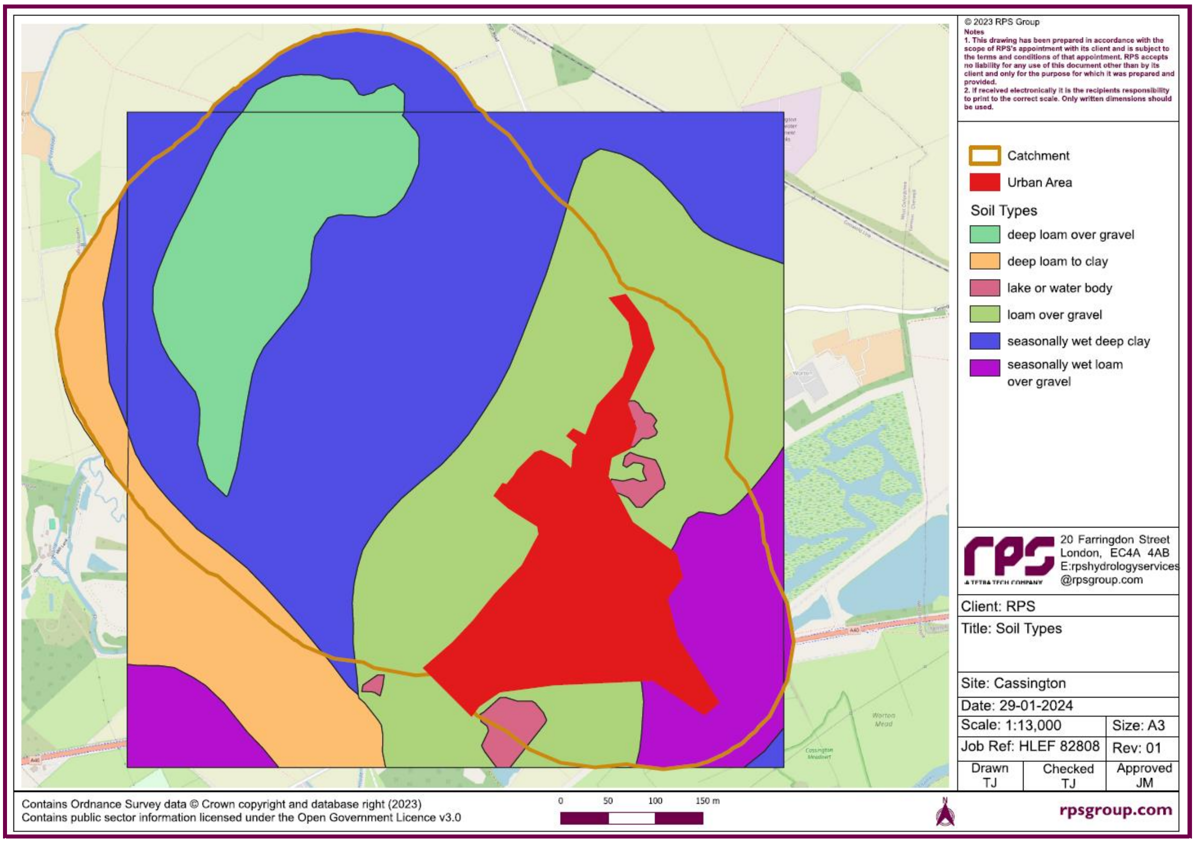

Figure 3.3: Soil Types within Catchment

Table 3.3: Soil Types Within Hydraulic Model

SoilScape Number	Soil Description	TUFLOW Soil ID	TUFLOW Definition
18	Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	1	Clay
7	Freely draining slightly acid but base-rich soils	8	Loam
8	Slightly acid loamy and clayey soils with impeded drainage	4	Clay Loam
28	Water	99	No Infiltration
N/A	Urban Area	12	12mm/hr

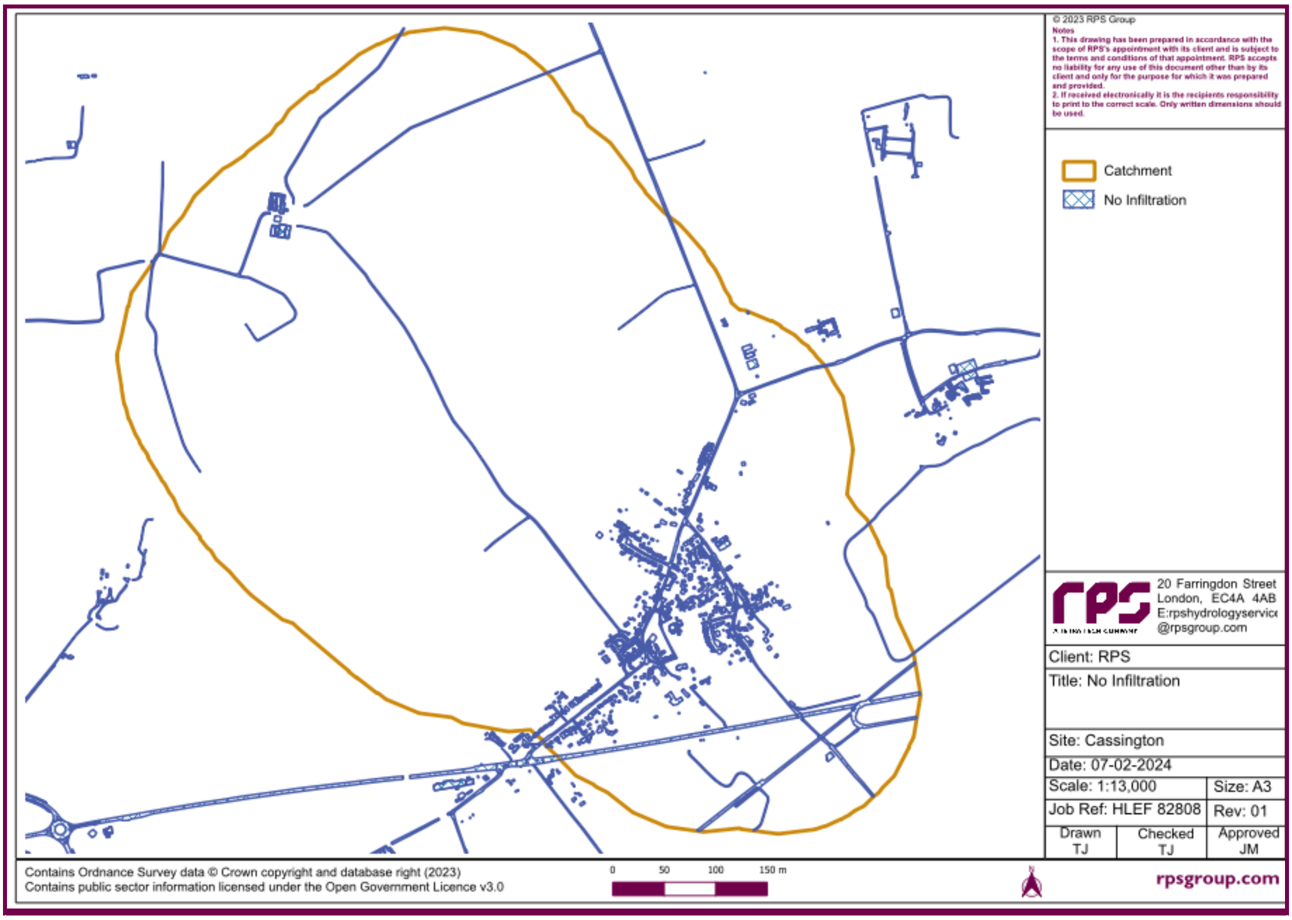

Figure 3.4: No Infiltration Locations

3.9 Topography

3.9.1 Topography has been determined from LiDAR derived DTM with a 1m resolution. As mentioned, the buildings and roads have been raised/lowered accordingly. These have been stamped as additional z shapes.

3.9.2 Cuts in the LiDAR has been made where there are culverts in the fields at the upstream extent of the modelled reach. These cuts in the LiDAR are applied using '2d_zsh' layer, with a 1.5m width and the upstream and downstream elevations extracted from the LiDAR. This allows water to flow through the drains to ensure there is no artificial backing up of water where the LiDAR is raised as it cannot pick up the culverts. This is a simplified approach to applying culverts in the fields in the absence of detailed site data.

3.10 Model Grid Size

3.10.1 The model grid size has been set at 2m. This provided a good balance between the degree of precision in order to model overland flow routes along roads and around pathways, as well as providing an appropriate model run (simulation) times.

3.11 Simulation Time

3.11.1 All the model runs have been run for 10 hours. The peak of the flood events had been reached, particularly in the area of interest by this time.

3.12 Timestep

3.12.1 The model was simulated with a 1 second time step in the 2D domain (TUFLOW), and a 0.5 second time step in the 1D domain (ESTRY). The chosen time steps were deemed suitable for the model grid size and have been shown to produce stable model results.

3.13 Model Stability

3.13.1 The cumulative mass error is outputted during the model simulation. This value provides an understanding of the stability of the model as well as the robustness of the model and its ability to stimulate a flood event accurately. A model is considered healthy if it falls between the recommended range of +/- 1% throughout the simulation. **Figure 3.5** shows that the model falls within or close to this range for the 1 in 100-year return period.

3.13.2 There is a high mass error towards the start of the simulation (-3%) however, this quickly levels out and subsequently remains between 0 and -0.5% throughout the remaining simulation. The TUFLOW manual indicates that an initial high mass error is acceptable provided it diminishes quickly. This is particularly common where there are small flow amounts such as overland flow models.

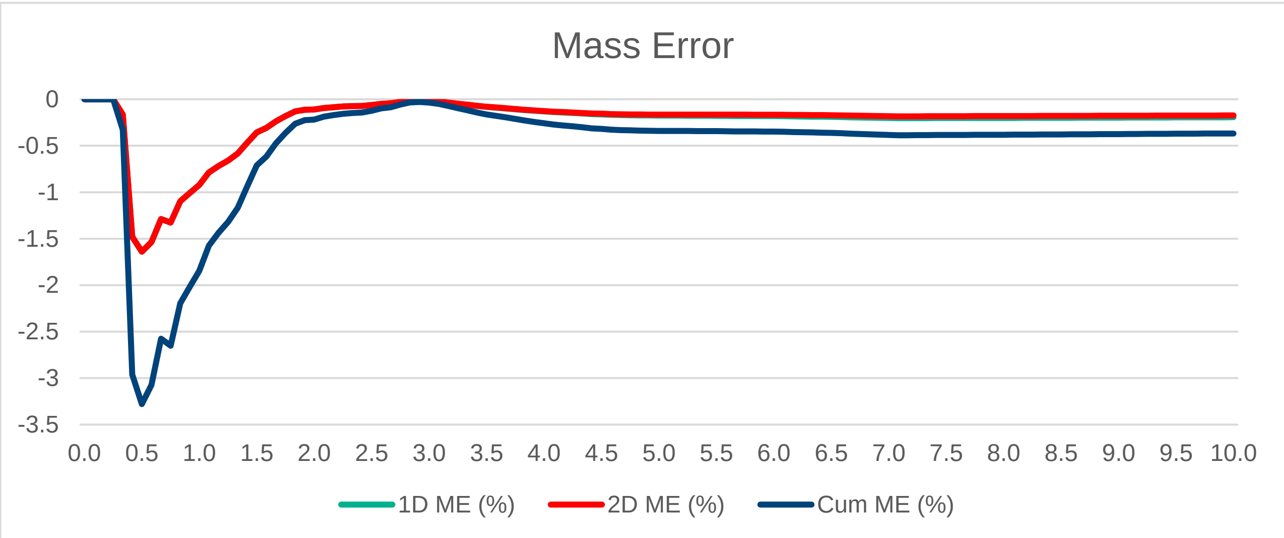

Figure 3.5: Mass Error (1D and 2D)

3.13.3 Other parameters such as warnings outputted during the simulation, provide details of the 'healthiness' of the model. Two warning messages related to the ZC value were found in the TUFLOW output, indicating adjustments to the culvert invert level at two points.

3.14 Modelling Limitations

3.14.1 All models are subject to limitations. The following limitations are listed as ways of improving the model for future simulations.

3.14.2 In the absence of site-specific topographic survey data, EA 1m LiDAR was used as an input for the topography. This has a typical accuracy of +/- 150mm. To improve the model resolution site-specific topographic survey can be obtained.

3.14.3 The culverts were either applied as a cut in the topography (LiDAR) in the rural areas, or as a 1D_nwke layer. In the absence of a detailed site-survey of the culvert widths, lengths and locations these were assumed from OS Mastermapping, aerial photography and the Atkins (2021) report. As such the model is subject to the limitation of lack of detailed information on the structures and can be improved through a topographic survey which includes these features.

3.14.4 Calibration events were not available, as such the model was calibrated against the EA RoFSW which is subject to its own limitations. In the absence of historical event data this was deemed the most appropriate option.

3.14.5 Finally, 1D pipe network data for the urban area was not obtained, this is as the mitigation features will be focussed on the upstream rural section of the catchment. However, in the absence of this data a standard infiltration rate of 12mm/hr as per EA guidance (2019) was applied within the urban area.

3.14.6 Although the model is subject to limitations it Is still deemed acceptable to inform mitigation options and provides a better understanding of the risk to the area. Further information in line with the above can be obtained at a later stage to refine the model if required.

4 Results

4.1.1 Model results are presented as depth and velocity maps for the full suite of return periods in this section. A hazard map has been produced for the 1 in 100 year + 30% climate change scenario. The nature of rain-on-grid surface water modelling is such that all cells in the model area will receive rainfall directly onto them and therefore show a degree of flood depth. Therefore, to aid clarity in the presentation of the results, very shallow depths have been omitted in the mapping. Thus, the depths map only show depths greater than 0.10 m (i.e. 10 cm) in magnitude.

4.1.2 On request all ‘raw’ model results files can be provided following completion of the proposed option modelling in electronic format alongside this report to allow further detailed interrogation of the results.

4.2 Baseline Scenario Results

4.2.1 The model has been run for pre-development existing conditions of the site.

Flood Depths

4.2.2 **Figure 4.1, Figure 4.2**, **Figure 4.3** and **Figure 4.4**, shows the maximum flood depths for the 1 in 30 year, 1 in 100 year, 1 in 100 year + 30 % Climate Change scenario respectively and 1 in 1000 year. The results and flow mechanisms are relatively similar throughout the return periods with some additional water pooling in the more extreme flood events particularly pooling with Cassington village.

4.2.3 Depths remain below 0.5m in all scenarios, there are two significant water pooling areas within the proposed solar farm extent at the downstream area adjacent to Cassington. There are also depths of up to 0.5m within Cassington village itself.

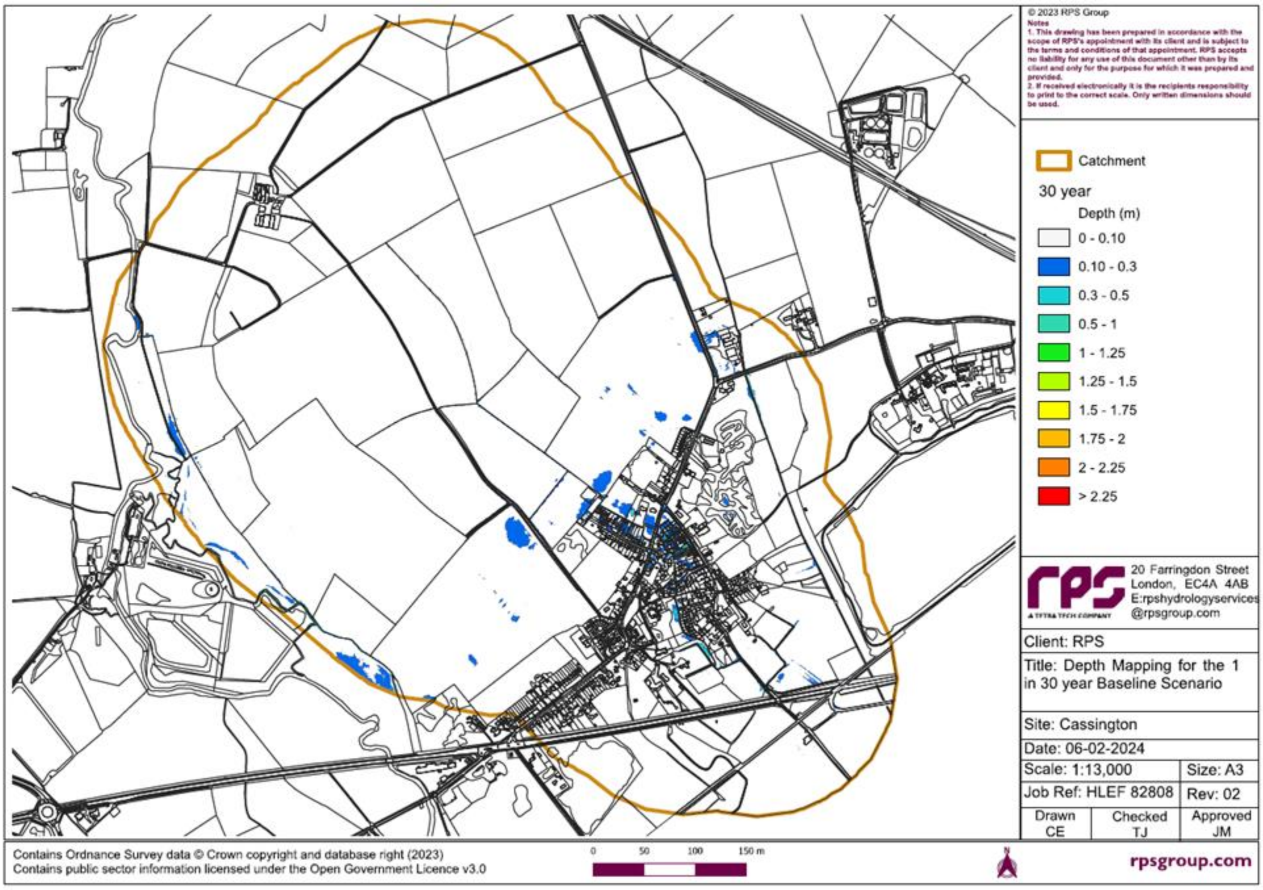

Figure 4.1: 1 in 30 year Baseline Flood Depths

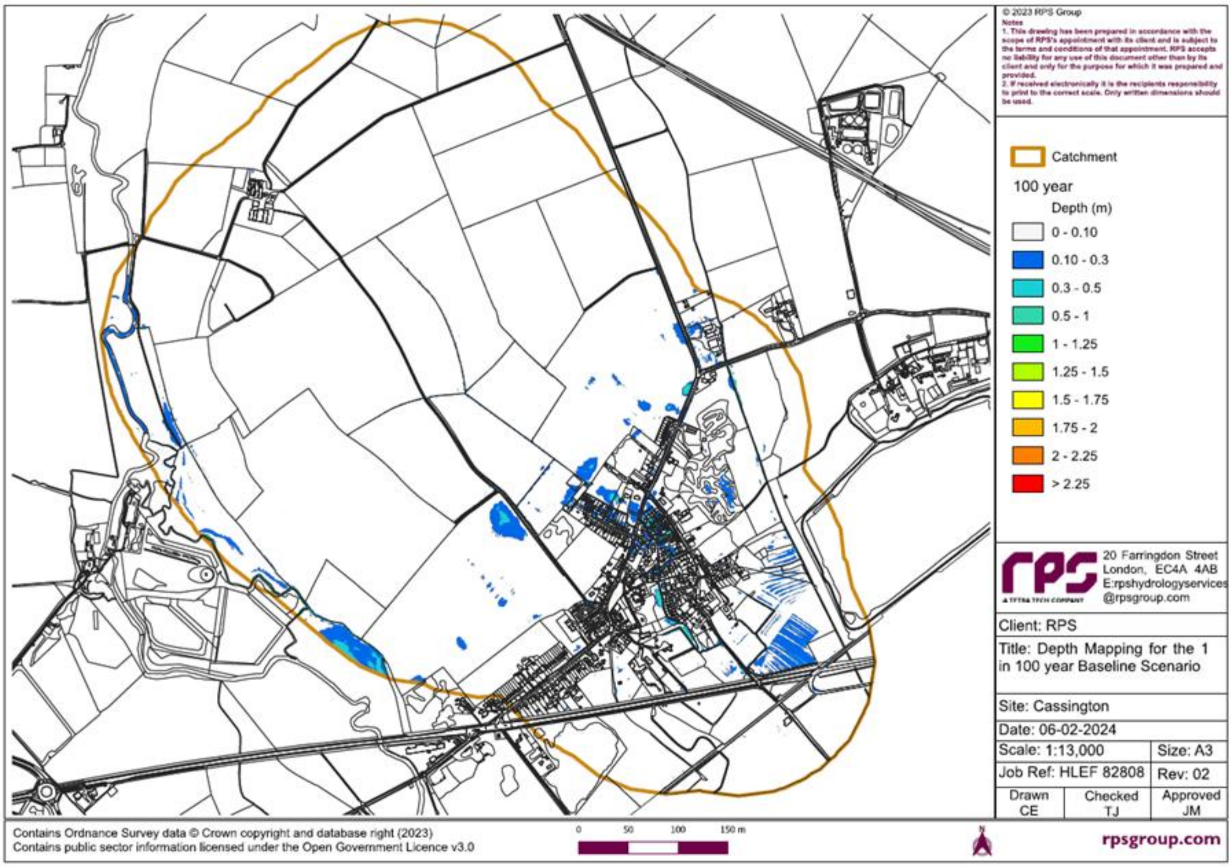

Figure 4.2: 1 in 100 year Baseline Flood Depths

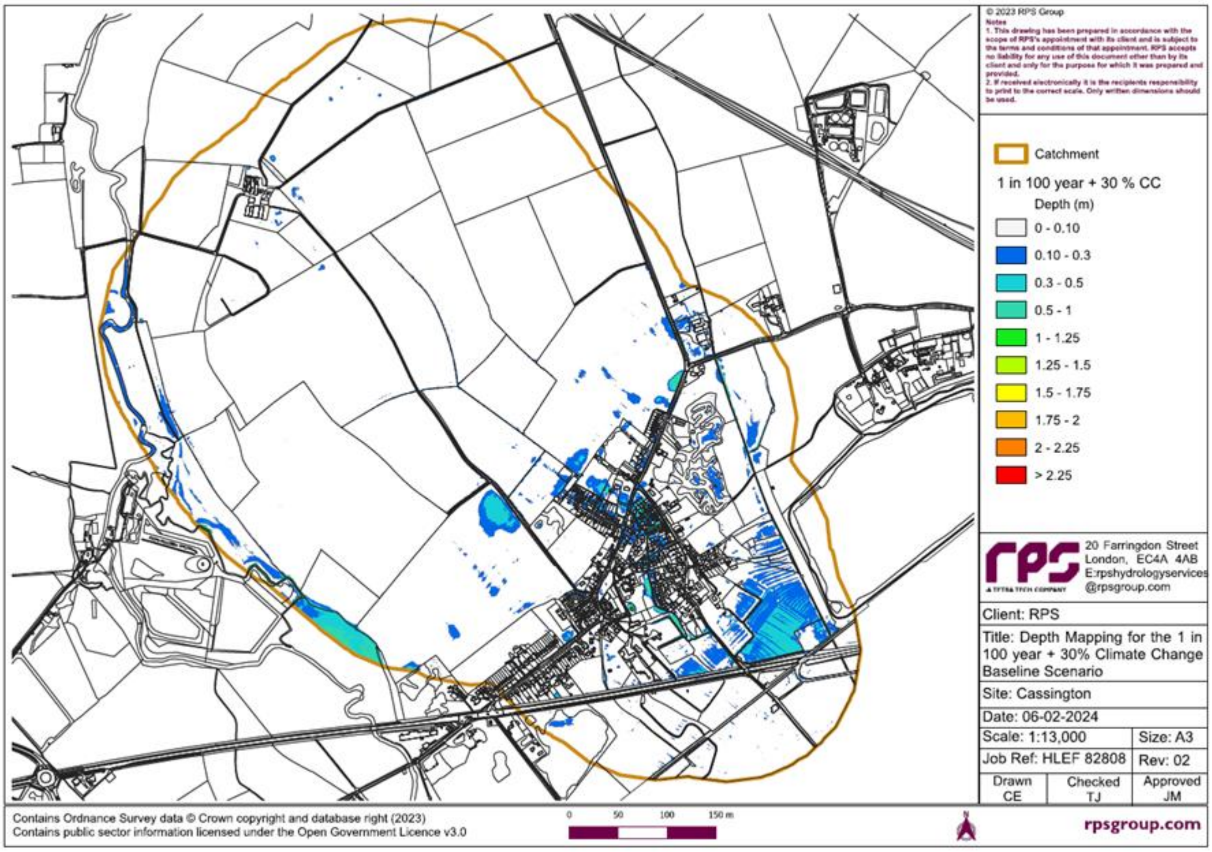

Figure 4.3: 1 in 100 year +30% CC Baseline Flood Depths

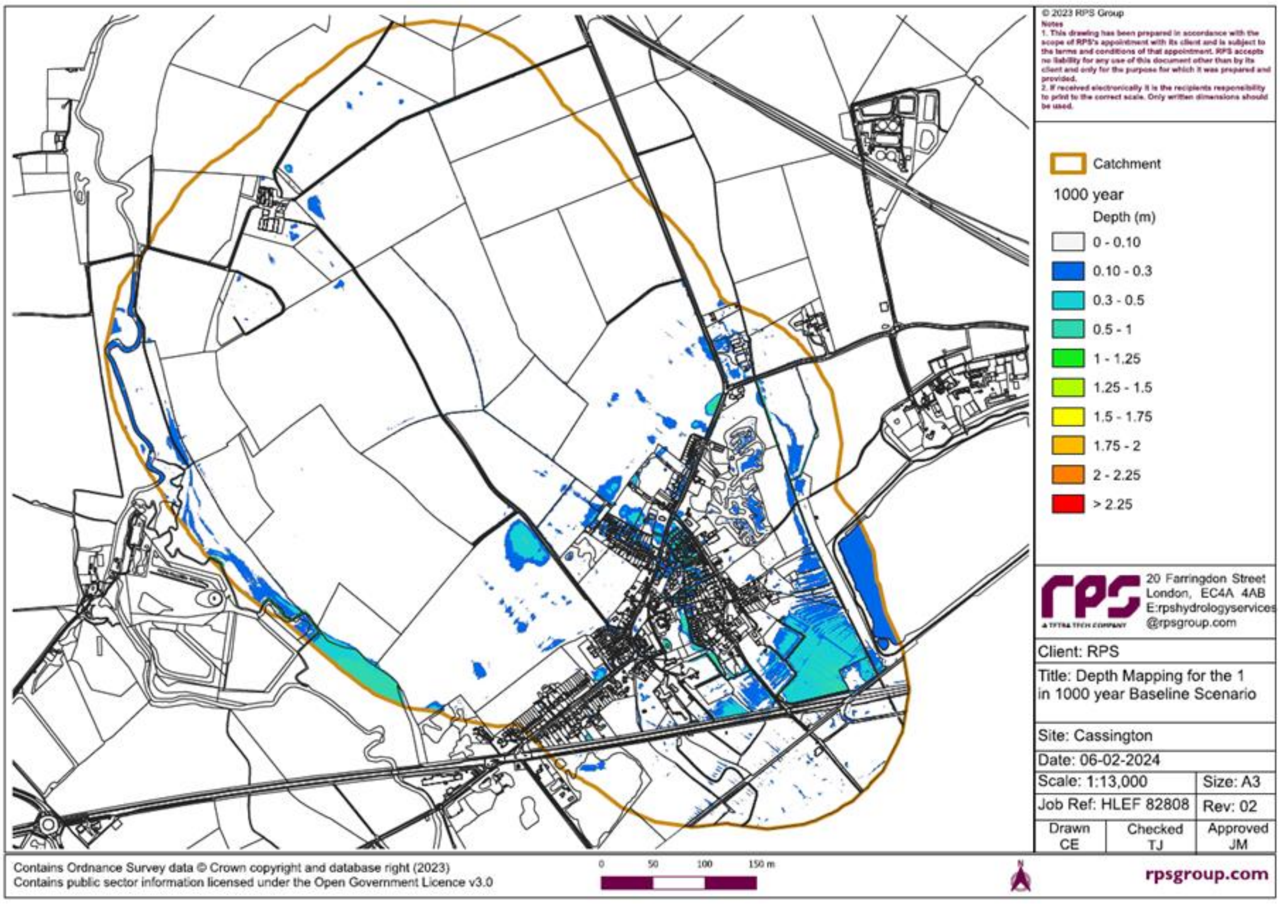

Figure 4.4: 1 in 1000 year Baseline Flood Depths

Flood Velocity

4.2.4 Flood velocities for the 1 in 100 year + 30% CC event is presented in **Figure 4.5**. This indicates velocities generally remain below 0.3m/s. In the upstream fields and drains velocities can reach between 0.3 and 1m/s, with the downstream stream through Cassington potentially reaching between 1.5 and 2m/s. This indicates velocities increase as water moved downstream through the catchment and is restricted by the urban area.

4.2.5 The flow pathways are also presented in **Figure 4.6** and shows the direction of water as it moves through the catchment, with the proposed solar panels overlain. The depths are also displayed in this mapping to show where water pools. As can be seen most of the flow accumulates from the fields and collects within the field drains and adjacent areas along the field delineations. The highest velocities and flows are in the central most prominent field drain.

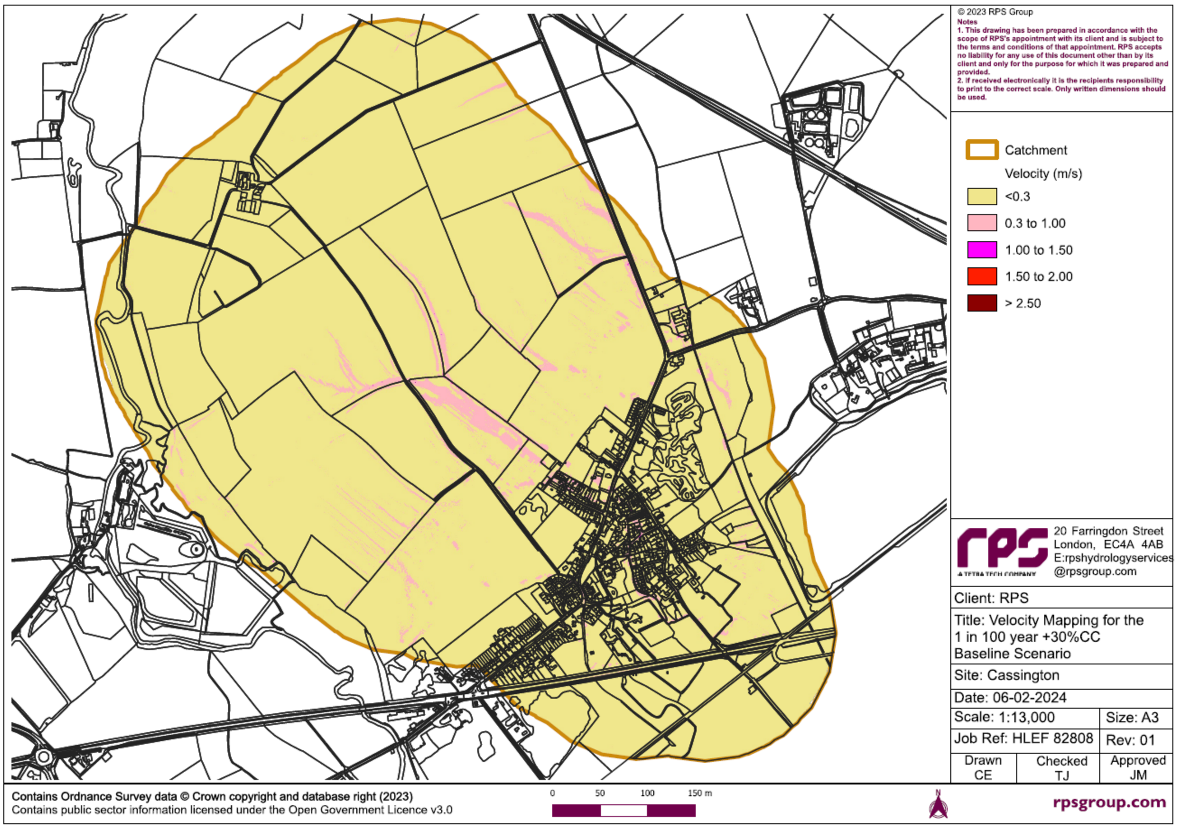

Figure 4.5: 1 in 100 year + 30% CC Baseline Flood Velocities

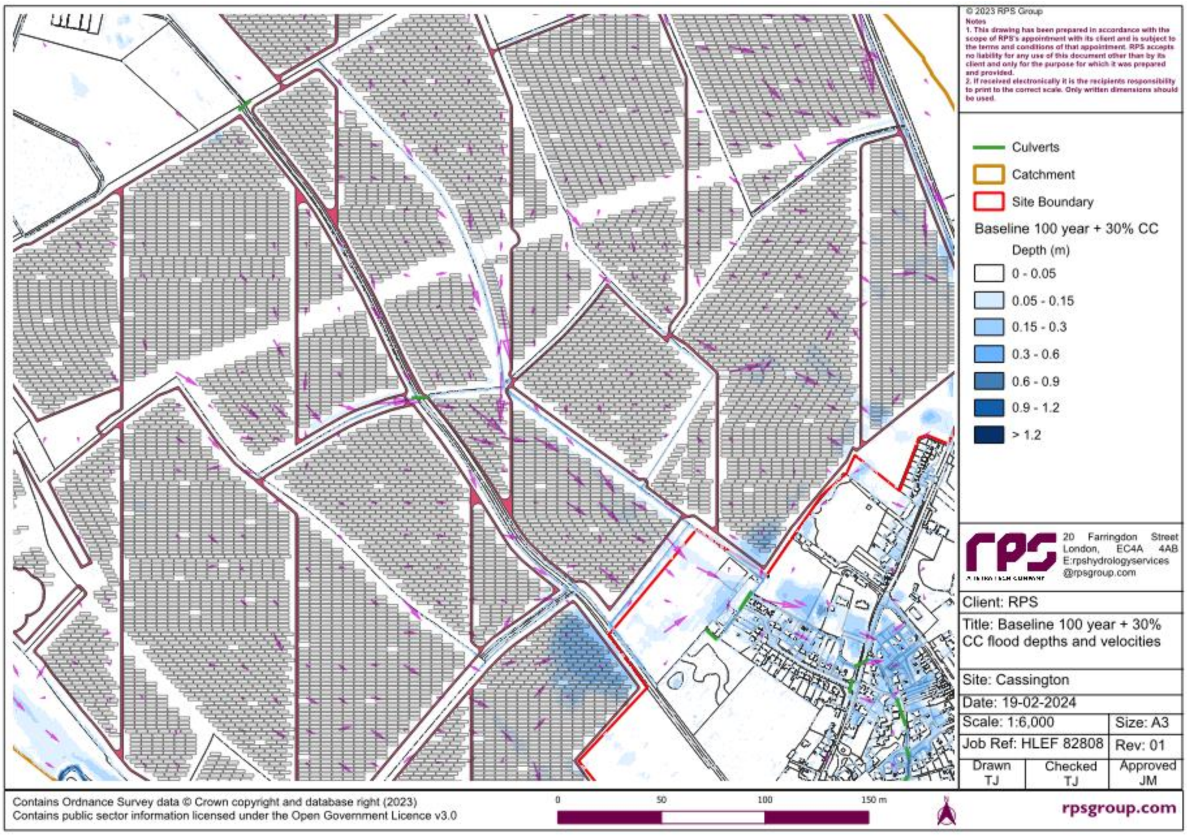

Figure 4.6: in 100 year +30% CC Baseline Flood Depths and Velocities (with proposed panels)

Flood Hazard

4.2.6 **Figure 4.7** shows hazard mapping for the 1 in 100 year + 30 % CC scenario, with **Table 4.1** showing how these values relate to the hazard categories. Most of the catchment is categorised as a 'Very Low Hazard'. Areas within the village and impacting properties adjacent to the stream are categorised as 'hazard to some' and 'hazard to most'.

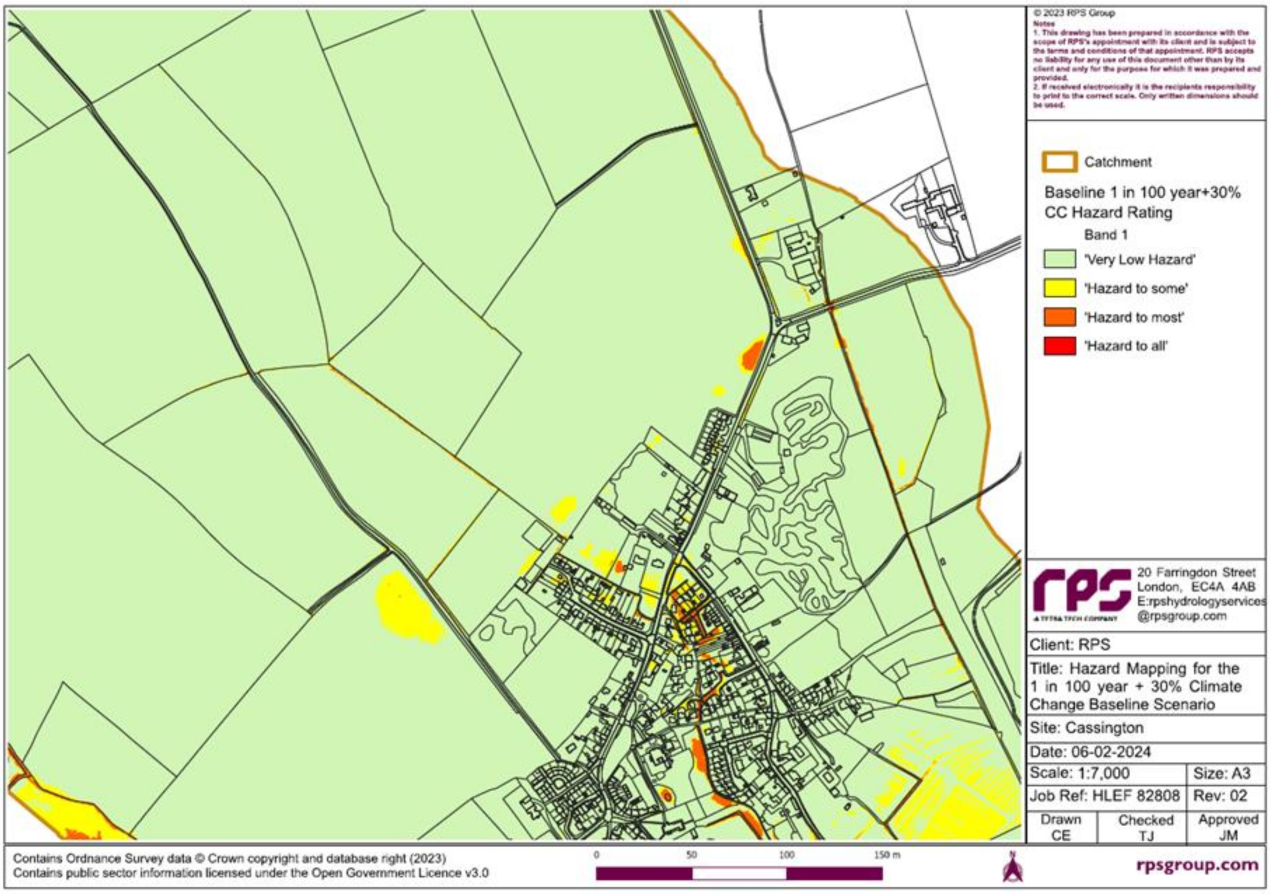

Figure 4.7: 1 in 100 year + 30% CC Baseline Hazard Mapping

Table 4.1: Flood Hazard Categories*

Flood Hazard Rating	Hazard to People
0	No Hazard
< 0.75	Very Low Hazard
0.75 – 1.25	Danger for Some
1.25 – 2.0	Danger for Most
> 2.0	Danger for All

*https://assets.publishing.service.gov.uk/media/602d04a98fa8f5037d371a08/FLOOD_HAZARD_RATINGS_AND_THRESHOLDS_explanatory_note.pdf

4.3 EA Surface Water Comparison

4.3.1 **Figure 4.8** shows the 1 in 100-year EA RoFSW against the 1 in 100-year RPS model results. All figures are displayed on the next page.

4.3.2 Model results indicate that the main source of overland flow to the site is flow from the fields collecting in the central drain which flows southwards towards the south. There are areas of pooling along the field boundaries. Water enters a stream which flows through the village, the channel capacity of this stream is exceeded, and water subsequently impacts buildings in the village. Water pools at the low-lying village to the south as, elevations are lower than the fields to the north.

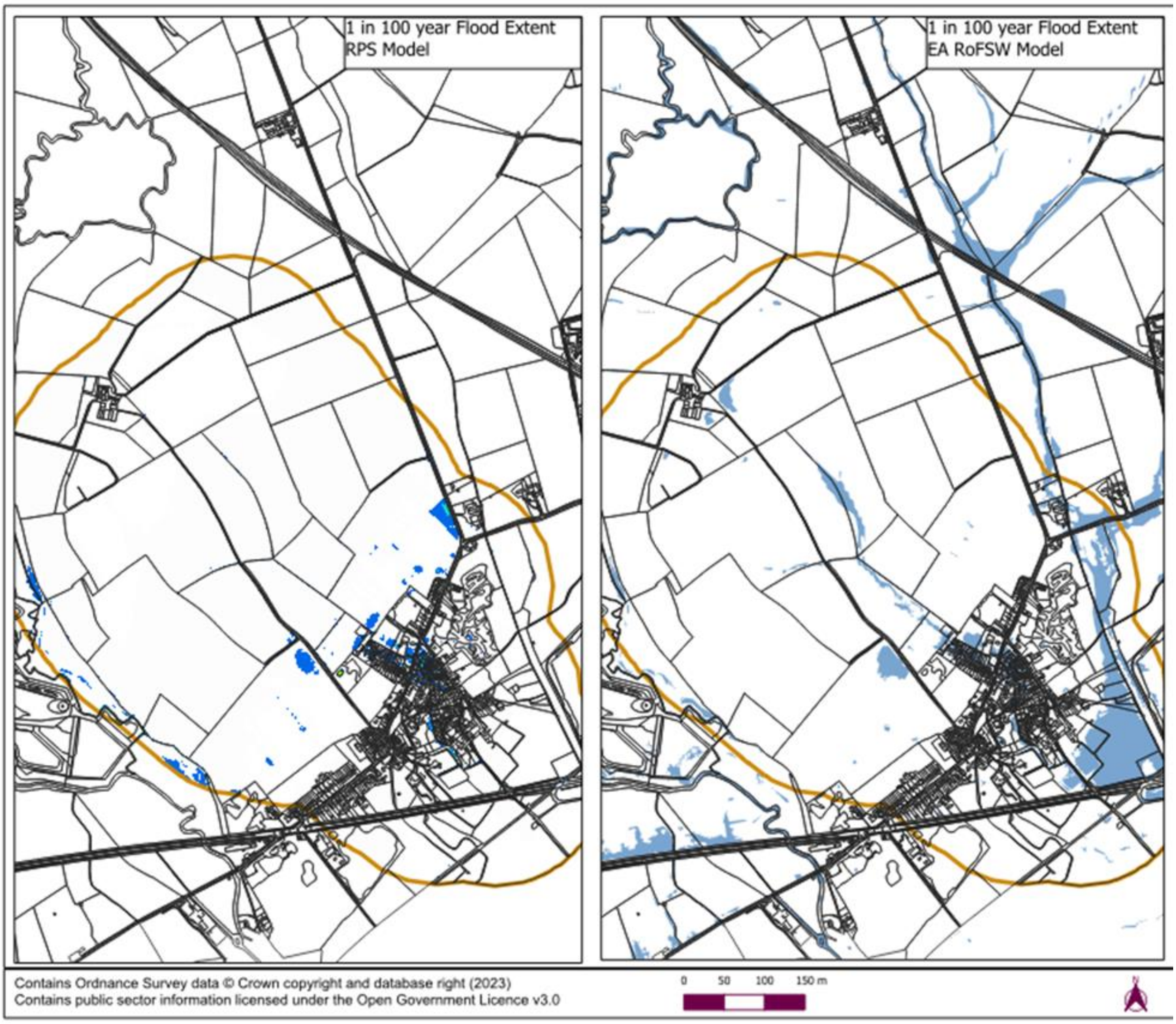

Figure 4.8: 1 in 100 year RoFSW Flood Extent vs 1 in 100 year RPS Flood Extent

4.4 Flows

4.4.1 PO lines have been applied at pertinent locations of the model. This is to extract more detailed information of the flows to determine the proposed mitigation scenario.

4.4.2 The maximum flows for the 100 year +30% CC flood event at pertinent locations of the model are presented in **Figure 4.9**, and **Table 4.2** respectively. Maximum flow at the top of the catchment (PO_1) is 0.093m3/s, with a total volume of 490.8m/s. At the top of the village (PO_5) the maximum flow is 2.130m3/s, with a total flow of 14,297.9m3. This indicates that approximately 2.037m3/s of flow and a volume of 13,807.1m3 accumulates in the fields within the catchment area.

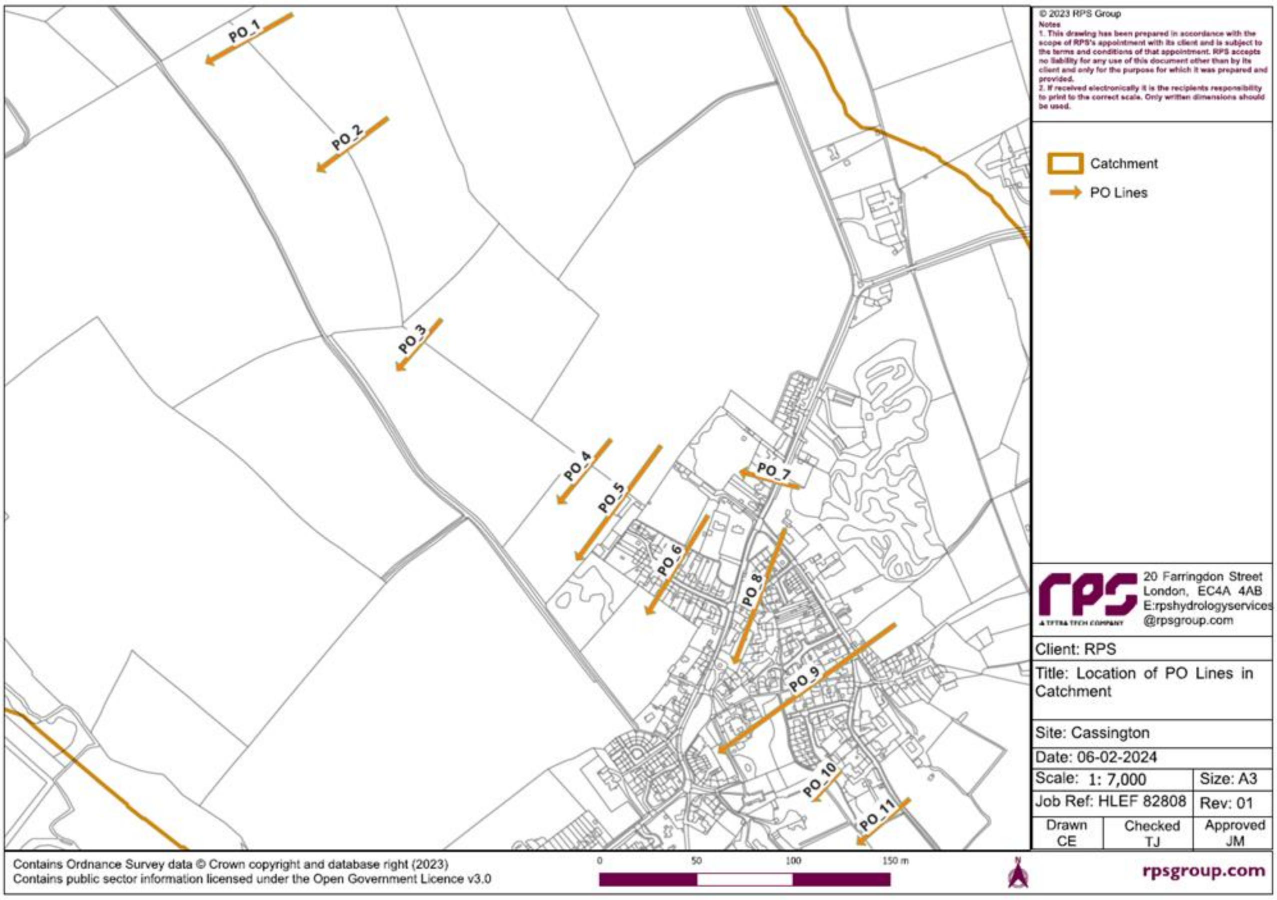

Figure 4.9: Location of PO Lines

Table 4.2: Total Flow of the 100 year +30% CC Flood Event Model Run at Each PO Line

PO Line	Maximum Flow (m^3/s)	Total Volume (m^3)
1	0.093	490.8
2	0.443	3039.1
3	1.424	10032.4
4	1.529	10258.0
5	2.130	14297.9
6	2.198	14252.1
7	0.070	426.3
8	2.158	13890.0

PO Line	Maximum Flow (m^3/s)	Total Volume (m^3)
9	2.146	13081.8
10	2.127	12685.1
11	2.119	12854.0

4.5 Calibration

4.5.1 The results have been calibrated against findings from reporting of flood events, the Atkins (2021) site visit and the EA RoFSW data.

4.5.2 The EA RoFSW map for the 1 in 100 year against the RPS model shows that the extents are relatively similar with overland flow within the fields and pooling in the village. This is shown in **Figure 4.8**.The site visit confirmed that there is fast flowing water within the ditches/drains in the fields. Anecdotal evidence from reporting of flood events, notably a Parish council report highlights that water accumulates at the northern extent of the village within a sports field. It also confirms the flooding seen is from overflow of the stream through the village.

4.6 Sensitivity Testing

4.6.1 Sensitivity testing has been undertaken to understand the impact of an alteration to the culvert dimensions in the absence of survey data.

4.6.2 **Figure 4.10** and **Figure 4.11** show 'Sens 1' and 'Sens 2' results compared against the baseline results. Sens 1 indicates a lesser impact on flood depths seen within the village; Sens 2 indicates there is minimal impacts on the depths within the village. Overall, the impact on the baseline model results is minimal.

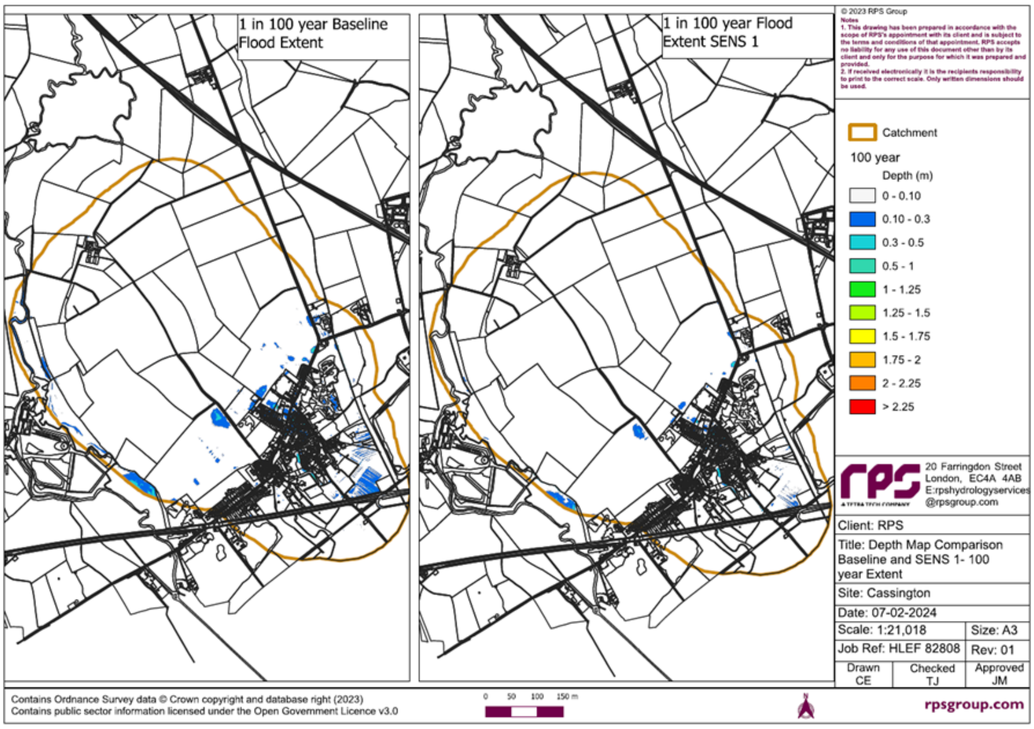

Figure 4.10: Sens 2 vs Baseline 1 in 100 year Flood Depths

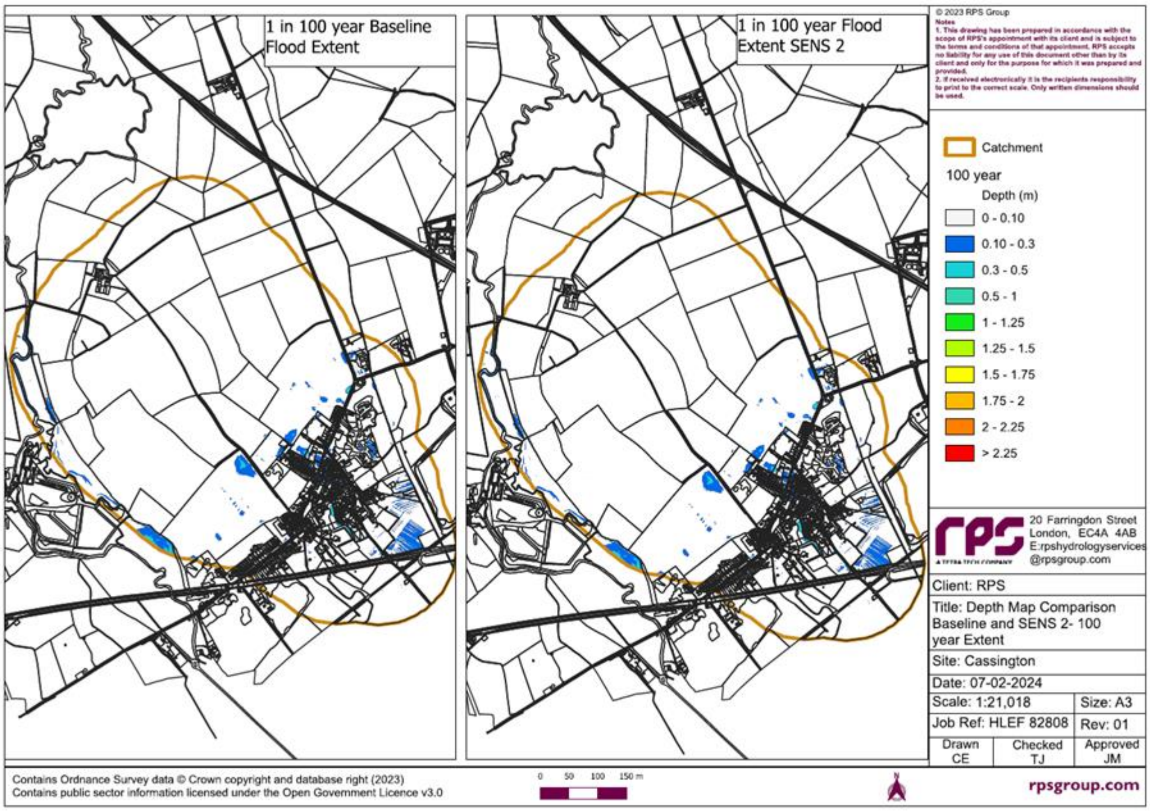

Figure 4.11: Sens 2 vs Baseline 1 in 100 year Flood Depths

5 Natural Flood Management Options

5.1 Introduction

5.1.1 The Natural Flood Management Handbook was published by the Construction Industry Research and Information Association (CIRIA) in May 2022.

5.1.2 The manual details options to provide natural flood management and how these should be implemented. NFM measures are divided into the following categories:

- Soil and land management
- Runoff management
- Runoff storage
- Woodland management
- Leaky barriers
- Offline storage
- Floodplain reconnection
- River channel restoration.

5.2 Potential Options within the Catchment

5.2.1 Those NFM measures which are relevant to the catchment and flow mechanism i.e. surface water runoff, have been explored further. The NFM Measures are presented alongside the most pertinent details, benefits and issues considering the Cassington catchment. This is presented in **Table 5.1** below.

Table 5.1: Potential Natural Flood Management Options at Cassington

Feature Type	Aim	Type	Benefits	Issues	Feasible option?
Soil and land management	Restore or enhance ability of wider catchment landscape to intercept, evaporate, infiltrate and store water.	Changes to farm management practices	Reduction in soil erosion, reduced fertiliser use, increase in biodiversity, habitats, water quality and soil carbon storage.	Reduces flood risk for small events only. Liaising with local farmers required.	X
		Reduce soil compaction	Increase in local biodiversity, increase nutrient available, more crop growth.	Reduces flood risk for small events only. Liaising with local farmers required. Shallow field drains restrict impact, short-term	X
		Encourage more natural habitats	More diverse and new habitats, landscape connectivity, increase in soil carbon storage.	Reduces flood risk for small events only. Liaising with local farmers required. Long-term commitment.	X
Runoff management	Slow or divert overland flow pathways across the landscape, encourage infiltration into the ground and divert water.	Cross drains and deflectors	Reduce accelerated runoff by diverting to fields and verges	No significant runoff from farm tracks identified so may not provide significant benefit.	X
		Cross slope hedgerows (including banked hedges)	Don't reduce farming practices as can be placed along field boundaries.	Management plan required to ensure plants established. Soil loss may occur. Limited establishment in waterlogged areas.	YES
		Buffer strips	Limited maintenance as land can be left to allow natural vegetation to grow	Unwanted invasive species may spread to farming area.	YES

Feature Type	Aim	Type	Benefits	Issues	Feasible option?
Runoff storage	Create and maintain capacity on runway pathways across the land to reduce overland flow. Fill during rainfall events and empty slowly.	Ponds (Contain water at all times)	Can be designed to accommodate a large storm event. Provide additional biodiversity and amenity benefits.	Requires a loss of farming area to implement. Need to ensure it works with slope of land. Need to consider flow exceedance or pond failure.	YES
		Scrapes (Temporary Ponds)	Can be designed to accommodate a large storm event.		
		Swales	Can be used in conjunction with ponds. Provides pollution control/	Slopes can become unstable if not placed at right location.	YES
		Bunds	Divert runoff, can be constructed across contour to slow runoff	May not provide enough mitigation for large events.	YES
Leaky barriers	Slow the flow and increase channel roughness, constructed across watercourse.	Leaky barriers	Relatively simple implementation and can be managed by farmers/ local community.	Requires storage capacity upstream of placement. Risk of washout causing damage to culverts/downstream properties	YES
Offline Storage	Areas that have been adapted to store water by diverting it from a runoff pathway, temporarily store it, and then slowly release water or allow it to infiltrate or evaporate after flood levels have receded.	Offline Storage	Can be placed in unproductive areas away from the farm area.	Creation of large structures may need planning permission. Large structures will need regular inspection.	YES

5.2.2 Construction costs vary depending on the size and location of the proposed feature. However, the Natural Flood Management Measures Booklet (Highways England, 2020) provides indicative pricing which was up to date at the time of reporting. Those measures which have been proposed to be taken forward have been included below along with their construction cost, and maintenance requirement and cost. This is shown in **Table 5.2.**

Table 5.2: NFM Options for Cassington Costs and Maintainance

Feature Type	Type	Construction cost (£)	Unit	Maintenance requirement & Cost
Runoff management	Cross slope hedgerows (including banked hedges)	21,600	Ha	~ 200 per ha per year
	Buffer strips	350-550	Ha per year	Low, ad hoc maintenance
Runoff storage	Ponds (Contain water at all times)	17.50	m^2	10% construction cost/feature
	Scrapes (Temporary Ponds)			
	Swales	20-60	Linear m	10% construction cost/feature
	Bunds	20-60	Linear m	10% construction cost/feature
Leaky barriers	Leaky barriers	500-2000	Per barrier	10% construction cost/feature
Offline Storage	Offline Storage	17.50	m^2	10% construction cost/feature

6 Proposed Option

6.1 Requirements

6.1.1 The requirement for reducing flow downstream of the proposed site is not a must. As such any options provided is anticipated to provide a betterment to the downstream catchment area.

6.1.2 The below details potential options to be considered for the proposed modelling stage.

6.1.3 At this stage the focus of the scheme and modelling is the requirement to provide appropriate flood storage volume to reduce the risk to properties downstream. It is proposed to provide an initial proposed options model to determine if this provides the required reduction in flood risk to properties in Cassington.

6.2 Option 1- Atkins

6.2.1 The proposed option which was determined as part of Atkins (2021) report has been evaluated to determine whether it provides appropriate attenuation.

6.2.2 This option is presented below alongside the construction costs. Please note we have excluded the option to 'cover crops and no till' which was previously presented in the Atkins (2021) report. This is as it is not feasible to model the proposed flood risk impact of this option and as this will significantly impact agricultural practices in the area. The placement of the proposed features has been redesigned in line with the baseline flood modelling, primarily using the results of the 100 year + 30% CC event.

6.2.3 We have digitised the proposed options to be modelled in the next stage of the model process. This is presented in **Figure 6.1** overlain on the current proposed plan below. This option if designed in full would result in the removal of c.1000 solar panels.

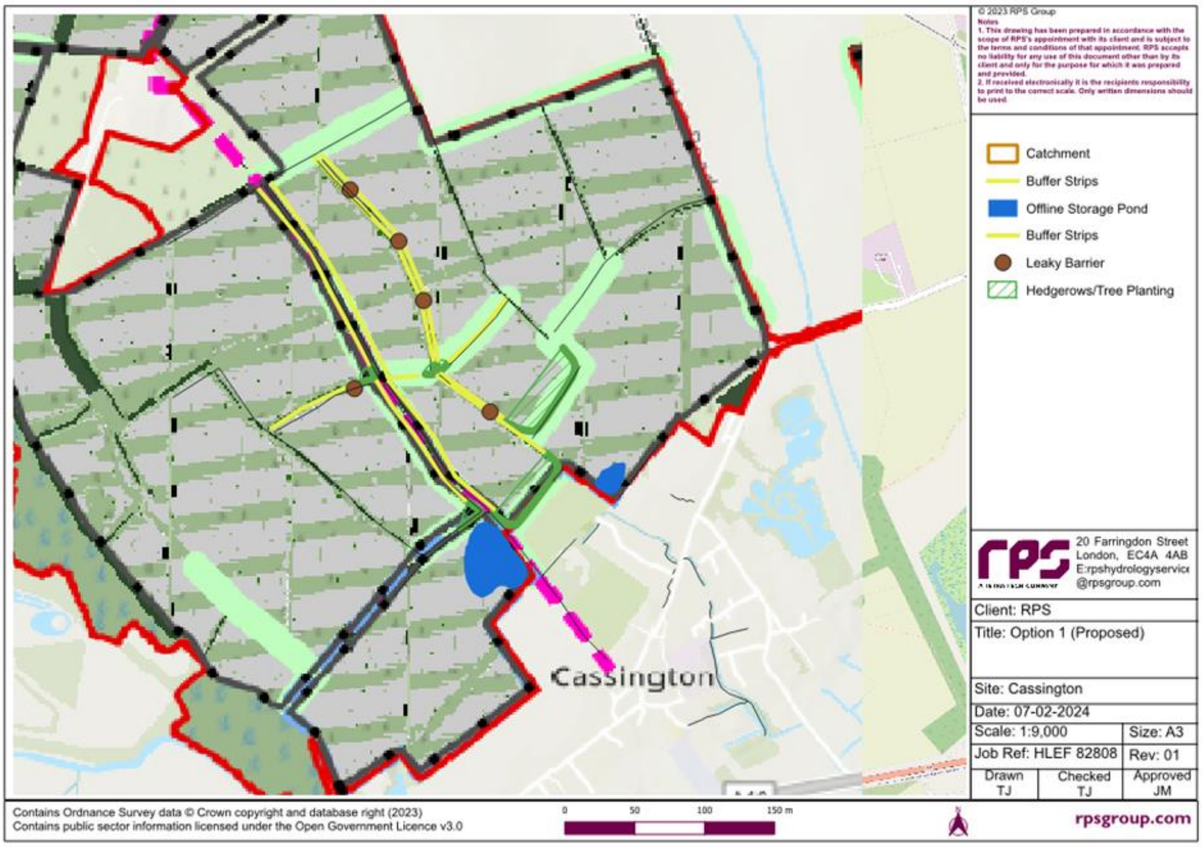

Figure 6.1: Option 1 Proposed Modelling

6.3 Option 2- Swales

6.3.1 Alternative options would seek to work with the existing solar farm layout and implement a series of swales throughout the site, particularly in the downstream sections of this field. This would minimise removal of solar panels. This scheme would redirect and hold back water during a flood event, to then be slowly released following the flood peak.

6.4 Option 3 – Offsite Pond

6.4.1 Another alternative option would be to use the sports field south of the development site, and lease with Cassington residents to place an offline storage pond here to capture flood water. This option would ensure there is no removal of solar panels.

6.5 Chosen Option – Shallow Ponds, Bunds and Ditch Widening

6.5.1 Upon discussion with the client and exploring the current layout the most feasible proposed option is a combination of shallow ponds, bunds and ditch widening. This proposed option will feasibly allow the current design whilst also providing a betterment to runoff and flow at Cassington.

6.5.2 Ditch widening will seek to increase the capacity of the channel to allow more water to be stored, reducing pooling off the fields. A land drainage consent may be required for this works.

6.5.3 Shallow ponds at a proposed 500mm depth will allow storage of water to reduce runoff during high intensity rainfall events. The ponds can work with the current layout as the panels are to be placed at a height of at least 800mm at the shallow edge, they can be placed within the shallow ponds and be raised above the water. Two ponds are proposed where water currently pools and collects at, collectively these will provide an approximate storage volume of 3,200m3. Reeding and planting can take place within the pond to increase the biodiversity and amenity of the landscape.

6.5.4 The earth works dug as part of the shallow pond creation can be reutilised to create bunds to provide bunds (elevated ground) to prevent direct runoff from the fields to Cassington. The bund will slow water from the fields and allow for direction to the ponds and/or widened ditches. This is shown in **Figure 6.2**.

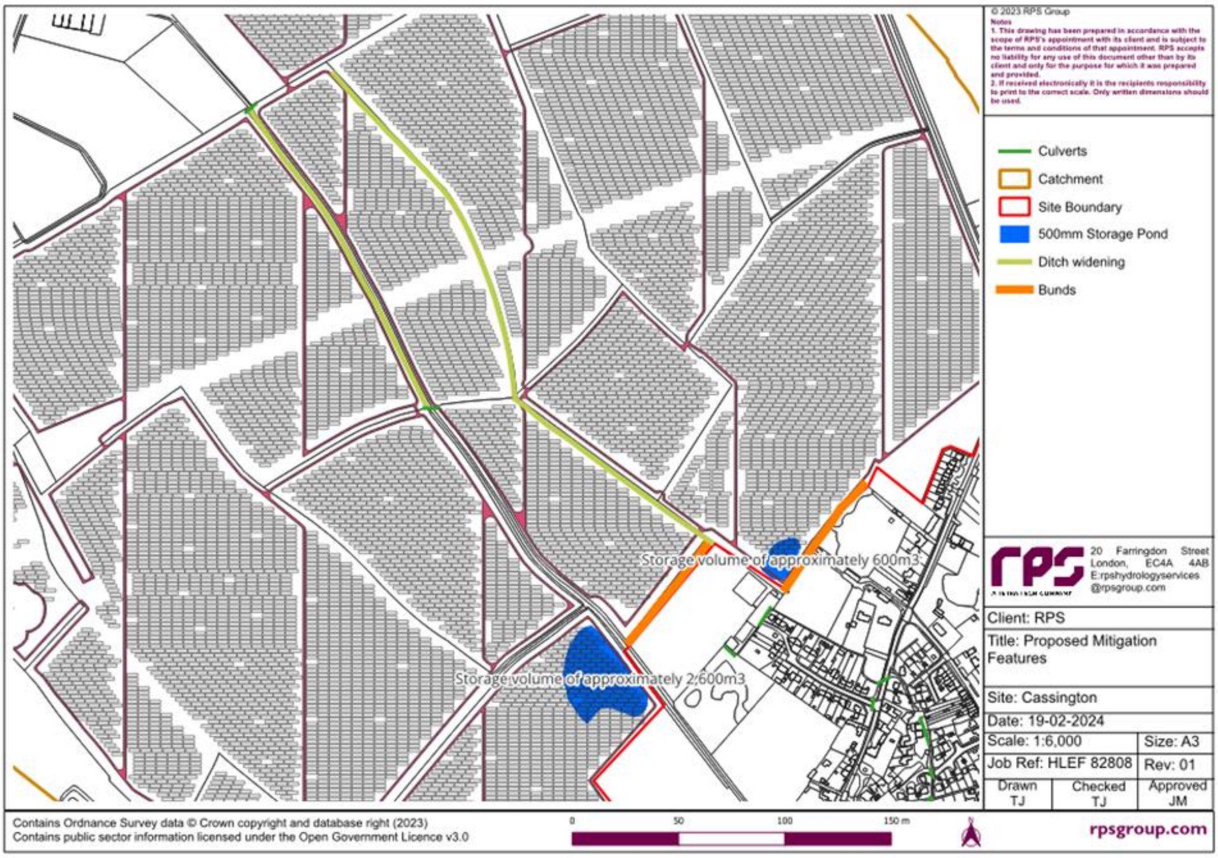

Figure 6.2: Option 4 Proposed Modelling

7 Conclusion

7.1.1 The purpose of this report is to assess the existing surface water flood risk to Cassington and the surrounding area.

7.1.2 A two dimensional (2D) hydraulic model using industry standard -TUFLOW software has been used to simulate surface water flood risk at and around the development site. The 1D structures (culverts) have been estimated using Atkins (2021) site photos and google imagery.

7.1.3 The baseline model results have indicated that the primary mechanism of flooding to the site is via an overland flow path through the fields collecting within a stream that then flows through Cassington. Water gets out of bank of the stream and floods properties in Cassington to depths of up to 0.5m.

7.1.4 Natural flood management measures have been explored in line with the most recent national guidance. This identifies a range of options which can be incorporated upstream of the Cassington village to reduce the flow and provide attenuation of flood water. The following are deemed feasible potential options:

- Buffer strips
- Cross slope hedgerows
- Flow pathway bunds
- Offline Storage Ponds
- In channel leaky barriers

7.1.5 The proposed mitigation measures will be tested at the next stage of the modelling to determine the impact on flows and depths within Cassington.

7.1.6 The chosen proposed option model will be compared against baseline modelling to assess whether the proposed option provides and acceptable reduction in flood risk. Any of the proposed options identified within Table 2 would seek to provide a betterment at the site. A careful consideration of other site constraints and development requirements is required to determine a feasible option.

7.1.7 It is noted that the design process if proceeded with for implementation is likely to be iterative and further consultation and stakeholder engagement is required to ensure the proposed option meets the requirements of all parties.

Appendix A

Cassington NFM (Atkins)

Cassington NFM

DesignBook

Blenheim Estate

June 2021

Notice

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This document has 26 pages including the cover.

Document history

Revision	Purpose description	Originated	Checked	Reviewed	Authorised	Date
Rev 1.0	Draft Report	ABulcock	MJordan	DGasca	BArkell	June 2021

Client

Client	Blenheim Estate (Vanburgh Trust)
Project	Cassington NFM

Contents

Introduction

Welcome to the DesignBook for the Cassington Natural Flood Management (NFM) scheme, in Oxfordshire. This report has been commissioned by the Blenheim Estate and summarises the outcome of initial desk and field studies to identify the main hydrological pathways and opportunities for NFM upstream of the village of Cassington.

This DesignBook is a live document that can be regularly updated as new information becomes available and/or the project moves through different design stages. The document provides both an audit trail describing scheme development, and a means of communicating the details of the NFM scheme both internally and externally.

Site Characterisation

Cassington

Site Character (see Figure 1)

NGR	SP450113 (approximate site centre point)
Extent of opportunity area	85 ha
Assets at risk	The NFM scheme is intended to protect a number of properties in the village of Cassington that have been affected by flooding in recent times. The village is not however within any of the flood zone areas identified by the Environment Agency (see Figure 1) and is affected mainly by surface water flooding from the catchment upstream of the village.
Catchment	A small, flashy stream (hereafter called the 'Cassington Stream') runs through the village. The catchment of this watercourse upstream of Cassington is 83 ha in extent. The downstream end of the catchment is considered to be where the Stream passes under the Cassington Road (see Photo 01). There is some uncertainty regarding the precise upstream boundary of the catchment draining towards the village of Cassington. This is mainly due to the effects of artificial drainage for agriculture upstream that has adopted natural topographic flow pathways. At this initial stage, and to take account of this uncertainty, a precautionary approach to catchment delineation and flood hydrology calculations has been adopted and includes all likely fields upstream of Cassington (see Figure 1) to provide a robust but worst-case scenario. The catchment is within the Thames (Evenlode to Thame) WFD Waterbody. The River Evenlode runs to the west of the site, and the River Thames runs to the north. The confluence of the Evenlode and Thames is close by, also in the village of Cassington.
Land cover and usage	Historical maps of the site suggest that the site has historically always been farmland (Appendix A). The catchment is currently predominantly arable land (Appendix B1), much of which has been formally drained. During the winter of 2020–21 most of the arable land was bare due to climate conditions in the preceding autumn that limited the sowing of crops (as elsewhere across the Evenlode catchment) (see Photo 02).
Ditches and drainage	The catchment is well connected hydrologically. Most of the field boundaries have been ditched (with evidence of active maintenance) and are connected by means of open (see Photos 03 and 04) and piped connections (see Photos 05 and 06). Numerous underdrains were also observed during a field walkover on 31 January 2021 (see Photos 07 and 08).
Geology and groundwater	Groundwater is likely to be an active source of floodwater in the catchment. The upstream reaches of the catchment are associated with local gravel deposits (Appendix B2 and B3) that act as a local aquifer and Ordnance Survey maps of the catchment identify a spring upstream that is piped into the local ditch system (Photo 08). The downstream parts of the catchment are underlain by the Oxford Clay Formation and West Walton Formation[1] (Appendix B2 and B3) where runoff will be more significant and groundwater less important.
Topography	The catchment slopes steeply from Purwell Farm (the catchment boundary to the north) to Cassington (the catchment boundary to the south) (see Site View). Whereas Purwell Farm and its immediate surrounds sit at an elevation of around 97 mOD, the village and road through Cassington are at an elevation of around 66 mOD (Appendix B4). Field slopes through the catchment vary from approximately 1 to 4 degrees (Appendix B5).
Soils	The soils across the catchment vary in response to topography and geology. A catchment soil map is provided in Appendix B6. The catchment extends across a number of the terrace deposits of the River Thames (see geological description). Different soils in the area have subtly different hydrological regimes and land use suitabilities.

Location	Soil Description	Geological description	Hydrological regime	Cropping and Land Use
Upper Catchment	0571u Sutton. Fine, loamy typical argillic brown earths over gravel at moderate depth. Typically found on level or gently sloping river terrace in the valleys of the Thames in Oxfordshire.	Hanborough Gravel Member[2]. Cold phase sands and gravels underlying Hanborough or Fourth Terrace of BGS Maps. Dominated by clasts of Middle Jurassic limestone, in some cases decalcified, leaving a deposit dominated by "Bunter" quartz/quartzite.	Well-drained, permeable soils through which excess winter rainfall drains rapidly. Moderate reserves of available water and are therefore slightly or moderately droughty for cereals and potatoes and very droughty for grass.	Good arable land with cereals and vegetables, mainly potatoes. Work in both spring and autumn is possible and there is limited risk of damaging the soil structure. Fast draining so it is also possible to be worked in winter
Mid-Catchment	0712b Denchworth[3]. Slowly permeable, seasonally waterlogged clayey and fine loamy over clayey soils. Landslips and irregular terrain locally. On Oxford Clay, the Denchworth soils usually contain calcium carbonate concretions within 60 cm depth.	Wolvercote Sand and Gravel Member[4]. Cold phase sands and gravels that underlie the Wolvercote or Third Terrace of BGS maps. Dominated by clasts of Middle Jurassic limestone, but also containing "Bunter" quartz/quartzite and a proportion of flint.	Slowly or moderately permeable in the topsoil, slowly permeable at depth and waterlogged for long periods in the growing season. Responds well to drainage measures. If annual rainfall is less than 600 mm the wetness class can be improved to 3 from 4/5.	Yields moderately good crops of grass, cereals and oilseed rape if underdrainage is efficient. Autumn sown crops favoured, as little to no work can be done in the spring. Soils can poach easily. Acidic soils. Good potassium status but phosphorus held in state not available for plants.
Lower Catchment	0511h Badsey[5]. Well drained calcareous and non-calcareous fine loamy soils over limestone gravel. Typical of level or gently sloping river terraces along the Thames and its tributaries in Oxfordshire. Gravel at shallow depth.	Summertown-Radley Sand and Gravel Member[6]. Cold phase sands and gravel that underlie the Summertown-Radley or Second Terrace of BGS maps. Dominated by clasts of Middle Jurassic limestone, with "Bunter" quartz/quartzite and some flint.	Well drained soils (wetness class 1) but droughty for cereals and grass with lack of early summer moisture influencing yields.	Can be cultivated in autumn and spring without damaging soil structure. Mainly mixed farming or dairying on ley grassland. Little risk of poaching by stock.

[1] https://webapps.bgs.ac.uk/lexicon/lexicon.cfm?pub=OXWW
[2] https://webapps.bgs.ac.uk/lexicon/lexicon.cfm?pub=HAN
[3] https://www.landis.org.uk/services/soilsguide/mapunit.cfm?mu=71202
[4] https://webapps.bgs.ac.uk/lexicon/lexicon.cfm?pub=WV
[5] https://www.landis.org.uk/services/soilsguide/mapunit.cfm?mu=51108
[6] https://webapps.bgs.ac.uk/lexicon/lexicon.cfm?pub=SURA

Flood dynamics

Flood Hydrology

The main source of the flood risk to the village of Cassington is the flow of runoff downslope from agricultural fields in the catchment upstream of the village. Groundwater is likely to contribute from the springs that are mapped in the catchment and shown in Figure 1. Ditches act as field boundaries and show a clear directional pattern downslope towards the village. The fields themselves also slope southwards towards the village. Flows are concentrated into the Cassington Stream that coalesces into a single watercourse near the community centre just upstream of the village. This hydrological system therefore provides a clear pathway for flood water to move from the catchment towards the village. All soils and fields are well drained, on sloping ground and with a limited storage capacity suggesting a flashy catchment that will respond rapidly during intense or prologued rainfall events that will drive flood events locally.

The flows and volumes of floodwaters likely to affect the village of Cassington have been assessed using the industry standard ReFH2.3 approach (Revitalised Flood Hydrograph Model). Understanding flows and volumes is the first step to understand the scale of NFM interventions likely to be required. ReFH also provides a way of quantifying the likely flood hydrograph in a catchment, how flashy it is and how quickly the catchment responds to rainfall, which are all important metrics to distinguish between measures that store or slow floodwaters.

ReFH2.3 was applied to Cassington using FEH catchment descriptors amended as follows:

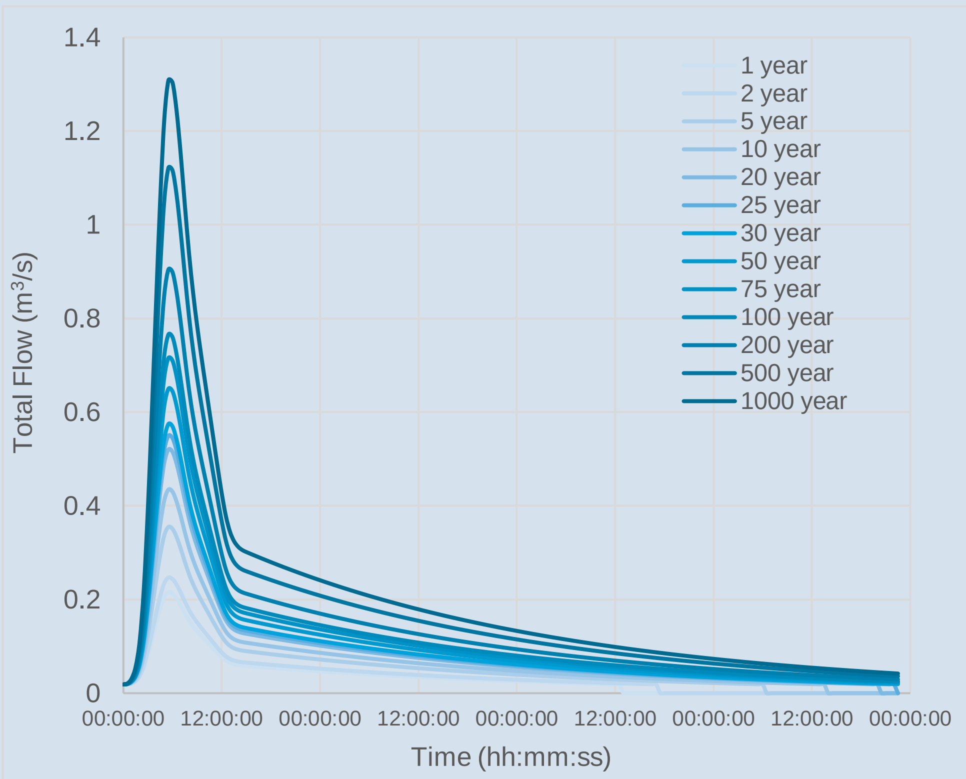
- Area – value estimated by the Flood Estimation Handbook (FEH) updated to the catchment area defined by field verification walkover surveys (shown in Figure 1);
- DPLBAR – re-calculated using updated catchment area (see above) and FEH equation; and
- Urbext2000 – updated to 0 due to the catchment area being confirmed as completely rural.

Flow hydrographs were exported for a range of return periods using:

- A winter rainfall profile due to Urbext2000 being lower than 0.3;
- Default ReFH2.3 parameters calculated from catchment descriptors; and
- A storm duration of 4.5 hours, as recommended by the ReFH2.3 software.

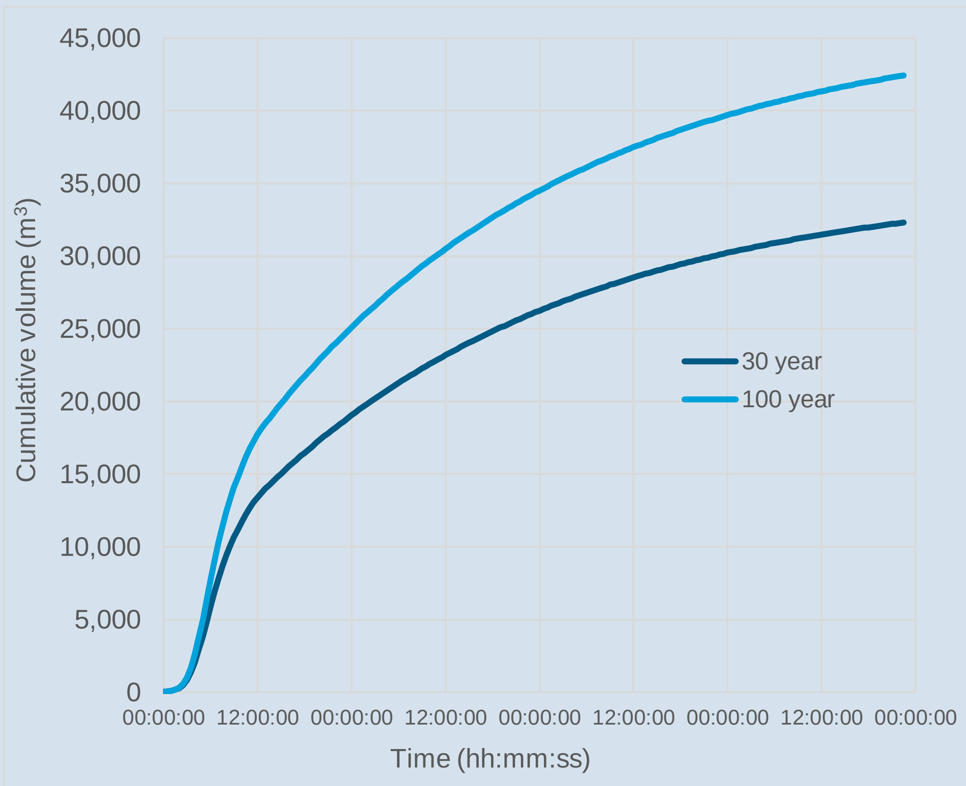
The ReFH2.3 outputs for the Cassington catchment are summarised in the figures below.

(a) Flood hydrograph



The graph above shows the hydrographs predicted for the Cassington catchment for floods of a range of return periods or probabilities. The results show that the Cassington catchment is flashy, responding rapidly to rainfall and peaking six hours after rainstorm events. The receding limb is as steep as the rising limb and most water passes through the catchment very quickly, in around 12 hours, with a slower gradual decline thereafter. The 1:100yr flow which is sometimes used for flood design is close to 0.8 cubic metres per second in this catchment.

(b) Cumulative flood volume



The graph above shows the cumulative water volumes passing through the village during the 30- and 100-year flood events (return periods frequently used in NFM studies). Understanding cumulative volumes can help establish the scale of storage that might be needed to help protect communities from flooding.

For the 30-year event, the total storm volume was just over 32,000 m^3 of which around 14,000 m^3 passed through in the first 12 hours during the peak of the flood.

For the 100-year event, the total storm volume was close to 42,500 m^3 of which around 18,000 m^3 passed through in the first 12 hours during the peak of the flood.

(c) Field sizes and flood volumes

Field	Area (ha)	Slope (degrees)		Defra Soil Erosion Risk	Volume 1:30-year flood	Volume 1:100-year flood
		Mean	Max			
1	20	2.2	14	Moderate	6,882	9,140
2	8	3.3	14	High	2,753	3,656
3	9	3.6	14	High	3,097	4,113
4	5	2.7	14	Moderate	1,720	2,285
5	5	2.1	14	Moderate	1,720	2,285
6	8	2.6	14	Moderate	2,753	3,656
7	20	1.7	14	Lower	6,882	9,140
8	18	3.2	20	High	6,193	8,225
TOTAL	**93**	**-**	**-**	**-**	**32,000**	**42,500**

The table to the left subdivides the catchment into eight main fields that, based on the January 2021 field visit, are thought to contribute most to flood risk. The fields are labelled on the Site View overleaf and on the Key Plan in Figure 1. The areas of each field have been calculated to understand the likely volumes of runoff that might be being generated in each field. This calculation can provide the starting point to understand the design of NFM features on a field by field basis, where some form of intervention is implemented in every field.

In addition, soil erosion risk in each field has also been calculated using a Defra approach (see Appendix C) that combines soil type and slope information. This can provide the starting point for the design multiple benefits into an NFM scheme. Where soil erosion risk is highest, implementation of NFM measures could have the highest chance of delivering, for example, improved water quality.

Due to the soil type and slopes across the catchment upstream of Cassington, most of the fields present a moderate-high risk of soil erosion confirmed during site visits that identified significant runoff pathways and sediment sinks (Photos 09–11). Any measures to slow or store water in the fields are likely to result in some water quality benefits.

Site view


Cassington
Field 8
Field 7
Field 4
Field 5
Field 6
Field 3
Field 2
Field 1

NFM opportunities

NFM handbook opportunities

NFM opportunities relevant to the Cassington catchment have been identified using the Natural Flood Management Measures Booklet (Highways England, 2020) on the Catchment Based Approach (CaBA) website[7]. This booklet provides a standardised list of 13, easy-to-understand NFM interventions that are relevant to most catchments in England. The booklet, which includes images showing what each measure looks like, is reproduced in Appendix D. The table below provides a high-level summary of each of the NFM measures described in the booklet, including their potential unit costs, in some cases updated using more locally specific costings.

Code[8]	NFM measures	Description of measure	Construction cost (£)	Unit	Maintenance requirement & cost
LM01.1	Buffer strip	Area of permanent vegetation to flow run-off and absorb rainfall.	350–550	ha per year	Low, ad hoc maintenance
LM01.2	Hedgerows/cross slope woodland	Cross-slope belt intercepts runoff down a hill and encourages infiltration of water in the soil.	21,600	ha	~200 per ha per year
LM02.1	Reducing soil compaction	Increases infiltration rates by reducing soil compaction / changes in soil management.	60–100	ha	Low, ad hoc maintenance
LM02.2	Herbal Leys	Increases infiltration by improving the soil structure with deep rooted herbal leys.	150–250	ha per year	Low, ad hoc maintenance
LM02.3	Cover crops and No Till	Cover crops to manage soil erosion and/or a direct drilling method of crop production to reduce interference in soil structure.	20–200	ha per year	Low, ad hoc maintenance
FR01.1	Overland leaky barrier	Reduces flood risk by holding back water behind the feature.	50–150	m length	10% construction cost/feature
FR01.2	Flow pathway bund	Shallow earth bunds intercept runoff down a hill and encourage infiltration of water in the soil.	50–150	linear m of bund	10% construction cost/feature
FR02.1	Offline pond	Ponds and wetlands can be used encourage more regular inundation and water storage.	17.50*	m³	10% construction cost/feature
FR02.2	Online pond				
FR02.3	Swale	Vegetated channel used to convey and treat runoff. It can be lined or unlined to allows infiltration.	20–70	linear m	10% construction cost/feature
WC01.1	In channel leaky barrier	Reduces flood risk by holding back water behind the feature.	500–2,000	Per barrier	10% construction cost/feature
WC01.2	Woody bundles	Brushwood and minor branches placed in dry valleys to slow overland runoff.	50–1,000	Per bundle	10% construction cost/feature
WC0.1.3	Moorland grips	Digging ditches to drain wet areas of heath and blanket bog.	50–250	Per feature	10% construction cost/feature

*Costs taken from the NFM handbook, except * which is based on more locally relevant information.*

NFM handbook measures relevant to Cassington (see Figure 2)

Not all 13 measures in the NFM Handbook are relevant to the Cassington catchment. An important assumption to develop a concept for an NFM scheme was to maintain all eight target fields in arable production. As a result, measures that maintain this land use were selected in preference to others such as arable reversion or herbal leys that are typically associated with more significant NFM benefits but would require significant changes in land use.

Other measures were distributed on field edges or corners, with a particular focus on interrupting runoff pathways between fields and ditches that were identified using detailed topographical information and field evidence of where these were located. The larger areas of mainly offline storage were positioned closer to the village where topography and known ground conditions indicated these would be most suitable. The potential position of these measures also acknowledges the important recreational and community resource features like this can provide; a feature of this type has already been constructed in this area (Photo 12) close to the allotment field.

The table below and Figure 2 summarise the concept for the Cassington NFM scheme. First-pass cost estimates based on assumptions regarding the relative scales of interventions are also provided in Table 2 below. These costs refer to NFM infrastructure that will store and slow the volumes associated with the full flood hydrograph; it is likely that these could be scaled back if the scheme were to target the flood peak only, but the information is presented to give the upper range of costs as a starting point.

Code	NFM measures	Field 1	Field 2	Field 3	Field 4	Field 5	Field 6	Field 7	Field 8	Total quantity	Unit	Construction cost
LM01.1	Buffer strip (ha)	0.652	1.015	0.644	0.311	0.616	0.286	-	-	3.524	ha	1,233–1,938*
LM01.2	Hedgerows and cross slope woodland (ha)	0.06	0.15	0.06	0.84	0.64	0.24	-	-	1.89	ha	43,200
LM02.3	Cover crops and No Till (ha)	20	8	9	5	5	8	20	18	75	ha	1,500–5,000*
FR01.2	Flow pathway bund (m)	68	113	75	270	150	250	-	-	926	m	46,300–138,900
FR02.1	Offline storage pond (m³)	-	-	-	-	-	-	7,614	1,743	9,357	m³	163,800
WC01.1	In channel leaky barrier (No.)	1	3	3	1	1	1		-	5	No.	2,500–10,000
											Total cost (£)	258,533–362,838

**Costs for single year only to cover transition from transition from current arable practice. Additional costs are possible year to year.*

Funding NFM implementation

The NFM measures above have been costed individually. More detailed re-costing through a formal design with Early Contractor Involvement (ECI) is recommended if the Blenheim Estate wish to take and NFM scheme concept forward. Whilst the landowner will be expected to contribute to the scheme, it is likely that potentially significant funding streams could be identified from the following sources:

- **Countryside Stewardship** agreements, arranged through discussions with Natural England CSF officers.
- **Biodiversity Net Gain** funding available for landowners through TOE2 (https://www.trustforoxfordshire.org.uk/biodiversity-net-gain-landowners)
- **Carbon credits** for tree planting for example through the Forest Canopy Foundation (https://forestcanopyfoundation.co.uk/about-us/) or for upcoming soil credits.
- **Statutory bodies** such as the Environment Agency and Local councils are all funding or have funded similar NFM schemes elsewhere.
- **Water companies** such as Thames Water also have initiatives that could contribute to funding an NFM scheme where it delivers multiple natural capital benefits.
- Local catchment and landscape **partnerships** may also have access to funding for NFM projects of this kind.

[7] NFM-Measures-Booklet.pdf (catchmentbasedapproach.org)
[8] Design-Specification-Catalogue.pdf (catchmentbasedapproach.org)

Buildability and consenting

Buildability

The table below outlines the current understanding of different elements that are likely to influence the buildability of the scheme. This is based on experience of delivering NFM schemes elsewhere. To help identify risks, each element has been RAG (Red, Amber Green) assessed to identify particular constraints that need to be addressed prior to construction to ensure safety of delivery contractors and mitigation of any known or unknown risks to construction.

No.	Risk	Description	Current risk status
a	Landownership	landowner is fully engaged with the scheme and is part of the collaborative design team.	Low
b	Designations	The site is not located directly within any designated areas but there are a number in the surround area. Cassington Meadows SSSI, Pixey and Yarnton Meads SSSI, Wytham Woods SSSI are directly to the south of, but outside, the hydrological zone of influence of activities in the project area. The Cotswolds AONB is to the north west and outside of the project area. The project area is within a Nitrate Vulnerable Zone (NVZ) and any NFM measures will need to align with requirements specified by this designation.	Low
c	Underground services	It is not currently known whether there are any underground services present on site and this assessment should be undertaken before the scheme goes ahead.	Medium
e	Overhead cables	The presence of overhead power cables has not been formally assessed as part of this study and should be considered before the scheme goes ahead.	Medium
f	Contaminated land	There is an historic landfill site to the east, west and south of the project area. These are not in hydrological connectivity with the site.	Low
g	UXOs	The UXO risk map shows the project area to be of Low risk relative to UXOs (Appendix E). A full UXO desk study and risk assessment would be required prior to construction.	Low
H	Ecology	No ecological surveys are known to have been undertaken across Cassington. A typical requirement for some funders is to provide an ecological baseline and Phase 1 habitat survey for sites subject to NFM type developments.	Medium
I	Ground conditions	A single borehole describing local ground conditions has been identified to the south of the site (Appendix F). Where NFM measures such as bunds are constructed, more detailed understanding of the nature of underlying material may be required to understand the stability and water holding capacity of any features proposed.	Medium
J	Spoil Management	It has been assumed that any spoil generated by the scheme will be reused on site either for construction or worked into local arable soils.	Low
K	Environmental Stewardship	There are no stewardship schemes currently on any of the fields considered in this report. There are clear opportunities to build any NFM interventions around a Countryside Stewardship application.	Low
L	Archaeology and heritage	There is a scheduled monument to the south east of the site and several listed building to the north and south of the project area but all are outside the project area. The long history of arable farming means any near surface archaeology will no longer be present.	Low
M	Local flood receptors	Cassington village and its road (both to the south of the catchment) are the main flood receptors. Any scheme developed will need to ensure that the scheme actively reduces flood risk to these assets.	Medium
N	Recreational access & health and safety	There are a number of public footpaths running through the project area (e.g. Photo 13) and it is likely that some form of Health and Safety management would be required once measures are in place (e.g. through signage).	Medium
O	Construction access & health and safety	There are a number of public footpaths running through the project area and it is likely that some form of access management (e.g. diversions, signage) would be required during any NFM construction.	Medium

Consenting, licensing and endorsements

The table below considers the likely licencing, consents and endorsements that may be required t implement an NFM scheme at Cassington. This helps to identify the relevant organisations that would need to be consulted forming the starting point of any project communication plan, whilst identify the likely participants in a partnership delivery of the scheme. The colour coding reflects the level of certainty and whether there are additional activities that need to be undertaken before the scheme is progressed further.

License/consent/endorsement	Authorising body	Requirement
Planning permission	Local Council	No requirement. Works to be delivered under permitted development.
Flood risk consent (to include excavation of floodplain)	County Council	Needs to be clarified through consultation with OCC. Site adjacent to Ordinary Watercourse. Flood risk should also be discussed with Environment Agency. Technical work to define effects on flood risk may be required.
Discharges to surface water	Environment Agency	No requirement. No discharges expected as part of the scheme.
CSF endorsement	Natural England	Consultation with Natural England.
Forestry Commission endorsement	Forestry Commission	Consultation with Forestry Commission in any tree planting proposed.
Catchment Partnership endorsement	Catchment Partnership	Consultation with Catchment Partnership.
Waste	Environment Agency	Consult with Environment Agency to identify requirements.
Historic Environment	County Council	Unknown at this stage.
Natural Environment	County Council	Unknown at this stage.

Consultation

The table below identifies the people consulted as part of the project at this stage.

Organisation	Staff consulted
Landowner	Roy Cox
Environment Agency	Jo Old
Natural England	Andrew Russell
Atkins	Dave Gasca, Amelia Bulcock, Marcus Huband, Ian Morrissey

Next steps

- This document presents a series of concepts for NFM upstream of the village of Cassington. To proceed further, more detailed discussions with landowners and managers would be required, alongside consideration of the actual functioning of the catchment during floods. Formal field surveys including topographic surveys to detail some of the features would also be required.
- Engaging an experienced local contractor at an early stage would also be beneficial, alongside consideration of feasibility items such as ground conditions.
- Very limited consultation has been undertaken at this stage but would be required under any future steps. For example, it is recommended that this document is shared with the Environment Agency and Oxfordshire County Council Lead local flood authorities.

Site Photographic Record

Photo 01. Downstream end of the catchment

Photo 02. Bare fields and runoff (January 2020)

Photo 03. Open ditch connection

Photo 04. Open ditch connection

Photo 05. Piped ditch connection

Photo 06. Piped ditch connection

Photo 07. Underdrainage

Photo 08. Underdrainage

Photo 09. Sediment and runoff pathway

Photo 10. Sediment deposition

Photo 11. Public footpaths

Photo 12. Existing pond

Figure 1 – Key Plan

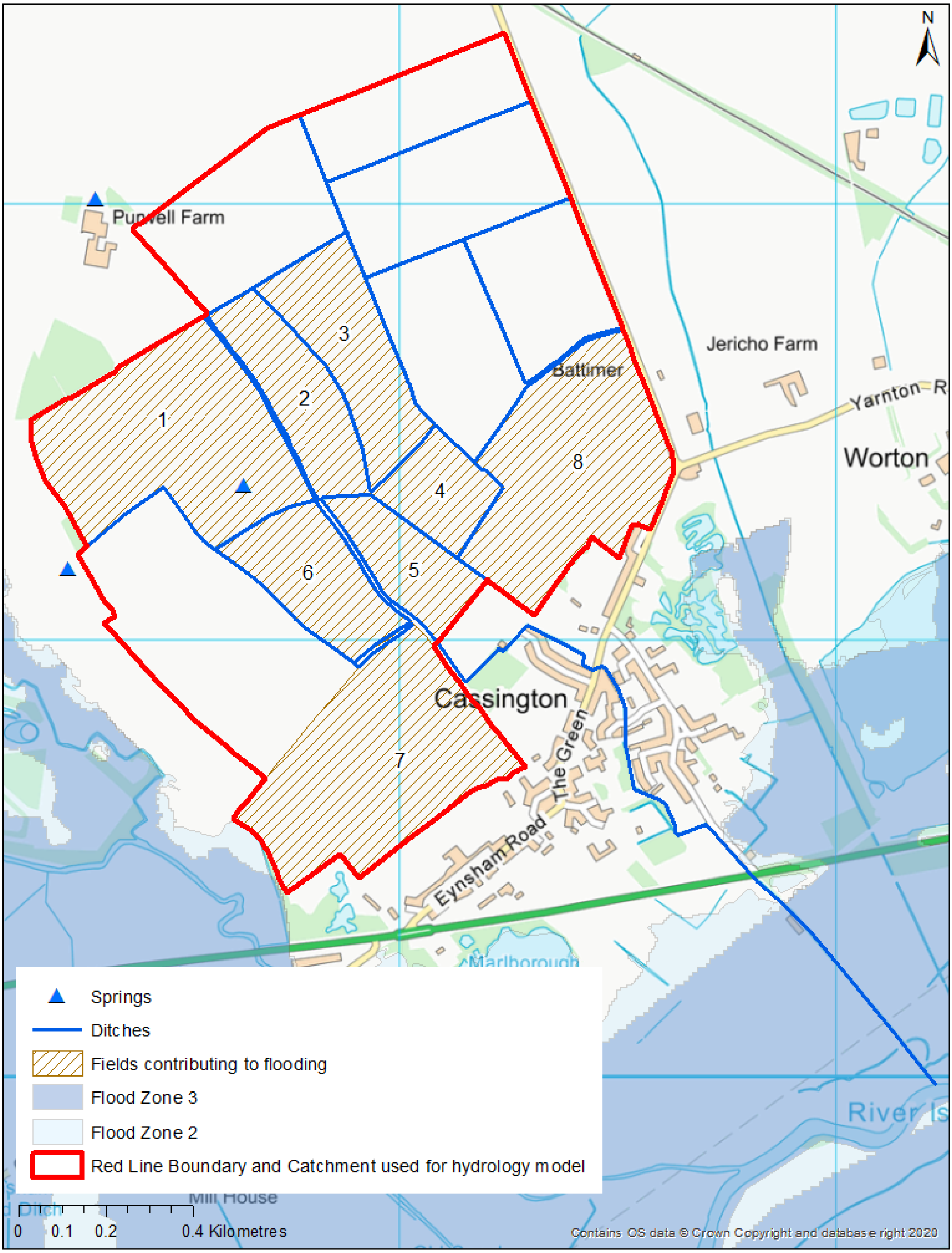
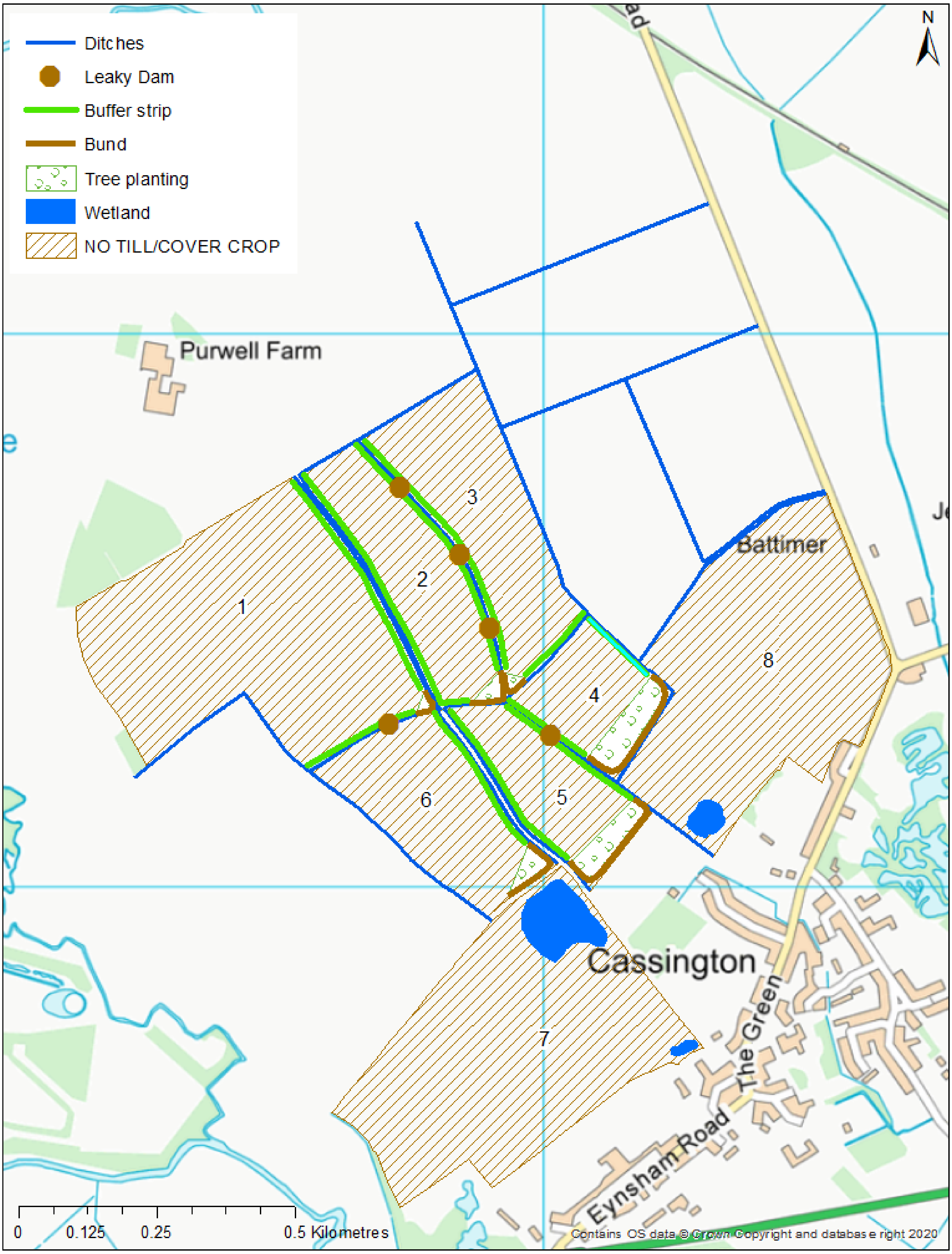


Figure 2 - Concept Plan



Appendices

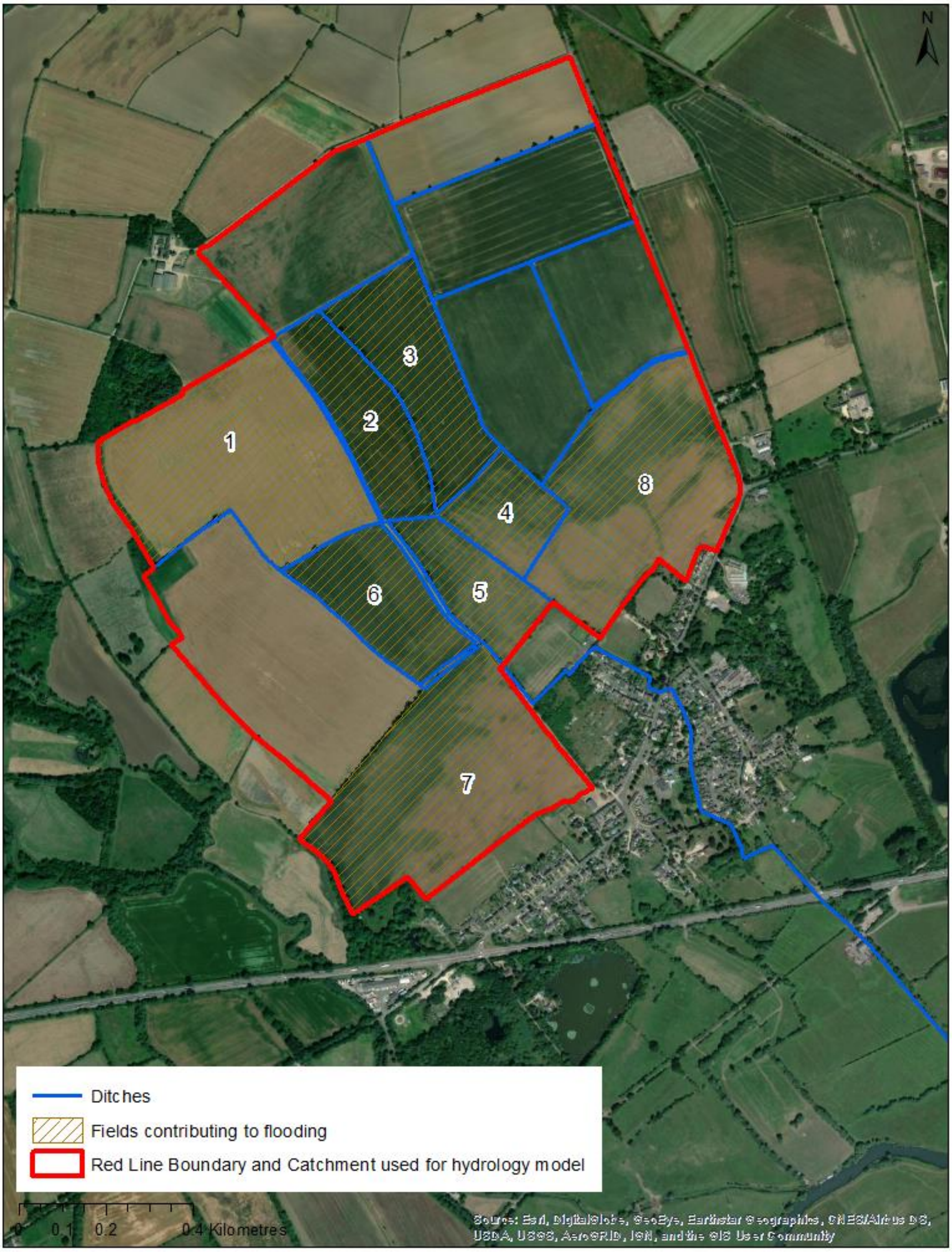
Appendix A. Historical mapping

(a) Historical Map from 1885 from the National Library of Scotland.

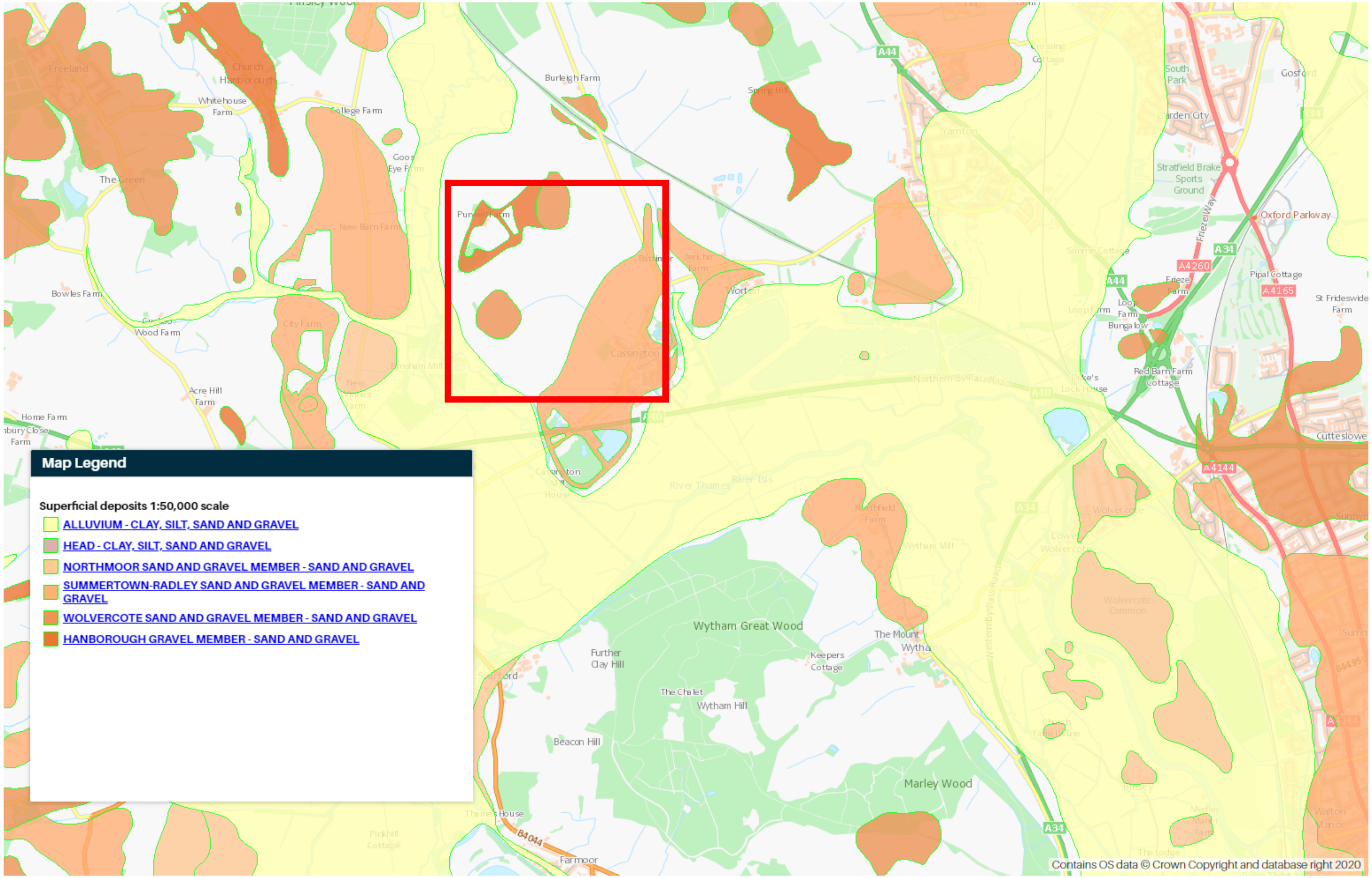
(b) Google Earth image from 1954

Appendix B. Site characterisation

B.1. Land use

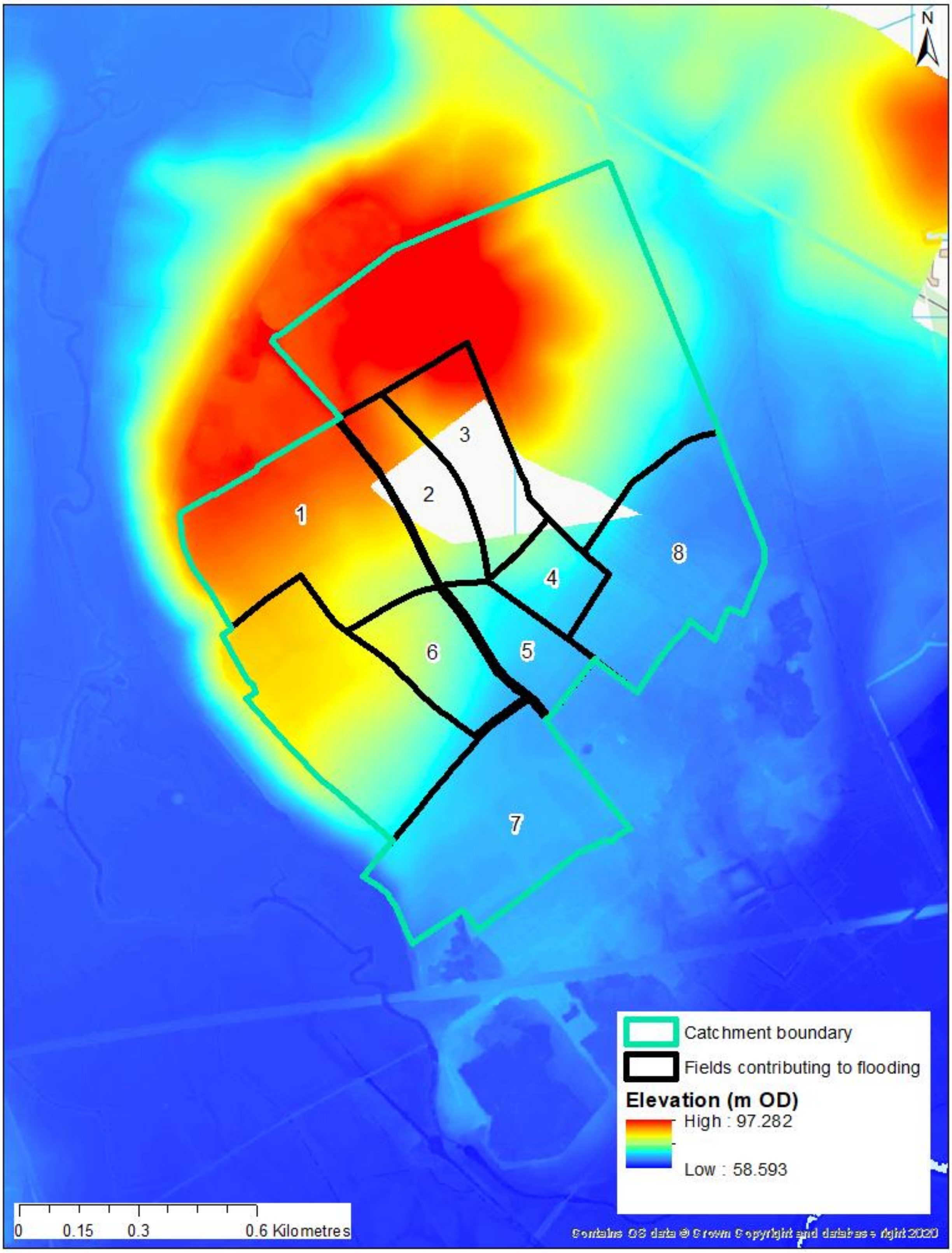


B.2. Superficial deposits

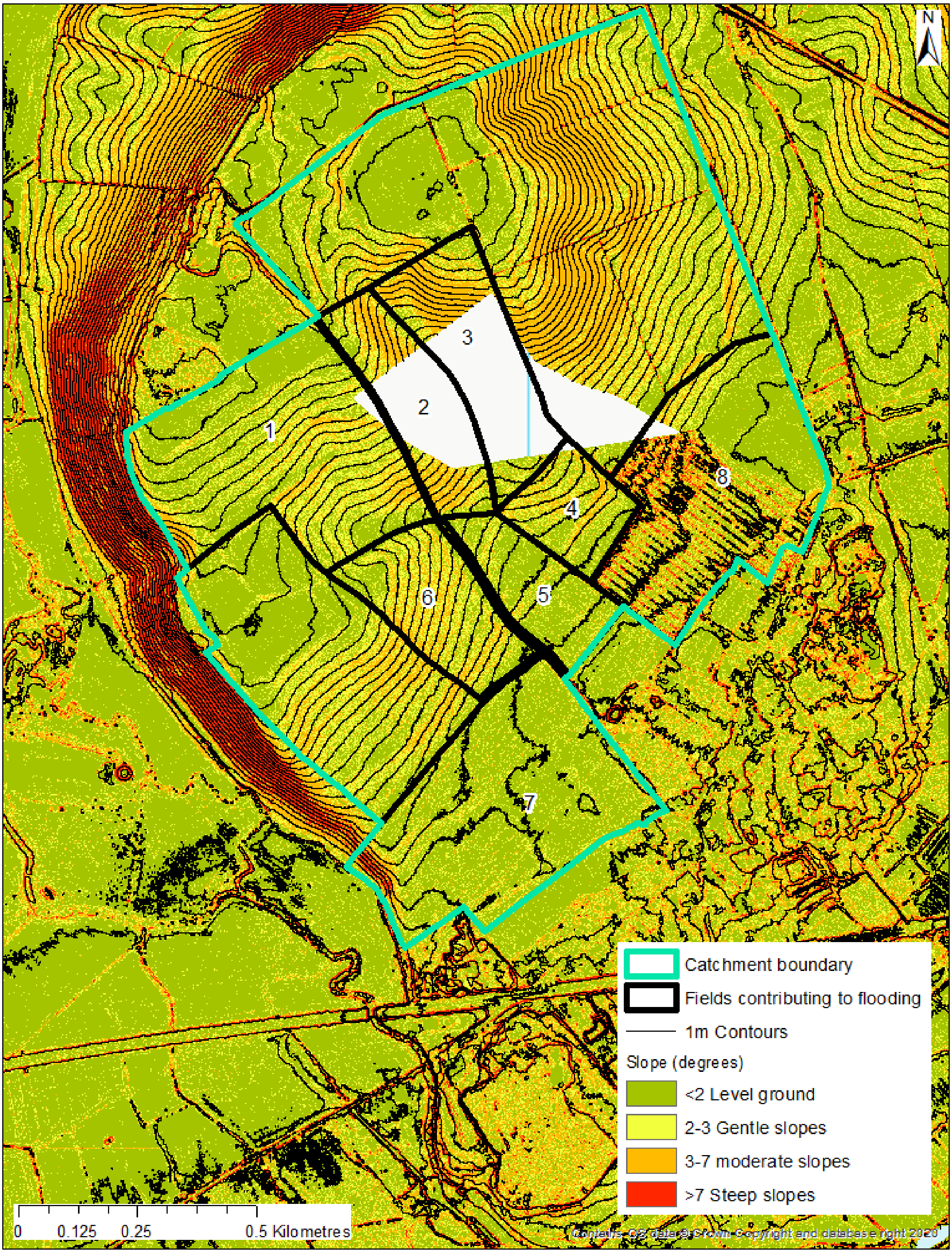


B.3. Bedrock geology

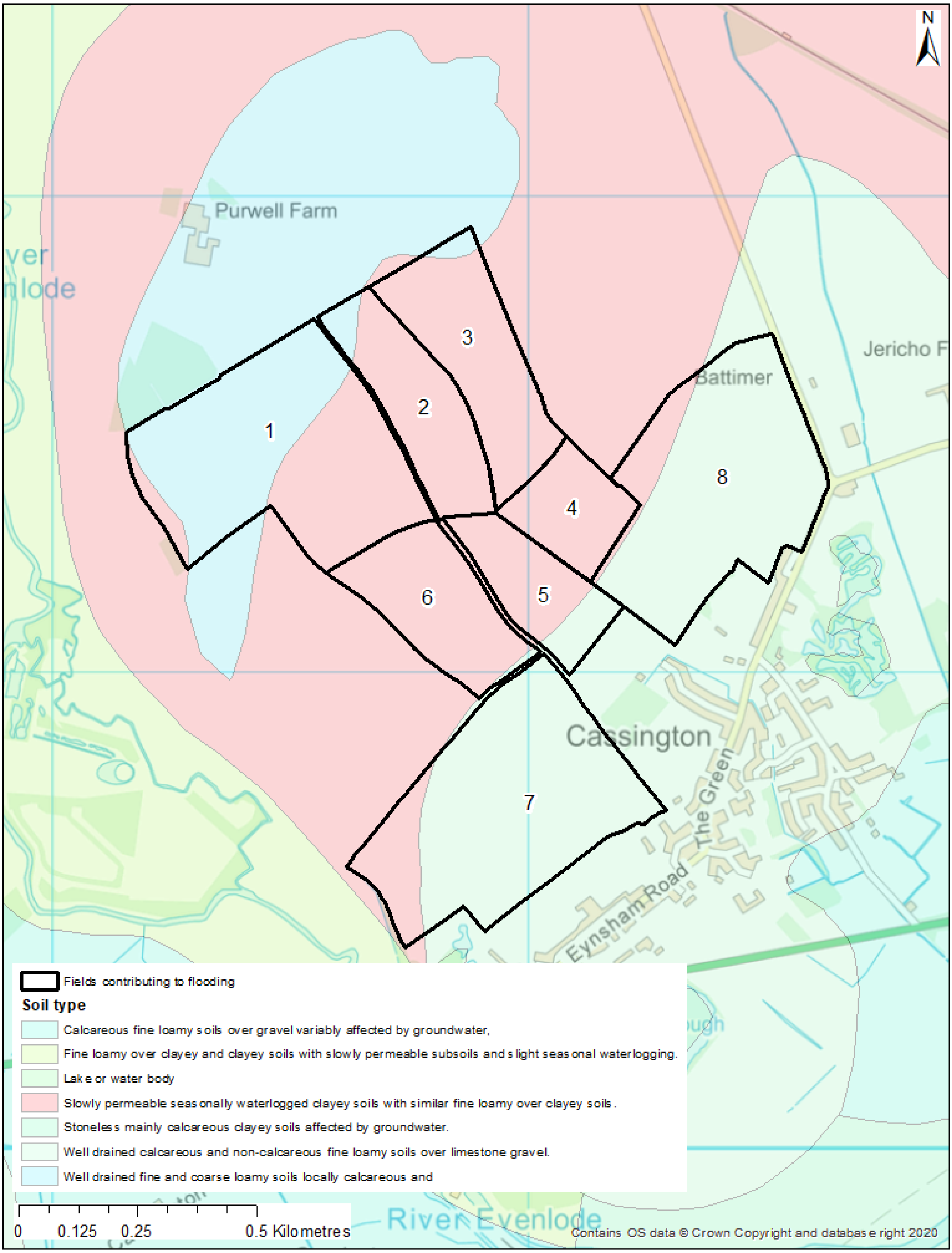
B.4. Topography



B.5. Slope


N
1
2
3
4
5
6
7
8
Catchment boundary
Fields contributing to flooding
1m Contours
Slope (degrees)
<2 Level ground
2-3 Gentle slopes
3-7 moderate slopes
>7 Steep slopes
0
0.125
0.25
0.5 Kilometres
Contains OS data © Crown Copyright and database right 2020

B.6. Soil map


N
Purwell Farm
Jericho F
Battimer
Cassington
The Green
Eynsham Road
River Evenlode
1
2
3
4
5
6
7
8
Fields contributing to flooding
Soil type
Calcareous fine loamy soils over gravel variably affected by groundwater,
Fine loamy over clayey and clayey soils with slowly permeable subsoils and slight seasonal waterlogging.
Lake or water body
Slowly permeable seasonally waterlogged clayey soils with similar fine loamy over clayey soils.
Stoneless mainly calcareous clayey soils affected by groundwater.
Well drained calcareous and non-calcareous fine loamy soils over limestone gravel.
Well drained fine and coarse loamy soils locally calcareous and
0 0.125 0.25 0.5 Kilometres
Contains OS data © Crown Copyright and database right 2020

Appendix C. Soil erosion risk

Soil textures	Steep slopes >7°	Moderate slopes 3°–7°	Gentle slopes 2°-3°	Level ground <2°
Sand	Very high	High	Moderate	Lower
Loamy sand	Very high	High	Moderate	Lower
Sandy loam	Very high	High	Moderate	Lower
Sandy silt loam	Very high	High	Moderate	Lower
Silt loam	Very high	High	Moderate	Lower
Silty clay loam	High	Moderate	Lower	Slight
Other mineral soils	Lower	Lower	Slight	Slight

Defra (2005). Controlling soil erosion. P14.

Appendix D. NFM measures summary

LM01.1: Vegetated Buffer Strips

Purpose of Measure

Vegetated buffer strips are typically located along field boundaries or adjacent to watercourses and drainage ditches. They provide a structured vegetated corridor typically composed of a mixture of grasses, herbs and wildflower. These act to protect watercourses and field edges from water and sediment runoff and livestock poaching. Buffer strips act by increasing the land surface roughness, slowing overland flow and increasing infiltration into the soil. By slowing water movement, buffer strips trap sediment before it enters the drainage system, enhancing local water quality and reducing channel sedimentation. Where planted alongside a watercourse, bank stability may also be improved by the stabilising effects of root development.

Vegetated buffer strips also enhance local biodiversity and landscape connectivity through the creation of wildlife corridors. Water quality may also be improved through a reduction in fertiliser runoff to watercourses. The reduction of sediment transfer to watercourses may also aid compliance with the Farming Rules for Water.

Design Parameters

Buffer strips shall be created either in-field, between fields, or adjacent to watercourses (riparian), including rivers, streams and ditch systems. In-field buffer strips shall be at a minimum 4 m wide and run for the length of the field where practically possible, with wider strips considered in areas of steeper gradient to maximise effectiveness. Riparian buffer strips shall be wider, typically between 6 m and 12 m. Fencing riparian buffer strips (**Figure 1**) can be undertaken to manage the interface between crops/grassland, livestock and watercourses. A reduction of poaching to watercourse banks may aid compliance with the Farming Rules for Water.

Buffer strips should be located where surface water runoff is known to move from one land parcel to the next or to the drainage network, whilst riparian buffer strips shall be targeted where the adjacent land is heavily grazed or used for intensive crop production. Buffer strips will be particularly effective when located at the bottom of long sloping fields to strategically intercept overland flow and sediment from areas susceptible to soil compaction and erosion. Distributing buffers across all downslope edges of fields will have a greater benefit than a single localised wide buffer.

Vegetated buffer strips shall be artificially sown with an appropriate seed mix with a traceable native provenance. Ground preparation shall be undertaken prior to sowing in line with seed merchant's recommendations, with sowing undertaken in spring (March/April) or autumn (August/September), noting a higher seed rate is often required for spring sowing. The seed mix shall be appropriate for the local soil conditions and contain grass species that will develop a thick sward ideal for trapping sediment in surface run-off e.g. cocksfoot or timothy grass. As well as grasses, the mix should include other species that act to increase roughness throughout the year and provide a valuable resource for wildlife e.g. wildflower mixes (**Figure 2**). The mixture shall aim to provide a year-round coverage and complex root development. Deep rooting species are desirable as they will improve soil structure, increase infiltration and reduce overland water flow more effectively.

Prior to creating a buffer strip the location shall be checked for the presence of scarce plants that would be lost following the development of a vegetated buffer strip.

Complementary Measures—Buffer strips may be implemented in conjunction with other land management (**LM**) or overland flow route (**FR**) measures. Buffer strips may aid with sediment management to improve performance and reduce maintenance requirements of other measures. Complementary measures may include reducing soil compaction (**LM02.1**) in adjacent fields to reduce the water and sediment runoff being intercepted by the buffer strip. Another complementary measure may be to include cross-slope woodland (**LM01.2**), where planted in proximity to a buffer strip. This may further support the improvement of soil structure and increased infiltration rates.

Maintenance Requirements

A low level of maintenance is required for vegetated buffer strips. In the first summer, cutting the sward when it is 10 cm tall is recommended to control weeds and encourage grasses to grow. This may require three cuts in the first summer with annual cuts thereafter to help prevent development of scrub and maintain buffer health. Removal of cut vegetation is desirable to prevent suppression of establishing plants and non-competitive desirable species. Furthermore, monitoring and control of injurious species in the buffer strip may be required and re-seeding of bare patches undertaken.

Where installed, checks and (where applicable) repairs to fencing may also be required on an ad hoc basis to ensure the exclusion of livestock. Cutting regimes may be adapted to increase the diversity of habitats for wildlife, for example through cutting alterative sections each year. However, excessive cutting is typically avoided to prevent the removal of any benefits of the buffer strip. Fertilisers and manures shall not be applied to buffer strips and regular vehicle access across buffer strips is best avoided as to not compact the soil.

Vehicle movements and footfall on buffer strips should be kept to an absolute minimum to avoid compaction and damage to the sword. Where access is required through a buffer strip e.g. footpath (**Figure 3**), localised cutting of the buffer strip may be required to maintain the public right of way.

Cost

The cost of implementing a vegetated buffer strip is typically between £350 and £550 a hectare per year, which accounts for loss of productivity from the land given over to the buffer strip.

Vegetated buffer strip seed mix costs are variable, between £40 and £250 per hectare, depending on the species mix, required sow rate and volume of seed required. Additional costs will be incurred in relation to ground preparation and machinery use. Should fencing be required this is typically costed at £4-8 per linear metre.

Further costs may be experienced through pre-implementation activities including planning and consultation, whilst further costs are associated with the maintenance requirements, see the "Maintenance Requirements" section.

Equipment and Materials

The following is a list of equipment and materials that are typically required for creating vegetated buffer strips.

Equipment:

- Seed spreader and/or broadcaster
- Ground preparation equipment—e.g. soil tiller
- Fencing tools— for construction of livestock exclusion fences if required

Materials

- Seeding mix
- Fence posts, wire, netting and staples— to construct exclusion fencing around planted area
- Herbicides—for treatment of noxious weeds (following appropriate guidance, especially in relation to riparian buffers)

Figure 1. Buffer strip with fencing (© Dave Gasca-Tucker)

Figure 2. Wildflower buffer strip providing year-round cover (© Chloe Palmer)

Figure 3. Buffer situated adjacent to a drainage ditch and with footpath access through the strip (© Dave Gasca-Tucker)

Consents and Permissions

It is unlikely that consents or permissions will be required for in-field buffer strips, although some exceptions may apply.

Compliance with the Farming Rules for Water will need to be considered, noting that any land with within 5 m of watercourses must prevent livestock poaching to reduce soil erosion and a reduction in water quality.

Further Reading

For further information on vegetated buffer strips refer to the following sections within the References (**REFS.X**) specification sheet:

General—references 1, 2, 3, 4, 12, 14 and 15

Measure Specific—LM01.1: Vegetated Buffer Strips—references 1, 2, 3, 4, 5 and 6

Consents and Permissions—references 5, 6, 7 and 14

ATKINS

Member of the SNC-Lavalin Group

Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

Atkins
The Hub
500 Park Avenue
Aztec West
Almondsbury
Bristol, BS32 4RZ

Client
Highways England

Project title
Highways England NFM Pilot

Drawing title
LM01.1: Vegetated Buffer Strips

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 19/11/20	Date 15/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/LM01.1 (v2.0)

LM01.2: Cross-slope Woodland & Hedgerows

Purpose of Measure

Cross-slope woodland and hedgerow planting acts to reduce flood risk by slowing the rate at which overland flow enters the drainage network and watercourses. This occurs through the interception of rainfall and overland flow, evapotranspiration, infiltration to ground (through soil improvements due to enhanced root growth) and by increasing surface roughness. Woodland understory planting may also be considered as a way to further enhance soil structure and roughen the ground beneath.

The planting of cross-slope woodland and hedgerows will act to improve local wildlife, biodiversity and soil health. Cross-slope woodland may also be planted in conjunction with many other natural flood management measures for added benefit.

Design Parameters

Cross-slope planting is typically undertaken along contours in areas prone to overland run-off, and adjacent to watercourses (**Figure 1**). Planting need not be extensive if strategically placed to target key flow routes (**Figure 2**). Functional and ecological value is often improved where the measure is used to extend cross-slope woodland, shelter belts and/or as a gapping-up measure for existing hedgerows. Standard woodland trees shall be planted at a density of 1 tree per 1 to 2 m^2 and as staggered rows where possible. Woodland trees are best supplied as bare root whips and/or feathered trees and planted at a ratio of 1 feathered to 5 whips. Cross-slope woodland strips are typically up to 10 m wide depending on land access and availability, although on steeper gradients, they may need to be wider to improve effectiveness (up to 30 m). Cross-slope woodlands are best planted as a mixed species stand, typically with a minimum of five species. For hedgerows, hedge species should be set out in two rows, 300 mm apart with plants at 450 mm centres (**Figure 3**). Bare root hedge species shall be planted as whips in same species groupings of three, five and seven. Standard tree species can be incorporated into hedgerows but should be off-set from the hedgerow by 1 m and at approximately 10 m intervals.

Planting shall occur between November and March, avoiding waterlogged or frozen conditions, and following appropriate ground preparation e.g. mulching of existing vegetation and soil de-compaction where appropriate. Planting may be manual (e.g. notch-planting) or through the use of machinery. Manual planting may allow for 200 or more trees to be planted per person per day (with bare root stock with no protection), whilst machines can allow for over 4 times that figure. In the presence of livestock, fencing (**Figures 3** and **Figure 4**) is required to remove grazing pressure and where deer are known appropriate exclusion is required, including the installation of double fencing. Fencing shall be at a minimum distance of 1 m from the nearest planted tree/hedge species and additional protection e.g. staking with tree guards/cardboard tubes, should be considered where there is a need to protect against deer, rabbits, mice, voles and any agricultural chemicals. Tube shelters shall be avoided for hedgerow species, however, if required for protection these should be removed after one-year to prevent restriction to horizontal growth. Methods to supress competitive growth around planted trees shall be considered on a site-by-site basis e.g. turf inversion, to facilitate early establishment. The use of rabbit-proof fencing may be considered as an alternative to guards in appropriate situations.

To qualify for funding all species shall be native and the trees should be sourced from nurseries which can prove provenance and quality assure against risks such as disease introduction. Species may include, but are not limited to, hawthorn, hazel, blackthorn, oak, birch, alder and willow. Plants shall be selected that are appropriate to the local soil type and moisture conditions on site. Fast growing species should be included within the planting schedule as a way to facilitate early establishment whilst the slower growing species take time to grow and mature. The potential implications of tree planting on the function of adjacent habitats shall be considered e.g. potential for negative effects of shading.

Complementary Measures—Cross-slope woodland and hedgerows can be planted alongside swales (**FR02.3**) or as a supplement to vegetated buffer strips (**LM01.1**) to improve interception and infiltration of run-off. Woodland planting can also be beneficial where planted adjacent to storage ponds (**FR02.1** and **FR02.2**) to roughen the surface and further attenuate flow. However, where trees as planted adjacent to other measures the potential implication for future access and function of the measures will need to be considered as the trees grow.

Maintenance Requirements

A medium level of maintenance is typically required for cross-slope woodland and hedgerows. Greatest effort is often required for the first 3-5 years after planting in relation to checks and maintenance of plants, guards and fencing. Following winter planting, summer/autumn checks are required to quantify any losses and assess establishment/condition of plants. Where trees/hedge species have failed, re-planting is recommended for the following winter period using species with the highest success rates in the plot. After 2—3 years all stakes and guards should be removed as plants should be well rooted.

Weeding to remove competition is also required on an annual basis, each spring/summer for the first few years. This may include mechanical weeding or mulching. There shall be no cutting of newly planted hedgerows for the first 5 years, after which maintenance to encourage hedge development and thickening, such as laying can be undertaken if well established. Regular checks and the replacement of damaged, stakes and guards is required.

Costs

Material costs will vary depending on the species mix used, density of planting and the level of protection required. Costs are typically £21,600 per hectare. Tree and hedging plant prices range between £0.5 and £3 per individual (supplied as whips/feathered bare root stock), whilst individual tree protection (guard and stake) will cost between £1 and £3 per tree (with economies of scale). Fencing is typically costed at £4-8 per linear metre.

There will be additional costs associated with design and maintenance, as well the potential for additional expenditure associated with unforeseen events e.g. adverse weather delaying planting and loss of trees through drought. A tree/hedge species mortality rate of 10 % is typical.

It is likely that further costs of up to 60 % of the installation cost may be experienced through pre-installation activities including design, planning and consenting, whilst further costs of roughly 10 % of the installation cost may be experienced through post installation activities, including maintenance and monitoring. For an example of typical maintenance requirements, see the "Maintenance Requirements" section.

It is typically predicted that maintenance costs may be in the region of £200 a hectare per year. However, this may vary greatly depending on all of the factors highlighted above.

Equipment and Materials

The following is a list of equipment and material that are typically required for planting cross-slope woodland and hedgerows.

Equipment:

- Tree planting spade
- Lump/sledge hammer—for driving tree stakes
- Tree planting machine—if a large number of trees are to be planted and access/site conditions permit
- Fencing tools—to construct and secure fencing and wire

Materials:

- Trees and hedging plants—typically supplied as bare root whips and bare root feathered stock
- Stakes and tree guards—for tree protection
- Fence posts, wire, netting and staples— to construct exclusion fencing around planted area

Figure 1. Cross-slope woodland planting conceptual design (© Atkins Ltd)

Figure 2. Recently planted cross-slope woodland (© Helen Winterburn)

Figure 3. Recently planted cross-slope hedgerow (© Tweed Forum, Hugh Chalmers)

Figure 4. Recently planted cross-slope woodland (© Tweed Forum, Hugh Chalmers)

Consents and Permissions

Consents are unlikely to be needed for small-scale tree planting, however, there may be some exceptions to this.

Should tree planting be large-scale or within a protected habitats (e.g. SSSI, AONB) then permissions will be required from the Forestry Commission and/or local and statutory authorities.

Furthermore, if trees are being planted within 8 m of a main river, Environment Agency consent may be required in the form of a flood-risk activity environmental permit. If trees are being planted adjacent to an ordinary watercourse, a land drainage consent may be required from the lead local flood authority.

Further Reading

For further information on cross-slope woodland & hedgerows refer to the following sections within the References (**REFS.X**) specification sheet:

General—references 1, 2, 3, 4, 5, 6, 7, 12 and 15

Measure Specific—LM01.2: Cross-slope Woodland & Hedgerows—references 1, 2 and 3

Consents and Permissions—references 3, 10, 12, 13 and 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website[redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client: Highways England

Project title: Highways England NFM Pilot

Drawing title: **LM01.2: Cross-slope Woodland & Hedgerows**

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 25/11/20	Date 12/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/LM01.2 (v3.0)

LM02.1: Reducing Soil Compaction

Purpose of Measure

Soil compaction occurs as a result of high pressure being exerted on to the soil surface. This acts to reduce the infiltration capacity of the soil by reducing soil pore space, which in turn can increase run-off from the land and lead to flooding. Soil compaction can also be detrimental to root growth and can create conditions of waterlogging. Compacted soils can be subject to greater levels of erosion and sediment transport to watercourses.

Compaction is most often associated with agricultural land that experiences frequent trafficking of heavy machinery or intense grazing (**Figure 1**), or following the removal of cover crop without the immediate implementation of cover crop (**Figure 2**). Soil compaction can occur at the field-scale but also be more acute in areas around gateways or livestock feeding/drinking troughs.

The measures detailed here reduce soil compaction, improve soil health and increase infiltration as a way of managing run-off and potential flooding.

Design Parameters

Methods to reduce compaction are site-specific, dependent on the soil type, land-use, the level of compaction and current soil health. They are best applied at the field scale.

In targeting the measures, local knowledge is best applied to identify where soil is most compacted or in the poorest health. Walkovers and further assessments can inform this process e.g. the use of a soil penetrometer to detect soil compaction (by measuring the resistance of the soil), conducting bulk density tests and digging of small trial holes to assess compaction. Common signs of soil compaction include waterlogging, standing water and crop discolouration (an indicator of poor nutrient levels resulting from highly compacted soil). Mechanical de-compaction measures are best implemented at the field-scale and may provided a more effective NFM function on slopes that link to the drainage network.

Compaction of soils is typically reduced through aeration (mechanical spiking of the soil) (**Figure 3**), sward-lifting (breaking up the topsoil without damaging the sward) (**Figure 4**) or subsoiling (breaking up the soil at depth) (**Figure 5**). The equipment required will be dependent on the depth of compaction, informed through the digging of soil pits. Soil aerators typically work to depths of around 10 cm and shall be used when soils are neither too wet, or too dry. In wet conditions soil aerators will penetrate to deeper levels and may damage topsoil, whilst if soil is too dry, aerators may not penetrate far enough to be effective. Soil aerators shall be set at 90° to the direction of travel to avoid sward damage. Sward lifters work to depths of 20-35 cm and are typically more effective than aerators at de-compacting soil. As a guide the minimum horsepower required for sward lifters is 140-160 HP. Again, as with soil aerators, sward lifters shall not be used in very wet or dry conditions to avoid further soil damage and maximise their effectiveness. Subsoilers typically operate at depths of 35-50 cm and commonly used in arable fields for deep de-compaction. If equipment is set at the incorrect level, the issue of compaction may be exacerbated rather than improved. For assistance with implementing this measure, please speak to the local Catchment Advisor.

Generally, the frequency required for mechanical de-compaction will depend on land-use and soil characteristics, with greater levels of compaction requiring more frequent attention. However in all instances, mechanical de-compaction should be a cyclical process and not a single-use measure (typically undertaken once every second year) and may be implemented in sequence with crop rotations. For further advice on this measure, please speak to the local Catchment Advisor. Other management options may also be applied to reduce compaction, including stocking density changes, mob grazing, avoiding the regular use of heavy machinery on wetted soils and varying vehicle tracking routes along land (see the "maintenance requirements" section for more information).

Complementary Measures—Mixed species herbal leys (**LM02.2**) and cover crops (**LM02.3**) with deep rooting species may help to break up and avoid soil compaction and may be used following the use of aerators, sward lifters or subsoilers. Vegetated buffer strips (**LM01.1**) may also be implemented cross-slope and along field boundaries if they do not compromise this activity.

Maintenance Requirements

Conserving good soil health is an on-going process which requires a low to medium level of maintenance following implementation of the measures described here. Mechanical de-compactors, whilst effective in the short-term, may only partially solve the issues of soil compaction. Other supplementary methods may be required to maintain soil health in the long-term.

These measures include, but are not limited to, controlled trafficking (including using optimum tyre pressures and avoiding extensive heavy machinery use on wet soils), minimum tillage techniques, cover crops, changes to livestock management and herbal leys with mixed deep rooting species.

Subsequent assessment of soil compaction will be required to inform on the need and frequency of repeated soil aeration and/or subsoiling.

Cost

Reducing soil compaction through the use of mechanical de-compactors can cost between £60 and £100 per hectare depending on whether the appropriate machinery is owned, rented or a contract hire is required.

The cost of additional land management actions to maintain low soil compaction are typically low and may result in higher grass and crop growth if compaction is remedied, making land more profitable. For further information on additional measures for maintenance, see the "maintenance requirements" section and the specification sheets for mixed species herbal leys (**LM02.2**) and cover crops (**LM02.3**).

Additional costs may be associated with planning and consultation requirements.

Equipment and Materials

The following is a list of equipment and materials that are typically required in the reduction of soil compaction.

Equipment:

- Tractor
- Aerator/sward lifter/subsoiler machinery—to be attached to tractor
- Excavator/spade— should trial holes be required to assess soil compaction
- Soil penetrometer—to measure soil compaction

Materials:

- Movable feed/water trough—to avoid poaching and soil trampling over the same patch of the field

Figure 1. Soil compaction from heavy machinery using access route (© Atkins Ltd)

Figure 2. Soil compaction through agricultural activities (© Chloe Palmer)

Figure 3. Soil aerator in operation (© Chloe Palmer)

Figure 4. Sward lifter in operation (© OPICO Ltd)

Figure 5. Subsoiler (© OPICO Ltd)

Consents and Permissions

Consents are unlikely to be required for reducing soil compaction, although consultation may be needed with the local Catchment Advisor for use of subsoilers and sward lifters.

The potential for archaeological features within the land should be considered prior to any works to control the risk of causing damage to heritage assets. This is particularly the case where land has not been mechanically de-compacted before.

Further Reading

For further information on reducing soil compaction refer to the following sections within the References (**REFS.X**) specification sheet:

General—references 1, 2, 3, 4, 5 and 12

Measure Specific—LM02.1: Reducing Soil Compaction—references 1, 2, 3, 4, 5 and 6

Consents and Permissions—references 9 and 14

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Notes

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Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client
Highways England

Project title
Highways England NFM Pilot

Drawing title
LM02.1: Reducing Soil Compaction

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 26/11/20	Date 12/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/LM02.1 (v3.0)

LM02.2: Mixed Species Herbal Ley

Purpose of Measure

Mixed species herbal ley is a measure particularly focused on improving soil health of grassland productivity over large field-scales. Over time, land used extensively for grazing can become compacted by livestock and soil structure can be damaged. Mixed species herbal ley involves using diverse and deep-rooting species to enhance soil structure and increase water infiltration capacity. Through a greater diversity of plant and grass species, soil can be enhanced with greater amounts of carbon, soil organic matter and a reduced bulk density (compaction), leading to greater water storage potential and a reduction in overall overland water flow.

This may be particularly important where extensively grazed grassland is adjacent to watercourses. This measure may have many additional benefits for livestock farming, including a reduction in fertiliser use, reduced expenditure on feed and reduced veterinary bills. Herbal leys may also increase local biodiversity and water quality.

Design Parameters

Mixed species herbal leys are preferably sown into a clean seedbed. Although, seed mixtures can be used to convert existing pasture into a herbal ley following appropriate ground preparation, in line with seed merchants advice. Seeds shall be sown in spring, between March and April, or alternatively in the autumn period, between August and late-September, should the climate facilitate establishment prior to the winter period. Sowing during hot dry summer periods shall be avoided.

Seed broadcasting is preferable to direct drilling as it leads to a better ley species distribution. If seed drilling is applied, this shall be no deeper than 1 cm. The soil shall be rolled immediately after sowing to ensure good seed-to-soil contact for better germination and establishment.

Typically, mixed species herbal leys include grasses, legumes, herbs and wildflowers (**Figure 1**) to ensure that enough variance in rooting depths and characteristics is observed. For increased effectiveness, the ley shall have a minimum of 10 % legumes, 10 % herbs and 10 % wildflowers, whilst the number of species included within the ley shall be at a minimum of eight. Advice shall be taken from the seed merchant on the suitability of species in relation to the soil conditions, although typical species are shown in **Figure 2**. Ryegrass shall not formulate the basis of the mix as this will act to reduce the effectiveness of the measure. Note also that species such as clovers grow poorly in acidic soils (particularly below pH 6).

To promote effectiveness of herbal leys, they are best used on rotation (typically four years) to maximise benefits to soil and livestock (**Figure 3**). Herbal leys typically allow for an extended grazing season. However, for it to achieve its purpose of improving soil health and reducing flooding, herbal leys shall be rotationally grazed to avoid degradation. This will require management of livestock activity within the herbal ley through the erection of exclusion fencing.

Herbal leys shall be established in areas that best target issues of poor infiltration and run-off. The conversion of uncultivated or semi-natural land to herbal ley is best avoided (to reduce potential for consenting and permitting), as are land parcels/fields with known pest problems to limit the need for herbicide/pesticide application.

Linked measures—Prior to the sowing of mixed species herbal leys, measures to reduce compaction (**LM02.1**) may be implemented to improve the soil structure and allow for better establishment of grasses and herbs. This may aid the overall benefit experienced through the implementation of herbal leys.

Maintenance Requirements

Mixed species herbal leys will typically have a period of 4 years at optimum functionality before rotations are needed.

A low level of maintenance is required following establishment, due to its self-sufficient nature and opportunities it presents for rotational grazing.

Fertiliser shall not be applied to herbal leys as this will encourage the grass species in the sward to proliferate at the expense of herb species. Herbal leys with circa 30 % legumes are typically very effective at fixing nitrogen and therefore require no artificial nitrogen fertiliser input, further reducing maintenance requirements.

Other complementary soil and land management measures will further enhance soil health when implemented alongside cover crop use, such as controlled trafficking of heavy machinery (including using optimum tyre pressures and avoiding extensive heavy machinery use on wet soils), minimum tillage techniques and changes to livestock management. Other measures may be specified as a landowner innovation idea (**LI01.1**).

Cost

The cost of implementing mixed species herbal ley is typically between £150 and £250 a hectare per year, which accounts for any potential loss of productivity from the land given over to the mixed species herbal ley.

Mixed species herbal ley seed is typically costed between £40 and £250 per hectare, depending on the supplier and the type of mixture purchased. Costs at the lower end of the range may include simple herbal ley mixtures with smaller numbers of species, whilst costs at the upper end of the above range may include more complex herbal ley mixtures with greater numbers of species and are more organic rather than conventional. Costs associated with implementation will vary depending on the ground preparation and machinery requirements.

Herbal leys are typically implemented without fertiliser-use and can support healthier livestock and subsequently lower veterinary bills than observed with traditional ryegrass mixtures.

Additional costs may be associated with planning and consultation requirements.

Equipment and Materials

The following is a list of equipment and materials that are typically required in the implementation of mixed species herbal ley.

Equipment:

- Tractor
- Seed spreader/broadcaster or drill
- Soil tiller and roller—for ground preparation

Materials

- Seed mix
- Herbicides—for targeted treatment of noxious weeds
- Temporary livestock fencing—should the ley be used for rotational grazing

Figure 1. *A typical mixed species herbal ley (© Chloe Palmer)*

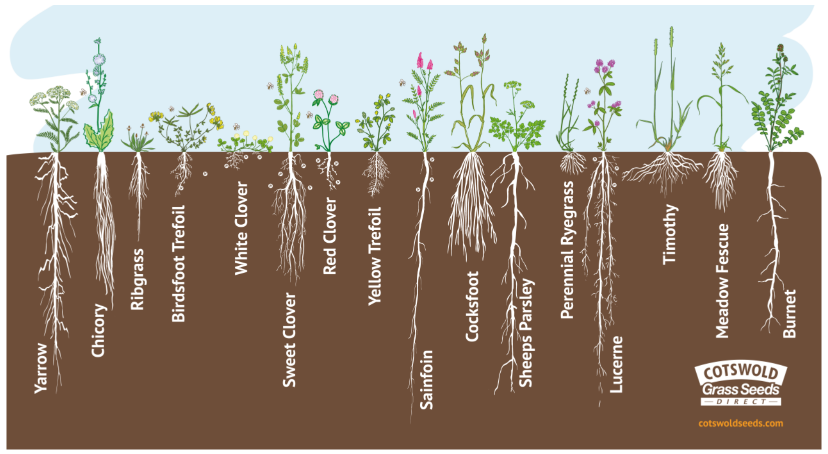

Figure 2. *Some of the different species to consider for mixed species herbal ley, and their differing rooting depths (© Cotswold Seeds Ltd)*

Figure 3. *Mixed species herbal ley being grazed off by cattle (© Chloe Palmer)*

Consents and Permissions

Consents and permissions are unlikely to be required for mix species herbal ley implementation.

Environmental Impact Assessment (Agriculture) Regulations may apply if the measure increases the productivity of land for agriculture (e.g. if the land used for herbal ley is permanently grazed and classed as permanent pasture), or if implemented on land of over 2 ha in total area.

Further Reading

For further information on mixed species herbal ley refer to the following sections within the References (**REFS.X**) specification sheet:

General—no general references

Measure Specific—LM02.2: Mixed Species Herbal Ley—references 1, 2, 3, 4, 5 and 6

Consents and Permissions—references 5, 6, 7, 8, 9 and 14

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Notes

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Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client
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Project title
Highways England NFM Pilot

Drawing title
LM02.2: Mixed Species Herbal Ley

Scale	Drawn	Check	Review
	SR	MH	IPM
A3	Date 18/11/20	Date 15/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/LM02.2 (v2.0)

LM02.3: Cover Crops

Purpose of Measure

Cover crops are non-cash crops that provide a protective cover for the soil of arable land which may otherwise be prone to erosion from wind and water between cash-crop cycles. They are commonly grown over winter, when they can also act as an NFM measure by reducing surface runoff.

Cover crops provide a natural flood management benefit as they act to intercept rainfall, maintain good soil structure and improve infiltration capacity through root development. They can also act to slow overland flow reducing the rate at which water enters the drainage network and watercourses.

Cover crops may also provide additional benefits such as increasing cash-crop productivity, through improvements to and maintenance of soil health. A reduced amount of weed management and fertiliser is often also observed which can reduce farming costs and improve local water quality. Cover crops can also provide feed for livestock as grazed biomass.

Design Parameters

The type of cover crop sown shall depend on soil characteristics, arable use, landowner requirements and existing operation. Depending on the length of rotation desired, certain cover crop species may be more preferable than others to fit within the cash-crop cycle. For further specific advice on cover crop species and design strategy, the local Catchment Advisor and agricultural specialists can be consulted.

Early sowing of cover crops (**Figure 1**) is desired where possible to allow time for successful establishment prior to the wetter winter period (**Figure 2**). Species sown shall have the ability to grow together and throughout the winter period (or period between cash crop growth), to ensure effective ground cover is maintained and a mix of species should be used. These include legumes, grasses, and brassicas to provide variability in root penetration as shown in **Figure 3,** and above ground complexity to protect the soil surface from rain splash and wind erosion. Buckwheat provides a good option should the cover crop be required over the summer period. Cover crop establishment methods will vary depending on the species choice and ground conditions, with uniformity in distribution being key. Seeds shall be spread using a seed spreader, at the rate indicated by the seed merchant. Where seed spreading is not favourable, seed mixtures may be drilled, however, periodic mixing in the drill is required. The soil shall be rolled immediately after sowing to ensure good seed-to-soil contact for better germination and establishment. Sowing windows range depending on the species mix, however, are typically from August to late-September.

At the end of a cycle, cover crops can be directly tilled back into the soil for enhanced nutrient availability, or the bulkiness reduced through the use of a crimper roller. Alternatively, cover crops may be grazed off to directly provide feed for livestock and prepare the crop for tillage back into the soil. These approaches are in preference to spraying off with potentially harmful chemicals e.g. glyphosate. Cover crops shall be planted immediately following removal of cash crops and be terminated, as standing residue (grazed off), as close to the period of sowing on the next cash crop, to ensure as close to year-round soil coverage as possible. Where annual cycles are not appropriate, cover crops may be maintained over longer periods, with the key to maintain soil coverage to maintain soil health, high infiltration capacity and protection from soil erosion.

Complementary Measures—Cover crops may be implemented alongside other land management (**LM**) measures including grassland buffer strips (**LM01.1**) and the reduction of soil compaction (**LM01.2**). Buffer strips can aid with reducing rapid runoff from the field into adjacent watercourses or other land parcels. Soil compaction reduction measures may be implemented before the sowing of cover crops to aid with improving soil structure and encourage the development of cover crops.

Maintenance Requirements

Cover crops typically provide cover for 5-8 months and are implemented on a yearly basis, in conjunction with cash-crops.

A low level of maintenance is required with cover crops. After initial sowing and establishment some re-seeding may be required where the cover crop has not taken. Consideration must be given into the on-going process of maintaining good soil health and the requirement for cyclical management, rather than a establishing cover crops as a singular event.

Other complementary soil and land management measures will further enhance soil health when implemented alongside cover crop use, such as controlled trafficking of heavy machinery (including using optimum tyre pressures and avoiding extensive heavy machinery use on wet soils), minimum tillage techniques and changes to livestock management. Other measures may be specified as a landowner innovation (**LI01.1**).

Cost

Cover crop seed is typically costed between £20 and £200 a hectare per year, depending on the supplier and the type of cover crop mixture purchased. Costs at the lower end of the range may include simple cover crop mixtures with smaller numbers of species, whilst costs at the upper end of the above range may include more complex cover crop mixtures with greater numbers of species and are more organic rather than conventional. Costs associated with implementation will vary depending on the ground preparation and machinery requirements.

Cover crops are typically associated with soil health improvements and subsequent improved cash-crop yields, which has the ability to make land more profitable. Following cover crop growth, cash crops may require less fertiliser usage.

Additional costs may be associated with planning and consultation requirements.

Equipment and Materials

The following is a list of equipment and materials that are typically required in the implementation of cover crops.

Equipment:

- Tractor
- Seed spreader/broadcaster or drill
- Soil tiller and roller—for ground preparation
- Crimper roller—an option to reduce bulkiness at the end of the cover crop cycle

Materials

- Seed mix
- Herbicides—for targeted treatment of noxious weeds

Figure 1. Cover crops containing radish, black oat and spring oats (© Peter Cartwright, Revesby Estate)

Figure 2. Winter cover crops (© Dave Gasca-Tucker)

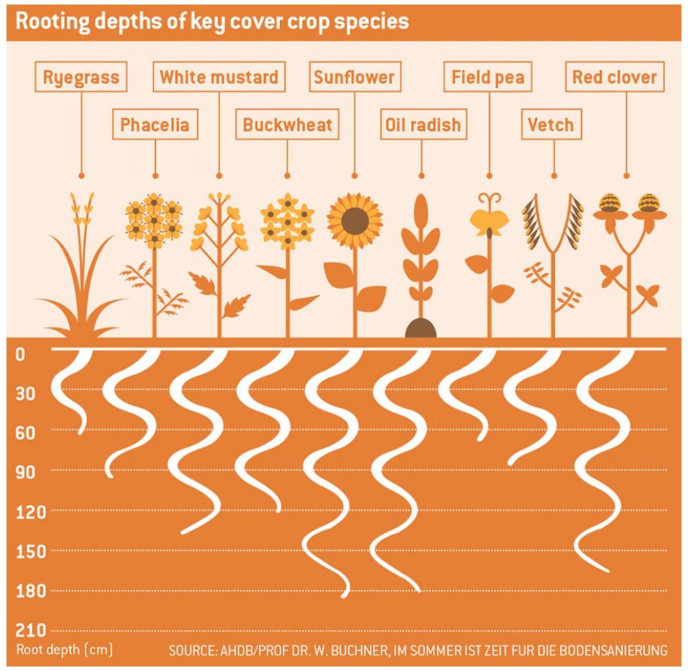

Figure 3. Some example cover crop species and their associated differing root depths (© Farmers Weekly)

Consents and Permissions

Consents and permissions are unlikely to be needed for the establishment of cover crops.

Further Reading

For further information on cover crops refer to the following sections within the References (**REFS.X**) specification sheet:

General—reference 2

Measure Specific—LM02.3: Cover Crops—references 1, 2, 3, 4, 5, 6 and 7

Consents and Permissions—reference 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client

Highways England

Project title

Highways England NFM Pilot

Drawing title

LM02.3: Cover Crops

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 19/11/20	Date 15/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/LM02.3 (v2.0)

FR01.1: Overland Leaky Barrier

Purpose of Measure

Overland leaky barriers are discrete large wood measures that are strategically located and fixed on a floodplain or along preferential flow routes to intercept and temporarily store water. They are primarily designed to operate during out of bank events or following heavy rainfall in areas that experience overland flow. The barrier acts to slow and temporarily store water by roughening the ground surface, which can also facilitate the management of sediment laden run-off.

They can be used in both lowland and upland areas and are well suited to woodland settings, where their inclusion can act to enhance local biodiversity and improve woodland condition. Woodland settings also provide local sources of materials for ease of construction.

Design Parameters

Overland leaky barriers are typically constructed from lengths of large wood (whole tree trunks) generated from tree felling (nominally 300—600 mm diameter) (**Figure 1**). The height and length of the measure can be increased through the use of multiple lengths (**Figure 2** and **Figure 3**) or through incorporation of composite materials such as brushwood or small logs (**Figure 4**). Positioning of the barrier shall be perpendicular to the overland flow route with its length and height governed by the floodplain character and flow route depth.

Measures are typically fixed by a minimum of four points to reduce risk of mobilisation. The number of fixings and exact method of securing the barrier will be site specific and based on factors such as the size of the wood, likelihood of mobilisation and risk to downstream assets should wood enter the main flow of a watercourse.

Overland barriers may be installed individually or in series, where effectiveness may be increased. The spacing and size of the barriers will be determined by the design height, floodplain slope and width of the flow route. Barriers are not to be installed immediately upstream or adjacent to a structure (typically within 30 m) e.g. a bridge, culvert or outfall, so as to reduce the risk to assets should wood become mobilised.

Since wood is a natural material there may be some gapping between the feature and the ground surface. In such instances packing with smaller branches and brushwood to manage porosity and improve connectivity with the ground level is advised.

Should vehicle access to the site not be possible, manual handling or lightweight machinery/equipment may be required to construct the barriers, for which health and safety considerations (e.g. no manual handling of objects over 25 kg) must be considered. Furthermore, if barriers are to be installed in proximity to a woodland area, this may reduce cost and time of construction, as locally sourced wood from the woodland may be used for barrier construction, following appropriate permissions and ecological checks.

Complementary measures — In-channel leaky barriers (**WC01.1**) may be used in the adjacent watercourse to promote water-spill from the channel on to the floodplain where it can be attenuated by overland leaky barriers. In certain situations, e.g. where the floodplain is constrained, an overland barrier can simply be an extension to an in-channel barrier, such as shown in the example provided as **Figure 2**. Construction of storage ponds (**FR02.1** and **FR02.2**) upstream of overland barriers may provide additional store capacity for flow which has been intercepted by an overland leaky barrier. Flow pathway bunds (**FR01.2**) may also be constructed to provide additional storage of water that has been attenuated by the overland leaky barrier, and may be constructed alongside a storage pond.

Maintenance Requirements

Overland leaky barriers typically have a 5—10 year design life at optimum functionality without the need for significant maintenance.

A low to medium level of maintenance is required for overland leaky barriers. Maintenance shall include bi-annual checks for litter and woody material that has been intercepted by the barrier. Additional checks shall also occur following each significant overland flow/floodplain inundation event, to ensure that the barrier is still firmly fixed and that no wood/construction materials have been dis-lodged or mobilised. Litter intercepted by the barrier should be removed and any damaged fixings replaced if there is risk of mobilisation.

Some minor adjustments may be required to the design height and the configuration of the component parts of a barrier should observations during a flood event identify the need to improve the storage potential of the barrier or series of barriers.

Cost

The construction of a overland leaky barrier, including equipment, materials and build-time, is typically between £50 and £150 per metre length of barrier. Therefore, a 3 m long overland leaky barrier may cost in the region of £150 to £450, depending on the ease of access, specific equipment required and proximity/source of materials. If multiple overland leaky barriers are constructed, the cost per feature is likely to reduce because the overheads of construction will be spread across multiple features.

The above cost estimates cover a 'fair weather' construction. If construction is undertaken in a particularly difficult location or planned for a time of year when weather may be inclement a contingency should be added. In addition an allowance should be made for pre-construction activities and maintenance. The cost of design, planning and consenting before construction can be 60% of construction cost. A typical allowance for maintenance costs is 10% of construction cost for each year a structure is in operation. For an example of typical maintenance requirements, see the "Maintenance Requirements" section.

Equipment and Materials

The following is a list of equipment and materials that are typically required for construction of an overland leaky barrier.

Equipment:

- Digger and operator—for manoeuvring of large wood
- Winches/strops/hoists—for manoeuvring and positioning of wood over 25 kg
- Fence post driver—for driving fixing stakes
- Fencing tools—to secure the barrier
- Chainsaw—to fell trees and yield wood material

Materials:

- Large wood —for main structural component
- Fixing stakes—to secure the barrier in place
- Wire and staples—to attach barrier to fixings
- Small branches/brushwood—to pack feature

Figure 1. An example of a basic overland leaky barrier on the River Soar NFM Pilot Scheme, made from a single tree trunk (© Atkins Ltd)

*Figure 2. A multiple log overland leaky barrier, with extended in-channel leaky barrier (**WC01.1**) and substantial fixings* (© Jay Neale)

*Figure 3. A multiple log overland leaky barrier, with extended in-channel leaky barrier (**WC01.1**) and substantial fixings* (© Jay Neale)

Figure 4. An example of a more complex overland leaky barrier, made from a hinged large trunk and smaller logs bundled together (© Atkins Ltd)

Consents and Permissions

Works adjacent to a watercourse will require consents from relevant authorities.

Should the barrier be constructed on the floodplain or adjacent to a main river channel, then a flood risk activity environmental permit will be needed from the Environment Agency. Overland barriers constructed adjacent to ordinary watercourses may require flood defence consents from either the Lead Local Flood Authority (LLFA) or the Internal Drainage Board (IDB).

Should trees need to be felled locally for the construction of an in-channel leaky barrier, a tree felling licence may be required from the Forestry Commission or the relevant local authority.

Surveys may be required to confirm the presence or absence of protected species in the local area, which if found, may require protected species mitigation licenses from Natural England.

Further Reading

For further information on overland leaky barriers refer to the following sections within the References (**REFS.X**) specification sheet:

General—reference 5

Measure Specific—FR01.1: Overland Leaky Barrier—no specific references

Consents and Permissions—references 1, 2, 3, 6, 10, 13 and 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client
Highways England

Project title
Highways England NFM Pilot

Drawing title
FR01.1: Overland Leaky Barrier

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 16/11/20	Date 15/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/FR01.1 (v2.0)

FR01.2: Flow Pathway Bund

Purpose of Measure

Storm water is often conveyed along preferential surface flow pathways during heavy rainfall events. This is often responsible for rapid water and sediment transfer to the drainage system and wider watercourse network which can contribute to flooding. The construction of bunds across overland flow pathways is aimed at attenuating and storing water at a target location. Water may be temporarily stored in ponds or swales "upstream" of the bund, where it can be left to infiltrate into the ground and/or evaporate. Bunds may also have the added benefit of improving local watercourse quality by capturing sediment and pollutants before they enter the drainage network.

Flow pathway bunds are versatile features that can be located throughout the catchment where pathways are identified. They can be sited in field corners as containment bunds to store large volumes of water, or as smaller cross-slope bunds which are aimed at strategically targeting overland flow pathways at a smaller scale. Although this guide specifically relates to earth bunds they can be constructed from, or in combination with, other materials such as dead wood or other vegetation.

Design Parameters

Flow pathway bunds shall be strategically located to temporarily store overland flow and designed to attenuate and store enough water to serve as an effective natural flood management measure (**Figure 1**). Thought should be given to their placement as to avoid disruption to farm operations or other land-use through water ponding/flooding e.g. target low margin land that is known to lie wet. Flow pathway bunds can often be installed as supplementary measures to water storage features (e.g. offline storage pond (**FR02.1**), shown in **Figure 2**) from which the spoil generated through excavation is used to construct the earth bund.

The form and location of the bund will be determined by the earth material properties, site topography and the volume of water requiring storage. Bunds shall be constructed across slope contours to intercept and store overland flow (**Figure 1**). Higher bunds are typically required to intercept and store water in steeper gradient settings. Long-term stability of the bund is a principal design factor, with a well compacted clayey sub-soil often providing the best stability and minimal settlement. Stable bund design can typically be achieved with slopes no steeper than 1:6 on the 'upstream' and 'downstream' face (**Figure 3**). Steeper slopes (**Figure 4**) can be maintained where earth material is cohesive. Base width shall be at a minimum, three times its height and constructed through the compaction of sub-soil layers approximately 15 cm deep at a time. Construction with damp soils allows for greater levels of compaction. Flow pathway bund water storage capacity shall typically not exceed 200 m^3.

A grass sward shall be established over the surface of the bund through re-use of top soil won from site and/or top soiling and seeding. Grass will increase stability and blend the measure into the landscape. Grass species should be tolerant to both dry and wet conditions e.g. smooth meadow-grass or creeping bent, and sown at a rate of 20—25g per m^2 at the appropriate time of year (typically autumn). A biodegradable geotextile such as coir matting can be pinned over the bund surface in combination with top soiling and/or seeding to add further stability during the grass establishment phase. No trees or shrubs shall be planted on the bund as this may result in loss of stability and an increase failure risk as the trees mature.

The design shall consider the requirement for water storage control. This can be passively achieved through the provision of a low-point in the bund that acts as a spillway, or through the incorporation of more active control measures such as outlet pipes within through the bund (**Figure 4** and **Figure 5**), or French drain beneath. Having control over the rate of release of water from the stored volume can be advantageous in situations where water does not discharge to ground quickly so that storage capacity can be recovered for subsequent events. Where outlet features are installed, these are typically designed to drain 50% of stored water within a 24 hour period. End of pipe scour protection e.g. tipped stone may also be required to protect soils on the water flow pathway "downstream" of the bund.

Measures to reduce structural damage to soil and compaction to the surrounding land from heavy machinery shall be implemented, as this can increase localised overland flow. Where the feature may be susceptible to livestock poaching, fences may be constructed (**Figure 4**). Bund placement shall consider tree root protection needs to avoid damage to root system immediately under and just beyond the crown.

Complementary measures—Offline storage ponds (**FR02.1**) may be constructed "upstream" of a flow pathway bund (e.g. **Figure 1**) as they can be used to provide additional storage for water intercepted by the bund. Spoil generated from pond excavation can be used to create an earth bund and reduce material disposal costs.

Maintenance Requirements

Flow pathway bunds constructed from earth typically have a 30 year design life without the need for significant maintenance.

A medium level of maintenance is typically required for flow pathway bunds. Visual inspections to check for obvious signs of bund movement, failure or erosion, which may include cracks or material loss shall be required and repairs undertaken where necessary. Such inspections are best undertaken following significant storm events. Occasional desilting and appropriate disposal of accumulated sediment build-up "upstream" of the bund may be required as overland flow pathways can transport sediment, organic matter and other debris. Should pipes be included in the bund design to control water levels then checks on their intended functionality are required in addition to checks for blockages and erosion at the pipe discharge point.

Seasonal grass cutting or topping is recommended to maintain vigorous growth and prevent the establishment of non-grass species on the bund.

Cost

The construction of a flow pathway bund, including equipment and materials, is typically between £50 and £150 per linear metre of bund. Therefore, a 10 m long flow pathway bund may cost in the region of £500 to £1,500, depending on the ease of access, specific equipment required and availability/properties of earth material. Costs at the lower end of this range are experienced where material for bund construction is generated locally e.g. through the excavation of a storage feature such as a pond or swale. If multiple flow pathway bunds are constructed the cost per bund is likely to reduce because the overheads of construction will be spread across multiple features.

The above cost estimates cover a 'fair weather' construction. If construction is undertaken in a particularly difficult location or planned for a time of year when weather may be inclement a contingency should be added. In addition an allowance should be made for pre-construction activities and maintenance. The cost of design, planning and consenting before construction can be 60% of construction cost. A typical allowance for maintenance costs is 10% of construction cost for each year a structure is in operation. For an example of typical maintenance requirements, see the "Maintenance Requirements" section.

Equipment and Materials

The following is a list of equipment and materials that are typically required in the construction of a flow pathway bund.

Equipment:

- Tracked excavator—preferably with a toothless tilting bucket head to allow for more complex contouring
- Tracked dumpers—for spoil movement and tipping
- Spades—for smaller scale bund adjustments
- Hammer—for driving stakes/pin required should a geotextile be required

Materials:

- Earth/spoil—for construction of bund
- Coir matting—for bund stability
- Wooden stakes/pins—for securing feature and coir matting
- Seeding—for vegetation development on bund
- Pipes —for outlet structure
- Gravel—for French drain
- Outlet scour protection (e.g. tipped stone)—to protect against erosion "downstream" of the measure

Figure 1. Flow pathway bunds strategically located to intercept overland flow before exiting fields on to a road (© Evenlode Catchment Partnership)

Figure 2. A newly constructed containment bund (with red dashed line) in conjunction with offline storage pond as part of the River Soar NFM Pilot Scheme (© Atkins Ltd)

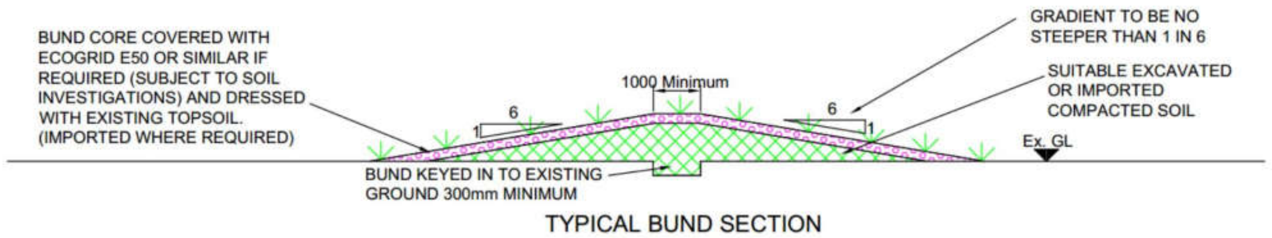

Figure 3. Flow pathway bund design (© Atkins Ltd)

Figure 4. A cross-slope bund with fence for added protection against livestock poaching (© Cumbria County Council)

Figure 5. A cross-slope bund with outlet pipe to reduce chance of overtopping during heavy rainfall events (© National Trust)

Consents and Permissions

Consent may be required for flow pathway bunds, especially when these occur within a floodplain, with exact requirements depending on the bund size, storage volume and location.

Advise on planning requirements should be sort from the Catchment Advisor. Large bunds in the floodplain often require planning permission accompanied by environmental reporting e.g. an Environmental Impact Assessment (EIA), flood risk statement/assessment and a waste management plan.

A flood-risk activity permit from the Environment Agency will be required for works adjacent to or within a floodplain of a main river. Bunds located adjacent to and/or alter the flow of an ordinary watercourse may need land drainage consents from the Lead Local Flood Authority (LLFA) or Internal Drainage Board (IDB).

Permissions may be needed from relevant historical and archaeological bodies e.g. Historic England to control for any potential disruption to heritage features.

Further Reading

For further information on flow pathway bunds refer to the following sections within the References (**REFS.X**) specification sheet:

General—references 1, 2, 3, 4, 5, 6, 7 and 8

Measure Specific—FR01.2: Flow Pathway Bund —references 1, 2 and 3

Consents and Permissions—references 8, 9, 10, 13 and 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client: Highways England

Project title: Highways England NFM Pilot

Drawing title: **FR01.2: Flow Pathway Bund**

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 16/11/20	Date 15/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/FR01.2 (v3.0)

FR02.1: Offline Storage Pond

Purpose of Measure

Offline storage ponds are designed to provide additional areas for water storage within the landscape that fill during a flood or heavy rainfall event. This acts to reduce the volume and/or rate at which water enters the river network. As an offline measure the ponds do not include within their design a direct connection to an existing watercourse (small ditch, stream or river) or waterbody (pond/lake), through for example, an open channel or a piped connection.

They may be constructed adjacent to a watercourse or outside of the floodplain, to intercept water moving along an overland flow route. They can be designed to permanently hold some water, or as temporary flood storage feature which is dry for most of the time. Ponds, both permanent and temporary, can add considerable biodiversity value to the local area. As such, consideration should be given to the ecological design of ponds to maximise opportunities for wildlife where this does not compromise the flood management function of the measure.

Design Parameters

Offline ponds shall be designed on a site-specific basis according to factors such as land use, soil type, existing drainage, local habitats, catchment setting and future maintenance requirements. Ponds may be designed as a single feature (**Figure 1** and **Figure 2**) or as a connected chain of ponds (**Figure 3**). Ponds may require an outlet structure or spillway to convey flow out of the pond or between individual pond features should overtopping be a strong possibility. This outlet feature or spillway shall include scour protection.

Pond sizes vary, however are most commonly between 100 - 400 m^2 with a depth up to 1.5 m. Size will be governed by access, available space, volume needed for water storage and ease of build. Where filled in pond features are present in the landscape their reinstatement should be considered. Ideally, reinstated ponds should not be excavated beyond their original size and depth profile for historical and ecological reasons.

Pond design shall ensure safe egress in the event of entering the pond through provision of appropriate bank slopes (no steeper than 1:3). Ponds potentially accessible to the public (i.e. near to footpaths) may need further measures such as warning signs and/or exclusion fencing. Ponds can either permanently or temporarily hold water. Ponds designed to hold water throughout the year must provide additional capacity to hold storm water. Temporary ponds are typically designed to drain within a short-term period, to ensure their storage space becomes available for longer duration rainfall events over multiple days. Lining of ponds is best avoided, especially for temporary ponds as infiltration to ground is an important flood reduction feature. An assessment of the suitability of the ground to retain water should be undertaken.

Additional storage can be created through bunding around a pond that ties into higher ground levels. Should bunding be undertaken (as shown in **Figure 1**) it must not result in more that 200 m^3 of additional above ground storage.

The ability for ponds to provide additional biodiversity to the local area should be considered in the design e.g. provision of variable depths, slopes and islands. Excavation of the pond will generate spoil material. Any design will need to consider how and where this material will be managed. The preference should always be local re-use, as this is often the most sustainable and cost effective option. Spoil re-use opportunities will be dependent on the material's properties and potential for contaminants to be present; both should be investigated as part of the design process.

Complementary measures— A complex system can be implemented, in which both offline and online storage ponds (**FR02.2**) combine to manage flood water. Spoil from pond excavation can be used to build a flow pathway bund (**FR01.2**) around the pond to increase storage capacity and reduce disposal costs. In-channel leaky barriers (**WC01.1**) may also be constructed in proximity to an offline storage pond to encourage water spill from a watercourse channel for storage within the offline storage pond. Planting cross-slope woodland & hedgerows (**LM01.2**) adjacent to offline storage ponds can also be beneficial to roughen the surface and further attenuate flow.

Maintenance Requirements

Offline storage ponds typically have a 10 year design life at optimum functionality, without the need for significant maintenance.

A medium level of maintenance is required for storage ponds, including regular checks for sediment build-up in the base of the pond (especially where unfenced and open to poaching) as this can reduce storage capacity and effectiveness over time. Occasional desilting and appropriate disposal of accumulated sediment may be required. This may be of higher importance if the pond design includes an outlet feature, to ensure blockages do not occur. Typically, maintenance is low whilst the pond feature is establishing, through vegetation growth and water filling.

Permanent storage ponds typically have a greater maintenance requirement than temporary storage ponds.

Cost

Construction of offline storage ponds is costed between £10 and £50 per m^3 of excavation (including equipment, materials and labour costs). However, in most examples the construction cost will be towards the lower end, assuming simplistic pond design, limited removal/disposal of soil and limited consenting requirements. There will be additional costs associated with any requirements to spread or remove spoil.

The above cost estimates therefore cover a 'fair weather' construction. If construction is undertaken in a particularly difficult location or planned for a time of year when weather may be inclement a contingency should be added. In addition an allowance should be made for pre-construction activities and maintenance. The cost of design, planning and consenting before construction can be 60% of construction cost. A typical allowance for maintenance costs is 10% of construction cost for each year a structure is in operation. For an example of typical maintenance requirements, see the "Maintenance Requirements" section.

Equipment and Materials

The following is a list of equipment and materials that are typically required in the construction of an offline storage pond.

Equipment:

- Tracked excavator—preferably with a toothless tilting bucket head to allow for more complex contouring
- Tracked dumpers—for spoil movement and tipping
- Lorries—should off site spoil disposal be required
- Water pumps—for dewatering excavations

Materials:

- Pipes—for outlet and inlet structures (**Figure 3**)
- Outlet scour protection—to protect against erosion downstream of the measure
- Pond liner (sheeting/clay)—should the pond be required to permanently hold water and infiltration to ground undesirable
- Seeding/planting—to facilitate vegetation re-establishment in working area

Figure 1. *A newly constructed offline storage pond as part of the River Soar NFM pilot scheme* (*© Atkins Ltd*)

Figure 2. *A single offline storage pond before vegetation establishment* (*© Evenlode Catchment Partnership*)

Figure 3. *A series of offline storage ponds forming a wetland habitat and benefits for NFM* (*© Tweed Forum, Hugh Chalmers*)

Consents and Permissions

Consent is often required for offline storage ponds, with exact requirements depending on the pond size, storage volume and location.

Large ponds may require planning permission from the local planning authority, with the permission request accompanied by environmental reporting e.g. an Environmental Impact Assessment (EIA) and a waste management plan.

A flood-risk activity permit from the Environment Agency will be required for works adjacent to or in the floodplain of main rivers. Ponds located adjacent to and/or alter the flow of an ordinary watercourse may need land drainage consents from the Lead Local Flood Authority (LLFA) or Internal Drainage Board (IDB)

Permissions may be needed from relevant historical and archaeological bodies e.g. Historic England to control for any potential disruption to heritage features. A waste management plan and exemption agreement or licence may be required for management of spoil generated by excavating a pond.

Further Reading

For further information on offline storage ponds refer to the following sections within the References (**REFS.X**) specification sheet:

General—references 2, 3 and 7

Measure Specific—FR02.1: Offline Storage Pond—reference 1

Consents and Permissions—references 6, 7, 8, 9, 10, 11, 13 and 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client
Highways England

Project title
Highways England NFM Pilot

Drawing title
FR02.1: Offline Storage Pond

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 25/11/20	Date 15/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/FR02.1 (v3.0)

FR02.2: Online Storage Pond

Purpose of Measure

Online storage ponds are water storage measures that are hydraulically connected to a watercourse via ditches (**Figure 1**), pipes, or within the watercourse channel itself (**Figure 2**). Online storage ponds are designed to slow the flow of water and store additional water during and initially after a storm event.

Online storage ponds can be designed to permanently hold water, or as temporary flood storage features which are dry for some of the time. Ponds, both permanent and temporary, can add considerable biodiversity value to the local area. As such, consideration should be given to the ecological design of ponds to maximise opportunities for wildlife where this does not compromise the flood management function of the measure.

Design Parameters

Online ponds shall be designed on a site-specific basis according to factors such as land use, soil type, existing drainage, local habitats, catchment setting and future maintenance requirements. Ponds may be designed as a single feature (**Figure 2**) or as a connected chain of ponds (**Figure 3**). Ponds often require an outlet structure or spillway to convey flow out of the pond or between individual pond features should overtopping or drying of the stream system be a strong possibility. This outlet feature or spillway may include scour protection, such as a gravel (**Figure 1**) or rock-armour spillway (boulders inserted into the channel downstream of the pond) (**Figure 2**) or a similar nature-based solution.

Pond sizes vary, however are most commonly between 100 - 400 m^2 with a depth up to 1.5 m. Size will be governed by access, available space, volume required for water storage and ease of build, as well as watercourse character such as width, flow velocity and bank height. Ponds of greater dimensions and storage capacity are possible, however, in all instances the design shall ensure safe egress in the event of entering the pond through provision of appropriate bank slopes (at least 1:3). Ponds potentially accessible to the public (i.e. near to footpaths) may need further measures such as warning signs and/or exclusion fencing. It may be possible to create additional flood storage within the pond by building bunds—however the bund and associated outlet structure must not inhibit passage of fish or result in more than 200 m^3 of additional above ground storage. Ponds can either permanently or temporarily hold water. Ponds designed to hold water throughout the year must provide additional capacity to hold storm water. Most online ponds will hold some water throughout the year, so to act as an NFM feature they must be built to provide temporary additional flood storage i.e. not be permanently full. This flood storage component of a pond's capacity needs to drain down within around 48 hours to provide storage for subsequent rainfall events. Lining of ponds is best avoided as infiltration to ground is an important flood reduction feature. However, if the local ground water infiltration to the pond is not optimal (likelihood of too much or too little filling) a pond liner may be required.

Excavation of the pond will generate spoil material. Any design will need to consider how and where this material will be managed. The preference should always be local re-use e.g. for local agricultural benefit, as this is often the most sustainable and cost effective option. Spoil re-use opportunities will be dependent on the material's properties and potential for contaminants to be present—both should be investigated as part of the design process.

A key multiple benefit of ponds is additional biodiversity. In particular, ponds with shallow side slopes and varied depths generate habitat complexity. Re-seeding of banks or islands with native species may be required to support vegetation re-growth and bank stability.

Complementary measures— A complex system can be implemented, in which both online and offline storage ponds (**FR02.1**) combine to manage flood water. In-channel leaky barriers (**WC01.1**) may be constructed in proximity to an online storage pond to encourage water spill from a watercourse channel for storage within the pond, before entry back to the watercourse. Spoil generated from pond excavation can be used to create a flow pathway bund (**FR01.2**) in adjacent land to attenuate overland flow before entering the watercourse or online storage pond.

Maintenance Requirements

Online storage ponds typically have a 10 year design life at optimum functionality without the need for significant maintenance.

A medium to high level of maintenance is required for storage ponds, including regular checks for sediment build-up in the base of the pond (especially where unfenced and open to poaching) as this can reduce storage capacity and effectiveness over time. Occasional desilting and appropriate disposal of accumulated sediment may be required. This may be of higher importance if the pond design includes an outlet feature, to ensure blockages do not occur and fish passage is not inhibited.

Any spillways or other outlet structures e.g. pipes, may also need checking routinely, to check for signs of erosion and remove any blockages that may be preventing water drainage back into the watercourse.

Permanent storage ponds typically have a greater maintenance requirement than temporary storage ponds.

Cost

Construction of online storage ponds is costed between £10 and £50 per m^3 of excavation (including equipment, materials and labour costs). However, in most examples the construction cost will be towards the lower end, assuming simplistic pond design, limited removal/disposal of soil and limited consenting requirements. Higher costs may be observed where ponds are adjacent to main rivers (due to consenting requirements) and where more complex designs (including outlet structure requirements) are used. There will be additional costs associated with any requirements to spread or remove spoil.

The above cost estimates cover a 'fair weather' construction. If construction is undertaken in a particularly difficult location or planned for a time of year when weather may be inclement a contingency should be added. In addition an allowance should be made for pre-construction activities and maintenance. The cost of design, planning and consenting before construction can be 60% of construction cost. A typical allowance for maintenance costs is 10% of construction cost for each year a structure is in operation. For an example of typical maintenance requirements, see the "Maintenance Requirements" section.

Equipment and Materials

The following is a list of equipment and materials that are typically required in the construction of an online storage pond.

Equipment:

- Tracked excavator—preferably with a toothless tilting bucket head to allow for more complex contouring
- Tracked dumpers—for spoil movement and tipping
- Lorries—should off site spoil disposal be required
- Water pumps—for dewatering excavations

Materials

- Outlet scour protection—to protect against erosion downstream of the measure
- Pond liner (sheeting/clay)— should the pond be required to permanently hold water and infiltration to ground undesirable
- Seeding/planting —to facilitate vegetation re-establishment in working area

Figure 1. Online storage feature at Magpie Farm , complete with armoured spillway (© Atkins Ltd)

Figure 2. An online storage pond within the channel, complete with rock armour spillway (© Newcastle University)

Figure 3. Online storage ponds with adjacent tree planting as part of the Evenlode NFM scheme (© Evenlode catchment Partnership)

Consents and Permissions

Consent will be required for online storage ponds, with exact requirements depending on the pond size, storage volume and location.

Large ponds may require planning permission from the local planning authority, with the permission request accompanied by environmental reporting e.g. an Environmental Impact Assessment (EIA) and a waste management plan.

A flood-risk activity permit from the Environment Agency will be required for works within or on the floodplain of main rivers. Ponds located adjacent to and/or alter the flow of an ordinary watercourse will need land drainage consents from the Lead Local Flood Authority (LLFA) or Internal Drainage Board (IDB).

Permissions may be needed from relevant historical and archaeological bodies e.g. Historic England to control for any potential disruption to heritage features.

A waste management plan and exemption agreement or licence may be required for management of spoil generated by excavating a pond.

Further Reading

For further information on online storage ponds refer to the following sections within the References (**REFS.X**) specification sheet:

General—reference 2, 3 and 7

Measure Specific—FR02.2: Online Storage Pond—see specific references for "FR02.1: Offline Storage Pond"

Consents and Permissions—references 6, 7, 8, 9, 10, 11, 13 and 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client
Highways England

Project title
Highways England NFM Pilot

Drawing title
FR02.2: Online Storage Pond

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 18/11/20	Date 12/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/FR02.2 (v2.0)

FR02.3: Swales

Purpose of Measure

Swales are artificial linear depressions/shallow channels that act to capture, temporarily store and occasionally redirect overland flow during and following heavy rainfall events. Swales can be installed on any land that is susceptible to overland flow and may be particularly effective when positioned in proximity to impermeable surfaces such as farm yards or tracks, or other surfaces that promote overland flow.

Vegetated swales increase roughness that slows the flow within the channel, which may be important should the swale be acting to direct water towards a storage area. Through attenuating and storing water, swales can promote water infiltration into the soil and can work to settle out pollutants and sediment, reducing the transfer of these to the drainage network and downstream watercourses. Swales can add biodiversity value through the provision of habitats in the local area. Through the attenuation and settling of sediment and pollutants, local water quality may also be improved through the creation of swales. Therefore, consideration should be given to the ecological design of ponds to maximise opportunities for wildlife where this does not compromise the flood management function of the measure.

Design Parameters

Swales are best targeted at improved/semi improved grassland or arable margins and shall be designed to take into account existing land-use and access requirements. Land characteristics such as slope and contours must be considered to ensure the swale can capture and attenuate overland water flow, by constructing along land contours so as not to create preferential flow pathways to watercourses (**Figure 1**).

Swales are typically appropriate for sloping fields (not steeper than 1:8) where they follow existing contours. The likely rate of runoff from the land must be considered to ensure the swale is of sufficient length, depth, width and orientation to intercept flow and provide effective storage. Swales shall have bank slopes not steeper than 1:3 to provide stability, aid in their maintenance and allow for safe egress. Swale top widths typically range from 1 m to 3 m (**Figure 2**), with a maximum depth to width ratio of 1:6. Depths shall not exceed 0.5 m. Widths of swales typically increase as the slope and size of land producing runoff increases.

Excavation of the swale will generate spoil material. Any design will need to consider how and where this material will be managed. The preference should always be local re-use, as this is often the most sustainable and cost effective option. Spoil re-use opportunities will be dependant on the material's properties and potential for contaminants to be present—both should be investigated as part of the design process. A simple option is to use the spoil on the downslope of the swale to slightly raise ground levels (nominally 300—400 mm) to provide additional storage capacity (**Figure 3**).

Lining of swales is not required as infiltration to ground is an important flood reduction feature of the measure. Swales shall not be designed to direct flow towards the local drainage/watercourse network without attenuation. They can be designed as isolated features or to drain to/connect to other NFM storage measures such as offline ponds (**FR02.1**). Connecting storage areas with swales can act to ensure the swale function is maintained for longer periods during rainfall events. Consideration will be required into the erosional potential of water moving to a storage area with appropriate erosion protection provided.

Following construction the swale shall be left to revegetate naturally where possible. It is recommended that turfs be stripped from the working area prior to excavation and translocated to areas of bare ground created by the works, such as any low level downslope bund. Re-seeding with an appropriate grass mix can also be used to encourage vegetation development, which can further promote infiltration and run-off control. Swales potentially accessible to the public or livestock may need further measures such as exclusion fencing (**Figure 3**) or crossing provision.

Complementary measures—Material generated from swale excavation can be used to create other connected measures such as flow pathway bunds (**FR01.2**) which will act to reduce material disposal costs. Cross-slope woodland & hedgerows (**LM01.2**) may be planted downslope of a swale to enhance infiltration and intercept overland flow (**Figure 2**). Offline storage ponds (**FR02.1**) can be hydraulically connected to swales and used to store water attenuated by the swale.

Maintenance Requirements

Swales typically have a 10 year design life at optimum functionality without the need for significant maintenance.

A low level of maintenance is required for swales, typically on an annual basis, including the removal of debris that may reduce storage capacity, as well as vegetation maintenance (cutting/controlled grazing) and removal of noxious weeds that may have become established.

Where swales are connected to storage areas, these may need routine checks for signs of erosion and/or the removal of any blockages that may be preventing water discharging to the storage area. Maintenance shall also be required to check for signs of erosion within the swale and along and downslope bund. Should any signs of failure or excessive erosion be observed, repairs will be required. Any fencing, crossing structures/rights of way will also be maintained.

Cost

Construction of swales is typically costed between £20 and £70 per linear metre, including equipment, materials and labour costs. In most examples, the construction figure will be towards the lower end of this estimate, assuming the spoil disposal is designed to be local and easy to complete. A cost of £20 per linear metre may include simple swales (constructed by a rotary ditcher for example) that are un-seeded and left to develop naturally, whilst the figure may be considerably further up the cost range if the swale is complex and requires further considerable effort to establish vegetation. Additional cost may also be observed if connecting to an offline storage pond, however, greater flood reduction and biodiversity benefits may be observed through combing these measures.

The above cost estimates cover a 'fair weather' construction. If construction is undertaken in a particularly difficult location or planned for a time of year when weather may be inclement a contingency should be added. In addition an allowance should be made for pre-construction activities and maintenance. The cost of design, planning and consenting before construction can be 60% of construction cost. A typical allowance for maintenance costs is 10% of construction cost for each year a structure is in operation. For an example of typical maintenance requirements, see the "Maintenance Requirements" section.

Equipment and Materials

The following is a list of equipment and materials that are typically required in the construction of a swale.

Equipment:

- Small excavator—to strip soil and cut swale, preferably with a toothless tilting bucket head
- Rotary ditcher— alternative to excavator for basic swale creation
- Tracked dumpers—for spoil movement
- Lorries—should off-site spoil disposal be required
- Spades—for hand excavation and minor works
- Fencing tools— for construction of livestock exclusion fences if required

Materials

- Seeding—should it be required to facilitate vegetation establishment in working area
- Fence posts, wire, netting and staples— to construct exclusion fencing around swale

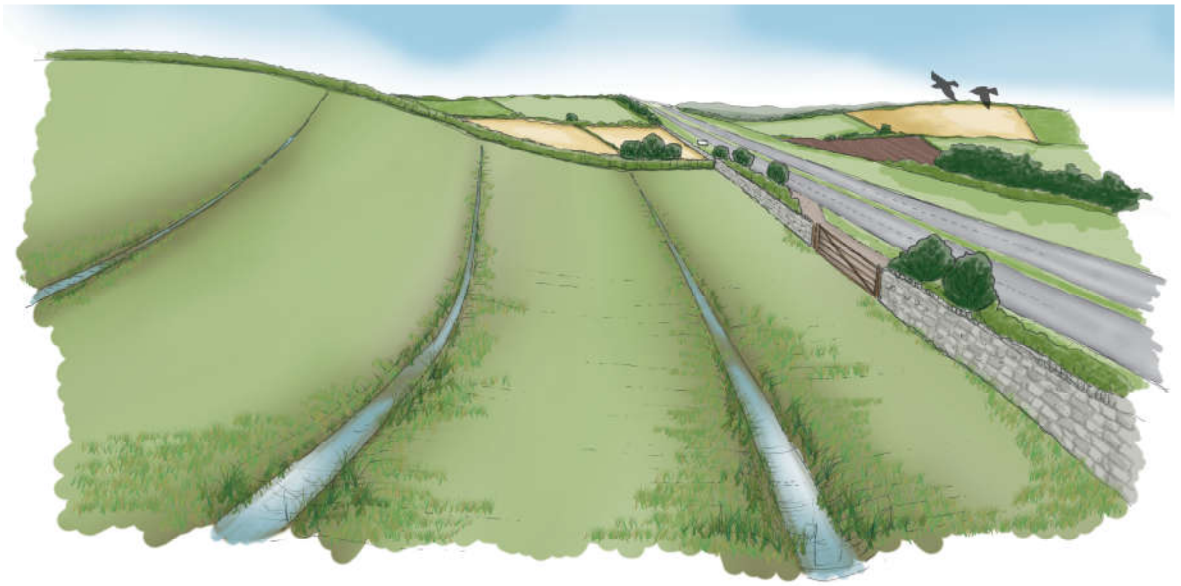

Figure 1. Cross-slope swales constructed along land contours to reduce overland flow to the road network (© Atkins Ltd)

Figure 2. Recently constructed cross-slope swale at field edge with tree planting, as part of the Evenlode NFM scheme (© Dave Gasca-Tucker)

Figure 3. Recently constructed cross-slope swale prior to vegetation establishment, with downslope low level bund and fencing to protect from poaching (© West Cumbria Rivers Trust)

Consents and Permissions

Consent is unlikely to be required for swales that are constructed in existing agricultural land.

However, a flood-risk activity permit from the Environment Agency will be required if the swale is constructed adjacent to or in the floodplain of a main river. Or if adjacent to an ordinary watercourse it may need land drainage consents from the Lead Local Flood Authority (LLFA) or Internal Drainage Board (IDB).

Permissions may be needed from relevant historical and archaeological bodies e.g. Historic England to control for any potential disruption to heritage features.

A waste management plan and exemption agreement or licence may be required for management of spoil generated by excavating extensive lengths of swale.

Further Reading

For further information on swales refer to the following sections within the References (**REFS.X**) specification sheet:

General—reference 2, 9, 10 and 11

Measure Specific—FR02.3: Swales—references 1, 2, 3, 4 and 5

Consents and Permissions—references 6, 7, 8, 9, 10, 11 and 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client

Highways England

Project title

Highways England NFM Pilot

Drawing title

FR02.3: Swales

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 18/12/20	Date 15/03/21	Date 16/03/21

Drawing no: 5158157/7.9.2.1/DG/FR02.3 (v2.0)

WC01.1: In-channel Leaky Barriers

Purpose of Measure

In-channel leaky barriers are designed to intercept and slow the flow of water within a permanently or intermittently flowing watercourse. Water is held back behind the barrier and may be encouraged onto the floodplain, where it can be stored within complementary natural flood management measures, or allowed to naturally drain back to the watercourse after the flood levels recede. Leaky barriers typically only become active during high flow events, with low flows not being affected by the structure. Leaky barriers are most suited to small watercourses that have been historically straightened, over deepened and in locations where storage will not cause a risk to people/property, structures or existing land-use.

In-channel leaky barriers have multiple benefits, including improvements to water quality, reduction of sediment transfer and enhanced local biodiversity through increased flow variation and the provision of more habitats supporting fish, plants and invertebrates around the woody features.

Design Parameters

In-channel leaky barriers shall be designed on a site-specific basis depending on watercourse width, bank height and flow conditions, along with location within the catchment and adjacent land-use. In-channel leaky barriers are typically designed for smaller channels, not greater than 3 m in width. Installation in channels larger than 3 m is possible, but these would need to be informed by a more detailed design approach. In upland areas, woody bundles may be a more applicable measure (see **WC01.2**).

In-channel leaky barriers are typically constructed from large wood (nominally 300 mm diameter) and/or large branches as the key construction material, with smaller branches and brushwood incorporated to manage porosity (**Figure 1** and **Figure 2**). Positioning of the barrier shall be perpendicular to the water flow. The length of the large wood foundations shall not be less than 1.5 times the channel width to provide barrier stability, and shall be secured to, or within banks (depending on bank stability) using driven stakes and ties. Fixing is likely to be required to manage the risk of the feature being washed away. The number of fixings and exact method of securing will be site specific and based on factors such as the size of the wood, likelihood of mobilisation, channel and floodplain roughness and risk to downstream assets.

Leaky barriers shall be installed individually, or in series where effectiveness may be increased. The spacing between barriers will be determined by design height and stream slope, but is typically 5 to 20 times channel width. Barriers are not to be installed immediately upstream of a structure e.g. a bridge, culvert or outfall, so as to reduce the risk to assets should wood become mobilised. The following rule shall apply in relation to the permitted distance of installation from a structure: no barrier shall be installed within a distance that is less than 30 times the channel width, as measured at the location of the barrier.

The height placement of leaky barriers will depend on the channel depth as normal/base flows shall be allowed to pass under freely, ensuring the barriers only become active at slowing the flow during the rising peak of flood events (**Figure 3** and **Figure 4**).

Should vehicle access to the site not be possible, manual handling or lightweight machinery/equipment may be required to construct the barriers, for which health and safety considerations (e.g. no manual handling of objects over 25 kg) must be considered. Furthermore, if barriers are to be installed in proximity to a woodland area, this may reduce cost and time of construction, as locally sourced wood from the woodland may be used for barrier construction, following appropriate permissions and ecological checks.

More formal leaky barrier designs can be employed which use wood (**Figure 1**) and/or wooden planks (**Figure 4**) to provide the barrier structure instead of more naturally looking wood accumulations. Similar design principles of structure size, positioning and fastening will be followed.

Complementary measures— Overland leaky barriers (**FR01.1**) can be constructed adjacent to the barrier, or where the floodplain is constrained, be simply and an extension of the in-channel barrier to store additional water. Flow pathway bunds (**FR01.2**) and offline storage ponds (**FR02.1**) may also be constructed on the adjacent floodplain to attenuate and temporarily store water pushed onto the floodplain by a leaky barrier or series of barriers.

Maintenance Requirements

In-channel leaky barriers typically have a 5—10 year design life at optimum functionality without the need for significant maintenance. Maintenance may include the replacement of fixings to ensure the barrier remains secure at the designed location, or addition/replacement of wood over time.

A medium level of maintenance is required for in-channel leaky barriers. Maintenance shall include regular bi-annual checks for litter and woody material that has been intercepted by the barrier, reducing its effectiveness. Additional checks shall also occur following each significant storm event, to ensure that the barrier is still firmly fixed and that no wood/construction materials have been dis-lodged or mobilised. Where safe to do so, litter intercepted by the barrier should be removed and any damaged fixings replaced.

Some minor adjustments in design height may be required should observations during a flood event identify the need to improve the storage potential of the leaky barrier or series of barriers.

Cost

Construction of in-channel leaky barriers is costed between £500 and £2,000 per barrier, including costs for equipment, materials and time. Despite this large range, costs may typically be at the lower end of this scale, with higher costs coming with increased complexity of construction. Smaller, more simple features in accessible areas will generally be lower costing, whilst large barriers with a more complex design, requiring more expensive equipment or difficult access may be towards the upper costing range. If multiple in-channel leaky barriers are constructed, the cost per feature is likely to reduce because the overheads of construction will be spread across multiple features.

The above cost estimates cover a 'fair weather' construction. If construction is undertaken in a particularly difficult location or planned for a time of year when weather may be inclement a contingency should be added. In addition an allowance should be made for pre-construction activities and maintenance. The cost of design, planning and consenting before construction can be 60% of construction cost. A typical allowance for maintenance costs is 10% of construction cost for each year a structure is in operation. For an example of typical maintenance requirements, see the “Maintenance Requirements” section.

Equipment and Materials

The following is a list of equipment and materials that are typically required for construction of an in-channel leaky barrier.

Equipment:

- Digger and operator—for manoeuvring large wood and excavation of bank slot trenches if required
- Winches/strops/hoists—for manoeuvring and positioning of wood over 25 kg
- Spades—for digging of slot trenches
- Fence post driver—for driving fixing stakes
- Fencing tools—to secure the barrier
- Chainsaw—to fell trees and yield wood material

Materials:

- Large wood/logs/planks—for main structural component
- Fixing stakes—to secure the barrier in place
- Wire and staples—to attach barrier to fixings
- Small branches/brushwood—to pack feature

***Figure 1**. Formally structured in-channel leaky barrier with rope and wooden stake fixings* (© Jay Neale)

***Figure 2**. Formally structured in-channel leaky barrier with wire fixings and trenched into banks* (© Eden Rivers Trust)

***Figure 3**. Fixed large wood in-channel leaky barrier storing water during high flow event* (© Dave Gasca-Tucker)

***Figure 4**. Formal in-channel leaky barrier constructed from wood planks, located above the base flow level and with notch in the top to allow spillage of high flows* (© Shropshire Wildlife Trust, Kirsty Brown)

Consents and Permissions

Works within a watercourse will require consents from relevant authorities.

Should the barrier be constructed in a main river channel, then a flood risk activity environmental permit or proof of exemption from the Environment Agency will be required. In-channel leaky barriers constructed in ordinary watercourses will require flood defence consents from either the Lead Local Flood Authority (LLFA) or the Internal Drainage Board (IDB).

Should trees need to be felled locally for the construction of an in-channel leaky barrier, a tree-felling licence may be required from the Forestry Commission or the relevant local authority.

Surveys may be required to confirm the presence or absence of protected species in the local area, which if found, may require protected species mitigation licenses from Natural England.

Further Reading

For further information on offline storage ponds refer to the following sections within the References (**REFS.X**) specification sheet:

General—All general references

Measure Specific—WC01.1: In-channel Leaky Barrier—references 1, 2 and 3

Consents and Permissions—references 1, 2, 3, 8, 10, 11, 13 and 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a “fit for construction” final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the “Further Reading” section.

Equipment and Materials

The list provided within the “Equipment and Materials” section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client

Highways England

Project title

Highways England NFM Pilot

Drawing title

WC01.1: In-channel Leaky Barriers

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 24/11/20	Date 17/03/21	Date 18/03/21

Drawing no: 5158157/7.9.2.1/DG/WC01.1 (v3.0)

WC01.2: Headwater Channel Woody Bundles

Purpose of Measure

Headwater channel woody bundles are of a similar concept to in-channel leaky barriers (**WC01.1**), however, they are more typically associated with temporarily (ephemeral) flowing channels/gullies in wooded sections of the upper catchment. The purpose of these measures is to roughen the flow route within the headwaters and in doing so slow and attenuate flow during storm events. The measures are typically designed to mimic naturally occurring woody accumulations that cause natural blockages and complexities within headwater channels (**Figure 1**).

Headwater woody bundles are typically installed in steep channels and gullies and may be particularly beneficial in reducing initial runoff and flow rates further downstream following rainfall events, by targeting water at the source. These measures may also provide considerable biodiversity benefits through provision of "dead wood" habitat.

Design Parameters

Headwater channel woody bundles shall be designed on a site-specific basis, accounting for variation in local topography, material availability and land access. The channel/gully dimensions along with typical flow regimes shall inform design requirements. However, woody bundles shall be installed in ephemeral headwater gullies (**Figure 2** and **Figure 3**) that are known to flow periodically, either throughout the wet winter months or more specifically, following a heavy rainfall event.

Headwater woody bundles shall be orientated in the direction of flow with the length of the large wood not less than three times the active channel width, and typically in excess of 100mm in diameter. The length of bundle run can vary, but shall not exceed five times the bundle width. In steeply sloped gullies effectiveness can be improved by adding elevation and tying into the valley slopes. Headwater woody bundles are typically installed in series and designed to "fill" the active channel in order to maximise effectiveness, acting to slow smaller volumes of water per feature, rather than store a large amount of water behind a single feature.

Large wood shall be securely fastened and meshed together to reduce the risk of mobilisation (**Figure 4**). This is particularly important where any movement and transport of wood downslope could result in blockages/damages to structures. The number of fixings and exact method of securing will be site specific and based on factors such as the size of the wood, likelihood of mobilisation, gully roughness and risk to downslope assets. The following rule shall apply in relation to the permitted distance of installation of a bundle from a structure: no bundle shall be installed within a distance that is less than 30 times the active channel width, as measured at the location of the bundle.

Should vehicle access to the site not be possible, manual handling or lightweight machinery/equipment may be required to construct the bundles, for which health and safety considerations (e.g. no manual handling of objects over 25 kg) must be considered. Since this measure is to be targeted at upland woodland areas, cost and time of construction is likely to be reduced due the presence of locally available wood for bundle construction. Following appropriate permissions and ecological checks, trees can be felled directly to the ephemeral channel/gully and processed in situ to reduce handling. Voids within the bundles can be packed with smaller branches and brushwood to manage porosity and make better use of tree work arisings.

Complementary measures—Overland leaky barriers (**FR01.1**), flow pathway bunds (**FR01.2**) and offline storage ponds (**FR02.1**) (assuming appropriate contours) may be constructed adjacent to woody bundles to attenuate and temporarily store water. In-channel leaky barriers (**WC01.1**) may be installed further downstream (in permanently flowing channels). There may be an opportunity to share wood required in the construction of barriers and bundles from a common source.

Maintenance Requirements

Headwater channel bundles typically have a 5 year design life at optimum functionality without the need for significant maintenance. Maintenance may include the replacement of fixings to ensure the bundle remains secure at the design location, or addition/replacement of wood over time.

A low level of maintenance is required for bundles. Maintenance shall include bi-annual checks for litter and woody material that has been intercepted by the barrier. Additional checks shall also occur following each significant overland flow event, to ensure that the bundle is still intact/firmly fixed and that no wood/construction materials have been dis-lodged or mobilised. Litter (e.g. plastic bags) intercepted by the barrier should be removed and any damaged fixings replaced if there is risk of mobilisation.

Some minor adjustments in design height may be required should observations during a flood event identify the need to improve the performance of the bundles.

Cost

Construction of headwater channel woody bundles is costed between £50 and £1,000 per woody bundle installed, including costs for equipment, materials and time. Despite this large range, costs may typically be at the lower end of this scale, with higher costs coming with increased complexity of constructions. Smaller, more simple features in accessible areas will generally be lower costing, whilst large barriers with a more complex design, requiring more expensive equipment or difficult access may be towards the upper costing range. If headwater channel woody bundles are installed in a sequence, the cost per bundle is likely to reduce because the overheads of construction will be spread across multiple features.

The above cost estimates cover a 'fair weather' construction. If construction is undertaken in a particularly difficult location or planned for a time of year when weather may be inclement a contingency should be added. In addition an allowance should be made for pre-construction activities and maintenance. The cost of design, planning and consenting before construction can be 60% of construction cost. A typical allowance for maintenance costs is 10% of construction cost for each year a structure is in operation. For an example of typical maintenance requirements, see the "Maintenance Requirements" section.

Equipment and Materials

The following is a list of equipment and materials that are typically required for construction of a headwater channel woody bundle.

Equipment:

- Winches/strops/hoists—for manoeuvring and positioning of wood over 25 kg
- Fence post driver/sledge hammer— for driving fixing stakes
- Fencing tools—to secure the bundle
- Chainsaw—to fell trees and yield wood material

Materials:

- Large wood/branches—for main structural component
- Fixing stakes—to secure the bundle in place
- Wire and staples—to attach bundle to fixings

Figure 1. *Felled trees placed to mimic naturally occurring woody accumulation as part of the Stroud District Council Rural SuDS Project (© Stroud District Council)*

Figure 2. *Headwater channel woody bundles after placement in a channel to mimic natural blockages, as part of the Stroud District Council Rural SuDS Project (© Stroud District Council)*

Figure 3. *Headwater channel woody bundles in a wooded valley (© Dave Gasca-Tucker)*

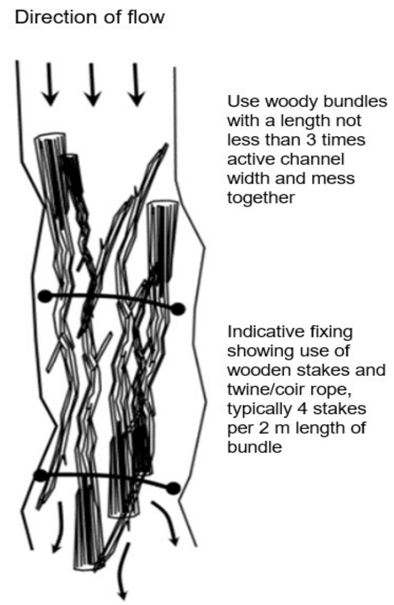

Figure 4. *Example conceptual design for headwater channel woody bundle (© Atkins Ltd)*

Consents and Permissions

As headwater channel woody bundles are targeted at temporarily (ephemeral) flowing channels/gullies in the upper catchment, it is considered unlikely that these will be in a designated main river. However, should the barrier be constructed in a main river channel, then a flood risk activity environmental permit, or proof exemption will be needed, from the Environment Agency. Headwater woody bundles are more likely to be constructed in ordinary watercourses, and as such will require flood defence consents from the Lead Local Flood Authority (LLFA) or Internal Drainage Board (IDB).

Should trees need to be felled locally for the construction of a headwater woody bundle, a tree-felling licence may be required from the Forestry Commission or the relevant local authority.

Surveys may be required to confirm the presence or absence of protected species in the local area, which if found, may require protected species mitigation licenses from Natural England.

Further Reading

For further information on headwater channel woody bundles refer to the following sections within the References (**REFS.X**) specification sheet:

General—reference 7

Measure Specific—WC01.2: Headwater Channel Woody Bundles—no specific references

Consents and Permissions—references 1, 2, 3, 10, 11, 13 and 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Client
Highways England

Project title
Highways England NFM Pilot

Drawing title
WC01.2: Headwater Channel Woody Bundles

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 26/11/20	Date 17/03/21	Date 18/03/21

Drawing no: 5158157/7.9.2.1/DG/WC01.2 (v3.0)

WC01.3: Moorland Grip and Gully Blocking

Purpose of Measure

Moorland and peatland landscapes can be highly responsive to rainfall events especially where they exhibit artificial grip and gully drainage channels. The rapid drainage from moorland areas can contribute to high flow rates and flooding in downstream watercourses. Moorland grip and gully blocking involves the construction of small in-channel structures to hold and store water within the drainage channels thus reducing the risk of downstream flooding (**Figure 1**).

Through the retention of water in the landscape and raising the local water table, grip and gully blocking can also promote the re-vegetation and restoration of peatland areas. Pools created by dams can also provide increased habitat for aquatic species and provide temporary (and often permanent) water storage, similarly to online storage ponds (**FR02.2**).

Design Parameters

The number, type and material used in the construction of dams to block grips and gullies will vary according to site characteristics and construction logistics. A range of dam typologies can be used including dams constructed from peat (**Figure 1**), machined wood (**Figure 2**) or stone (**Figure 3**). Wood or stone dams typically require materials being transported to site using heavy machinery, or through air-lifting, that are both costly and risk damaging the peat landscape. Construction of peat dams shall be the preferred approach.

To construct a peat dam, unoxidized peat from the bottom of the grip or gully shall be lifted, inverted and placed immediately downstream from where it was removed. Additional peat shall then be gathered to complete the dam. To increase stability, peat dams are typically keyed into the gully through excavation of the gully banks by a minimum of 500 mm and gully base by a minimum of 200 mm. Each dam shall be constructed higher than the gully banks where possible to ensure that water will be displaced on to the moor prior to any overtopping (**Figure 4**). Dams are typically compacted by mechanical means e.g. excavator bucket, to ensure the dam is impermeable and stable. Peat dams shall be constructed with shallow-sloping sides to increase structural stability and allow for safe egress of livestock or people should they enter the gully. To further enhance stability peat dams may be "seeded" with viable Sphagnum moss propagules or through the use of locally translocated turfs to hasten vegetation establishment. This will promote rejuvenation of the moorland, add local biodiversity and improve carbon storage.

Peat dams may be designed as impermeable structures to trap and hold water, or have an outlet structure (e.g. piped outlet or French drain) so the dam will slow the flow of water during storm events. This allows a designed amount of water to pass-through, whilst maintaining storage for subsequent events. Where dams are likely to overtop, or designed to be "leaky" through pipe installation, then scour protection is typically required to prevent erosion and under-cutting on the downstream side of the dam. Scour protection may be in the form of rock or coir matting to overlay the peat and provide protection.

Where multiple dams are being installed (**Figure 1** and **Figure 4**), a top-to-toe principle approach is typically taken ensuring the base of the upstream dam is at least level with the top of the downstream dam to prevent over-topping on to bare peat or soil. This may not be required should leaky dams be constructed. However, as the gradient of gully or grip increases, dams shall be constructed in smaller intervals to reduce erosion in each section.

Where the use of existing peat is not feasible, alternative approaches shall be considered such as the use of wooden drop boards (**Figure 2**) or stone check dams (**Figure 3**). Should stone or wooden dams be required, consideration must be given to the material origin and additional costs associated with procurement and transport to site. Any vehicular/machinery access that is required to undertake the work must be planned and routed to avoid damaging peat, moorland habitats and associated species. Public, livestock and wildlife access/safety shall be considered within the design process in relation to potential barrier formation..

Complementary measures—No specific complementary NFM measures, but consider options such as vegetation reintroduction through the landowner innovation option.

Maintenance Requirements

Moorland grip and gully blocking using peat dams typically has a 5-10 year design life at optimum functionality without the need for significant maintenance.

A low level of maintenance is typically required for moorland grip and gully blocking. Maintenance may include the checking of vegetation establishment and its encouragement where necessary, including the translocation of additional turf. Should dams become damaged or weathered over time, remedial works may be required to support the dam, including the addition of peat or additional structural supports.

Cost

Moorland grip and gully blocking using the techniques described is costed between £50 and £250 per feature installed. This range includes cost of equipment and materials. Construction costs will be towards the lower end where equipment needs are minimal and access to the site is good. If multiple dams are constructed, the cost per feature is likely to reduce because the overheads of construction will be spread across multiple features. Costs may be observed towards the upper end of the range where equipment hire is expensive, outflow control structures are included or access requirements are complex. This may include the need for more specialist equipment, or difficulty accessing the site due to the local topography. Costs of other techniques such as use of wooden boards and stone dams will be at the upper and lower end of the cost range respectively.

The above cost estimates cover a 'fair weather' construction. If construction is undertaken in a particularly difficult location or planned for a time of year when weather may be inclement a contingency should be added. In addition an allowance should be made for pre-construction activities and maintenance. The cost of design, planning and consenting before construction can be 60% of construction cost. A typical allowance for maintenance costs is 10% of construction cost for each year a structure is in operation. For an example of typical maintenance requirements, see the "Maintenance Requirements" section.

Equipment and Materials

The following is a list of equipment and materials that are typically required in the construction of a peat dams.

Equipment:

- Low ground pressure 360° tracked excavator—preferably with a toothless tilting bucket head and <10t to avoid compaction to the surrounding peat
- Water pumps—for dewatering excavations
- Spades—for lifting and translocating peat/turfs

Materials:

- Pipes—for "leaky" dams if designed to pass-through flow
- Outlet scour protection—e.g. rock or coir matting to protect against erosion of the peat downstream of the dam
- Seeding/planting —to facilitate vegetation re-establishment in working area

Figure 1. *A series of peat dams (© Moors for the Future Partnership)*

Figure 2. *Formal leaky wooden dam blocking a moorland gully (© Dartmoor National Park Authority (DNPA), © Environment Agency)*

Figure 3. *Stone dams blocking a gully. Vegetation has re-established within the channel following gully blockage (© Moors for the Future Partnership)*

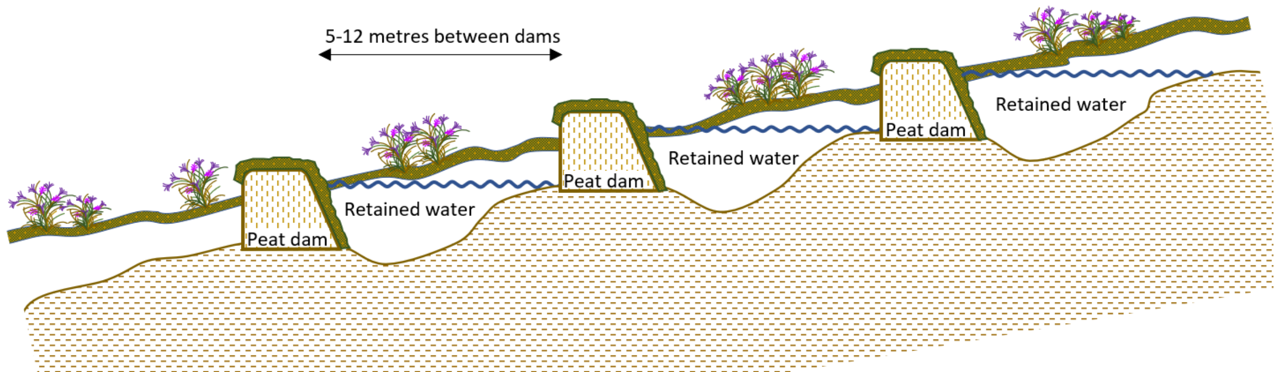

Figure 4. *An example design of a series of peat dams (© Atkins Ltd)*

Consents and Permissions

Large areas of moorland are designated as open access land and therefore any works may require Public Rights of Way and Open Access consents from the County Council or relevant local authorities. If any works are being completed that may impact public right of way or the people using it, then additional permissions and safety plans may be required.

Large areas of moorland are designated as protected areas (e.g. SSSI, SAC, SPA) and any works may require a Habitat Regulation Assessment (HRA) under the Conservation of Habitats and Species Regulations 2017 (as amended), in consultation with Natural England.

Consultation with the Local Flood Authority (LLFA) or on flood defence consent requirements is also advised. If large-scale gully blocking is taking place then planning permission may be required from local authorities.

Further Reading

For further information on moorland grip and gully blocking refer to the following sections within the References (**REFS.X**) specification sheet:

General—reference 2

Measure Specific—WC01.3: Moorland Grip and Gully Blocking—references 1, 2, 3, 4 and 5

Consents and Permissions—references 9 and 14

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Notes

This Design Specification Sheet is to be read in conjunction with the Natural Flood Management Measures Booklet, Design Specification Catalogue, the Natural Flood Management Fund Handbook and the Fund website [redacted]

Design Considerations

This sheet is for design information only and is NOT to be used as a "fit for construction" final design specification. Where specific design parameters are stated for the measure, these shall be adhered to.

Maintenance and Liability

The landowner shall be responsible for the implementation and maintenance of any NFM measure on their land and will hold the liability for said measure during its design life. Refer to the Natural Flood Management Fund Handbook for Terms & Conditions governing participation in the Fund.

Cost

Costs are based on available information from a range of sources relating to the measure. Costs should therefore be treated as a guide only. For further information and additional reading, see references detailed in the "Further Reading" section.

Equipment and Materials

The list provided within the "Equipment and Materials" section is typical for the measure type. Equipment and materials usage will vary by design, site characteristics and material availability, therefore, the list should NOT be taken as exhaustive.

Consents and Permissions

The information provided is NOT an exhaustive list but includes guidance on common requirements for the measure. For further consenting and permissions advice, please make contact with the Catchment Advisor who will assist in identifying site specific requirements for the measure.

Health and Safety Considerations

The Construction (Design and Management) Regulations (CDM) 2015 provide a helpful reference for identifying the roles and responsibilities for people involved in the design and construction process and what is needed to protect them from harm. Further specific information on health and safety in agriculture is available from the Health and Safety Executive (HSE) Farmwise booklet.

Design

A design risk assessment is required to identify the hazards and evaluate the risks that may arise from the design. Dependent upon the hazard, the designer shall implement appropriate controls to minimise or remove the risk. Considerations include, but are not limited to, location of services and public rights of way, UXO risk, accessibility for machinery, waste management, consenting requirements, presence of protected species/ habitats, invasive non-native species presence and future maintenance needs.

Construction

Working method statements, risk assessments, biosecurity procedures and environmental/site management plans shall be produced and adhered to at all times. Ensure all construction staff are fit for work, appropriately trained, hold the correct tickets/permits for machine operation and have access to appropriate PPE and on-site welfare.

Operation/Maintenance

Post-construction activities will also need to be considered in project planning to ensure that specified inspection and maintenance requirements can be undertaken safely. As with the construction phase, inspection and maintenance activities shall only be undertaken by appropriately trained individuals. During operation ensure that any interfaces with the public are appropriately controlled and maintained.

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Project title
Highways England NFM Pilot

Drawing title
WC01.3: Moorland Grip and Gully Blocking

Scale	Drawn	Check	Review
A3	SR	MH	IPM
	Date 18/12/20	Date 16/03/21	Date 18/03/21

Drawing no: 5158157/7.9.2.1/DG/WC01.3 (v2.0)

Appendix D. NFM measures summary

Appendix E. UXO assessment

UNEXPLODED BOMB RISK MAP

zeticaUXO

SITE LOCATION

Map Centre: 444772,211722

LEGEND

High: Areas indicated as having a bombing density of 50 bombs per 1000acre or higher.

Moderate: Areas indicated as having a bombing density of 15 to 49 bombs per 1000acre.

Low: Areas indicated as having 15 bombs per 1000acre or less.

military | industry | UXO find | transport | dock | Luftwaffe targets | utilities | Bombing decoy | other

How to use your Unexploded Bomb (UXB) risk map?
The map indicates the potential for Unexploded Bombs (UXB) to be present as a result of World War Two (WWII) bombing.

You can incorporate the map into your preliminary risk assessment* for potential Unexploded Ordnance (UXO) for a site. Using this map, you can make an informed decision as to whether more in-depth detailed risk assessment* is necessary.

What do I do if my site is in a moderate or high risk area?
Generally, we recommend that a detailed UXO desk study and risk assessment is undertaken for sites in a moderate or high UXB risk area.

Similarly, if your site is near to a designated Luftwaffe target or bombing decoy then additional detailed research is recommended.

More often than not, this further detailed research will conclude that the potential for a significant UXO hazard to be present on your site is actually low.

Never plan site work or undertake a risk assessment using these maps alone. More detail is required, particularly where there may be a source of UXO from other military operations which are not reflected on these maps.

If my site is in a low risk area, do I need to do anything?
If both the map and other research confirms that there is a low potential for UXO to be present on your site then, subject to your own comfort and risk tolerance, works can proceed with no special precautions.

A low risk really means that there is no greater probability of encountering UXO than anywhere else in the UK.

If you are unsure whether other sources of UXO may be present, you can ask for one of our **pre-desk study assessments (PDSA)**

If I have any questions, who do I contact?

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The information in this UXB risk map is derived from a number of sources and should be used in conjunction with the accompanying notes on our website: **(https://zeticauxo.com/downloads-and-resources/risk-maps/)**

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It is important to note that this map is not a UXO risk assessment and should not be reported as such when reproduced.

*Preliminary and detailed UXO risk assessments are advocated as good practice by industry guidance such as CIRIA C681 'Unexploded Ordnance (UXO), a guide for the construction industry'.

Appendix F. Borehole records

SP 41 SE 2 | 4525 1071 | Cassington House, Cassington | Block C

Surface level (+63.1 m) +207 ft
Water struck at +59.0 m
Shell and auger (modified) 6 in (152 mm) diameter
January 1971

Overburden 1.1 m (3.5 ft)
Mineral 5.1 m (17.0 ft)
Bedrock 0.9 m+ (3.0 ft+)

Geological Classification	LOG Lithology	Thickness m	Thickness (ft)	Depth m	Depth (ft)
	Made ground	1.1	(3.5)	1.1	(3.5)
Second Terrace Deposits	'Clayey' gravel Gravel: medium to coarse, white limestone with angular flint and subrounded quartz Sand: medium to coarse, light brown	5.1	(17.0)	6.2	(20.5)
Oxford Clay	Clay, bluish grey, stiff	0.9+	(3.0+)	7.1	(23.5)

SP 41 SW 29 | 4386 1291 | New Barn, Church Hanborough | Block C

Surface level (+64.6 m) 212 ft
Groundwater conditions not recorded
Shell and auger (modified) 6 in (152 mm) diameter
January 1971

Overburden 0.7 m (2.5 ft)
Mineral 3.0 m (10.0 ft)
Bedrock 0.3 m+ (1.0 ft+)

Geological Classification	LOG Lithology	Thickness m	Thickness (ft)	Depth m	Depth (ft)
Alluvium	Soil on clay, silty, yellowish brown	0.7	(2.5)	0.7	(2.5)
First Terrace Deposits	Gravel Gravel: fine to coarse, white oolitic limestone with reddish brown sandstone, subrounded quartz and flint Sand: medium to coarse, light brown, quartz	3.0	(10.0)	3.7	(12.0)

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