NORFOLK WATER STRATEGY PROGRAMME

Best Practice Guidance:

In-field monitoring of Nature-based Solutions for improved water management

River Stiffkey floodplain reconnection | ©Norfolk Rivers Trust

Norfolk County Council

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The Nature Conservancy

Nature for Water Local solutions. Global impact.

Introduction I How to use this guide

Click on the tab to skip to a section

The purpose of this guide is to inform standard procedures for the Norfolk Water Fund relating to in-field monitoring of Nature-based Solutions (NbS) for improved water management, especially those that align with requirements for recording key performance indicators (KPIs), alongside natural capital revenues including Replenish, Biodiversity Net Gain (BNG) and Nutrient Neutrality (NN). The guide is intended as an information resource for practitioners. An overview of the content of each section is outlined below.

The document is designed to be 'browsed' with clickable links between sections, with forward ▶ and back ◀ options on each page, and the ability to skip to the beginning ⏮ or the end ⏭. The next page explains the icons used throughout this guide to indicate ecosystem services benefits provided by each of the Nature-based Solutions (NbS). For convenience, a List of Acronyms is provided in the Resources section.

Introduction I How to use this guide

Throughout this guide you will see the icons shown below. These indicate the ecosystem services benefits provided by each of the Nature-based Solution (NbS) discussed in this guide.

Ecosystem Service icons

Flooding

NbS options that can reduce flood risk (e.g., store water during rainfall events)

Water quality

NbS options that can improve water quality (e.g., reduce nutrient pollution)

Water resources

NbS options that can increase available water resources (e.g., increase groundwater recharge)

Aquatic habitats

NbS options that can improve aquatic habitats (e.g., creation of new wetland environments)

Terrestrial habitats

NbS options that can improve terrestrial habitats (e.g., creation of wildflower meadows)

Physical interventions

NbS options that can improve morphology and physical habitat structure (e.g., reconnecting floodplains)

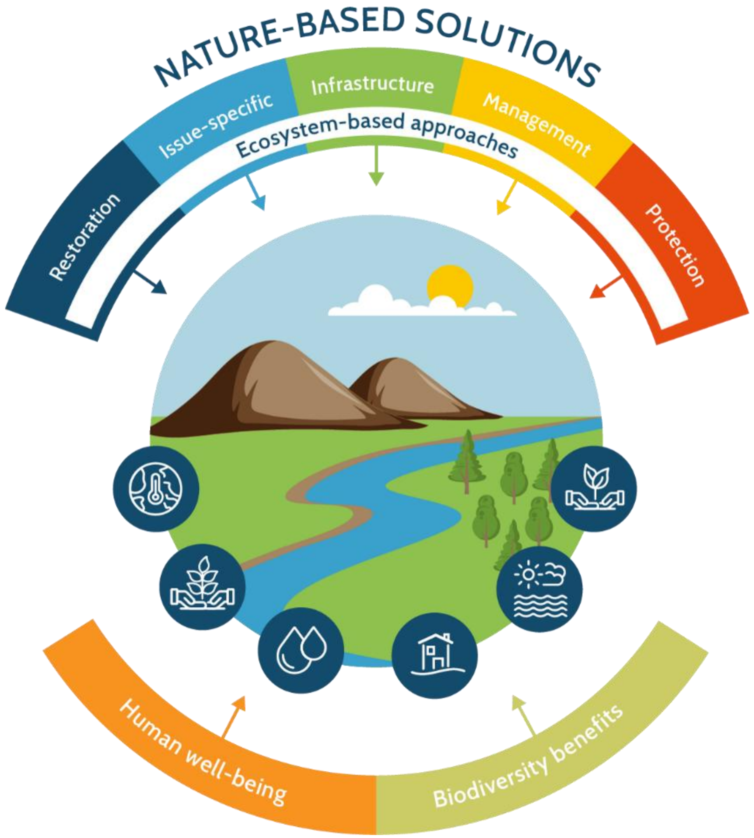
Clicking the icon links in the document will bring you back to this page for definitions.

Introduction I What are Nature-based Solutions (NbS) ?

Nature-based Solutions (NbS) are strategies that seek to utilise natural processes to address environmental, societal, and economic challenges such as climate change, water security, natural disasters and biodiversity loss. Nature-based Solutions are designed to work with, rather than against, nature and offer cost-effective, sustainable, and resilient alternatives to traditional engineered, human-centric, approaches.

Key objectives of NbS for water resources management

1. **Reducing flood risk** | slowing, storing, and absorbing excess water to mitigate flood impacts.
2. **Reducing drought risk** | increasing rainwater infiltration to enhance groundwater recharge and support river baseflows.
3. **Improving water quality** | intercepting, retaining, and absorbing pollutants to reduce contamination of waterbodies.
4. **Restoring ecosystems** | enhancing biodiversity through restoration of natural aquatic and terrestrial habitats.
5. **Enhancing climate resilience** | making landscapes and water resources more resilient to climate variability and extreme weather events.



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https://iucn.org/news/ecosystem-management/201901/informing-global-standard-nature-based-solutions

Introduction I What are the key elements of a monitoring framework for NbS ?

Establishing an effective monitoring framework for Nature-based Solutions requires consideration of five main aspects:

1. **Defining objectives and key performance indicators (KPIs)** | establish clear, quantifiable, and outcome-driven KPIs for each specific NbS that align with desired environmental and socio-economic benefits.
2. **Baseline assessments and reference conditions** | conduct baseline monitoring or collate preexisting historical datasets to establish pre-implementation benchmarks, adopting a before-after, control-impact approach.
3. **Spatial and temporal considerations** | design monitoring protocols that account for site-specific heterogeneity and temporal variability.
4. **Analysis and interpretation** | consider the most appropriate methods for interrogating monitoring data and comparing against baseline assessments and predefined KPIs.
5. **Stakeholder engagement and participatory monitoring** | integrate community-based approaches and multi-actor collaboration to enhance stakeholder involvement and support effective policy integration.

Photo credit: Wensum Demonstration Test Catchment (DTC)

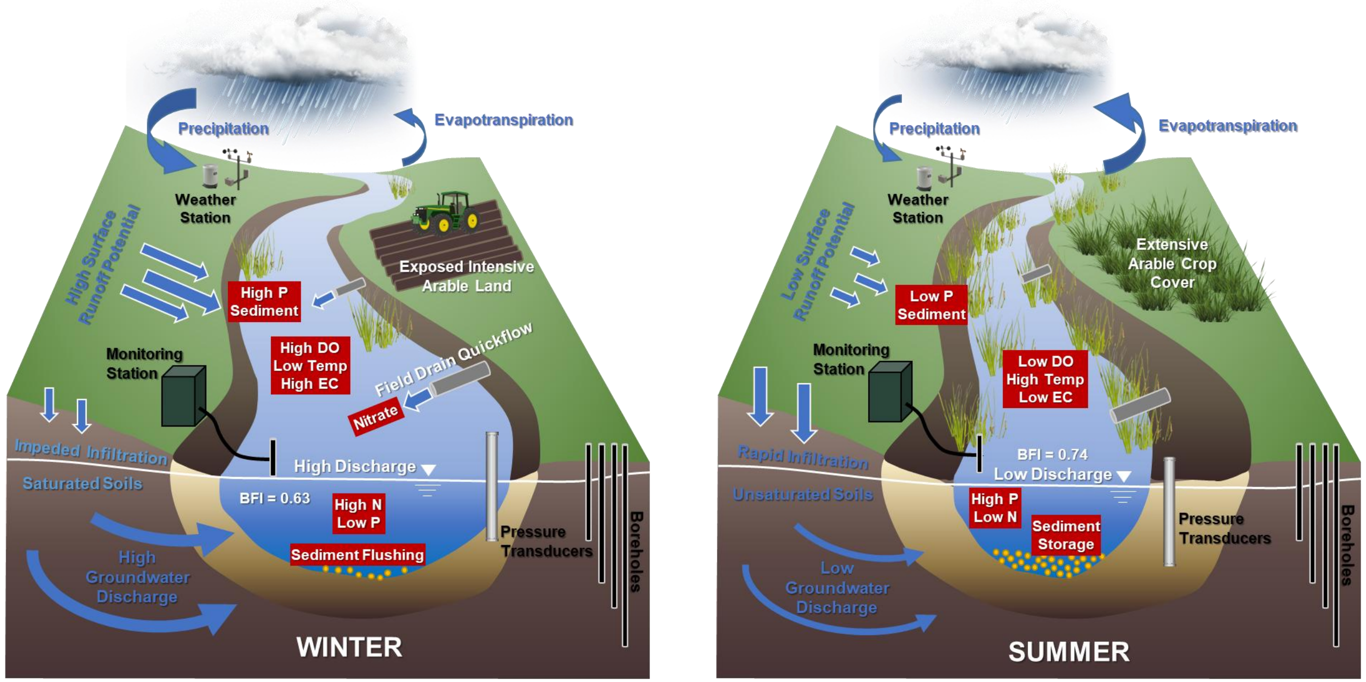
Designing a monitoring platform | Considerations

1

The purpose of monitoring: Determines the appropriate temporal and spatial resolution required and the parameters to be monitored. For example, is it to identify pollution sources, assess NbS effectiveness, or to understand the existing conditions?

2

Catchment characteristics: Strongly influences catchment dynamics. Properties such as land use, soil type, topography, geology and climate all influence hydrological functioning and, consequently, NbS performance.



3

Which parameters to monitor?

Water quality
- ✓ conductivity
- ✓ pH
- ✓ turbidity
- ✓ dissolved oxygen
- ✓ temperature
- ✓ nitrate
- ✓ total nitrogen
- ✓ phosphate
- ✓ total phosphorus

Meteorological
- ✓ temperature
- ✓ precipitation
- ✓ solar radiation
- ✓ humidity

Terrestrial ecology
- ✓ birds
- ✓ pollinators
- ✓ mammals
- ✓ plants

Hydrology
- ✓ stage
- ✓ discharge
- ✓ groundwater level

Soil
- ✓ pore water quality
- ✓ infiltration rate
- ✓ bulk density
- ✓ nutrients
- ✓ moisture content
- ✓ biology
- ✓ carbon content

Aquatic ecology
- ✓ diatoms
- ✓ invertebrates
- ✓ fish
- ✓ macrophytes

Designing a monitoring platform | Considerations

4

What monitoring resolution is required?

High-resolution
In-situ telemetered sensor technologies

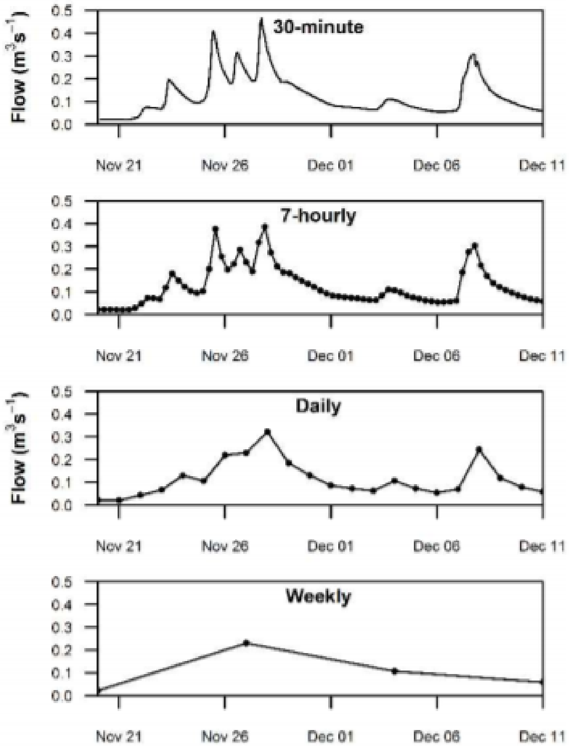
+ Reveals intricate dynamics of rainfall-dependent pollutant transfers
+ Enables identification of periods of pollutant mobilisation and storage
+ Enables determination of pollution pathways and catchment response times
+ Provides insights into pollution sources and pollution loads
+ Potential to develop conceptual models of hydrochemical processes
+ Powerful tool for landowner engagement

- High capital costs of installing, maintaining and running instrumentation
- High labour costs for equipment maintenance and data processing
- Can be unreliable, leading to instrument breakdowns and data gaps
- In-situ sensors only available for a limited range of water quality parameters

Low-resolution
Manual sampling with lab analysis

+ Quicker to conduct and easier to deploy over a wider geographic area
+ Significantly cheaper with minimal capital, installation, and maintenance costs
+ Can be used to produce data on a full suite of water quality parameters
+ More reliable data generation with minimal downtime
+ Provides valuable understanding of baseline conditions

- Fails to capture the full range of pollutant concentrations
- Fails to capture precipitation event responses
- Greater uncertainty in pollution load estimates
- Harder to identify the sources and pathways of pollution



Impact of monitoring resolution upon data interpretation

High-resolution in-situ monitoring

Low-resolution monitoring

Key message High-resolution, long-term monitoring provides more detailed evidence on catchment behaviour, but greater costs mean it must be selectively targeted to maximise benefits. Such monitoring cannot deliver an understanding of the full range of pollutants and therefore needs to be paired with manual sampling and laboratory analysis to provide a complete picture to inform catchment management decision making.

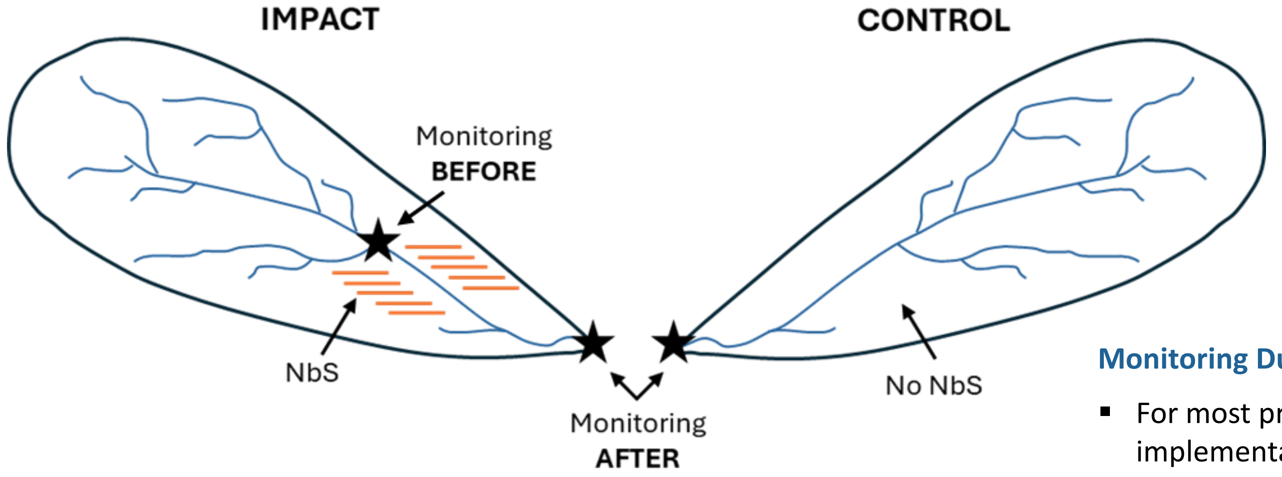
Designing a monitoring platform | Considerations

5

Choice of monitoring equipment: Determined by the purpose, parameters, and resolution required to effectively monitor the impact of the chosen NbS. Also determined by the funding available and duration of the project. Long duration projects supported by substantial funding would benefit from a **Gold Standard** approach utilising specialist in-situ telemetered technologies, whilst short duration projects with limited funding are likely to rely on **Basic** or **Standard** approaches using cheaper 'off the shelf' sensors and manual analysis.

6

Before-after, control-impact approach: Required to ascertain the impact of the chosen nature-based solution compared to baseline conditions.



- Compare manipulated site (**impact**) with non-manipulated site (**control**) before & after implementation of Nature-based Solutions
- Measurements taken pre-deployment of NbS (**before**) provide a baseline against which to compare post-deployment conditions (**after**).
- Neighbouring **control** site provides additional spatial reference that can be used to remove confounding effects from natural variability in the weather.

Monitoring Duration

- For most projects, obtaining a full hydrological year of monitoring before and after implementation is highly recommended to determine NbS performance under a wide range of weather conditions.
- Larger-scale NbS features (e.g., floodplain reconnection and land use change) are likely to benefit from longer-term monitoring (5-10 years) after implementation to capture changes in slower responding environmental components (e.g., biodiversity, soil carbon).

Designing a monitoring platform | Considerations

7

Monitoring trains: Allow for a more accurate assessment of NbS efficacy by capturing pollutant dynamics along the full length of the source-pathway-receptor continuum. An example of a five-stage monitoring train for assessing the efficacy of winter cover crops at reducing nitrate leaching losses from arable fields is outlined below:

- **Stage 1 (source):** at the impact site, sample and analyse cover crop leaf and root material to determine the % nitrogen content and enable calculation of nitrogen uptake rates from the soil (kg N/ha).
- **Stage 2 (source):** conduct soil sampling (0-30 cm depth) and analysis across both control and impact sites to determine residual soil nitrogen content (kg N/ha) that is vulnerable to leaching.
- **Stage 3 (pathway):** install network of ceramic porous pots (90 cm depth) across the control and impact fields to capture soil water leaching through the upper soil horizons. Soil water samples extracted by vacuum pump and analysed for nitrate concentration (mg N/L) in the laboratory.
- **Stage 4 (pathway):** sample outflows of subsurface (100-150 cm depth) agricultural field drains which discharge soil water directly into the ditch/river in control and impact areas. Analyse nitrate concentration (mg N/L) in the laboratory and calculate nitrate loads released from the drainage network (kg N/ha) by measuring drain discharge rates (L/s).
- **Stage 5 (receptor):** analyse ditch/river nitrate concentrations (mg N/L) and loads (kg N), downstream of the control and impact sites to determine the extent of nitrate pollution in the waterbody.

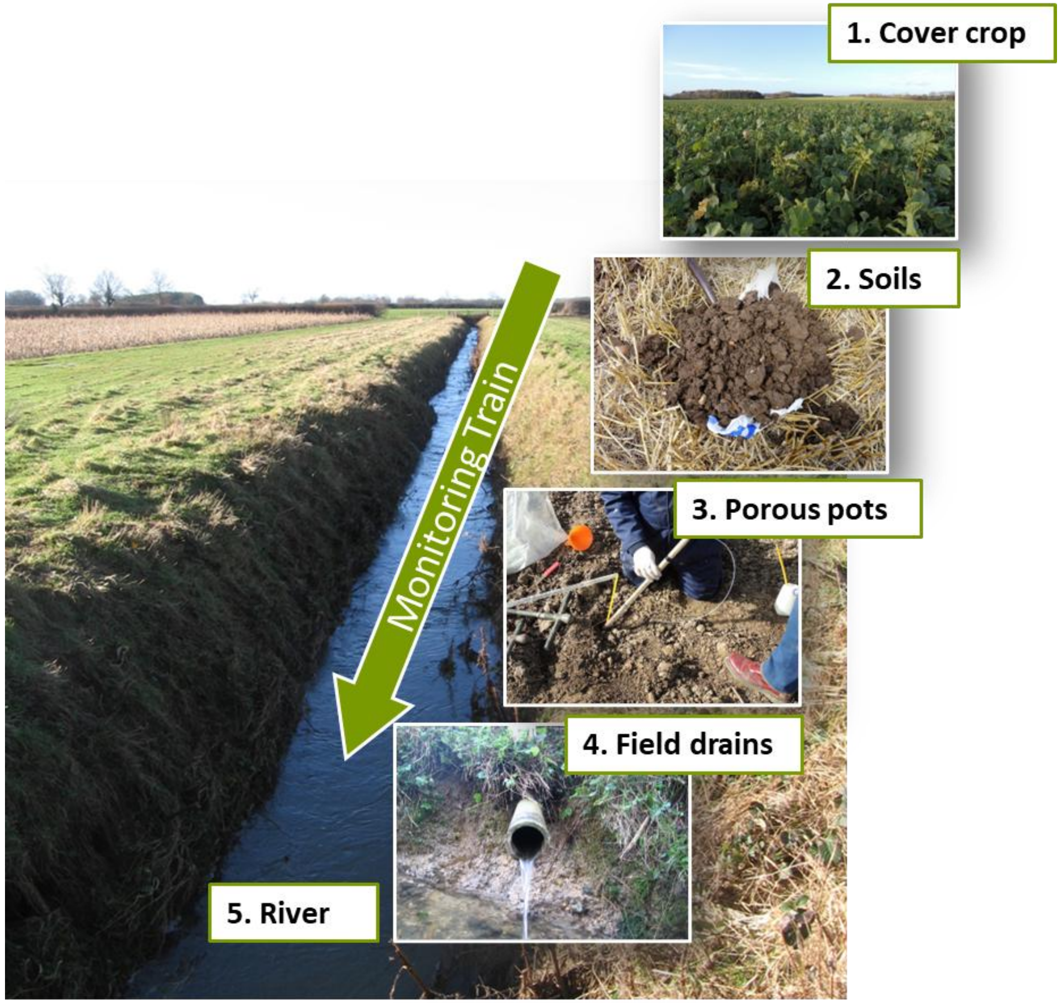


Photo credit: Wensum DTC

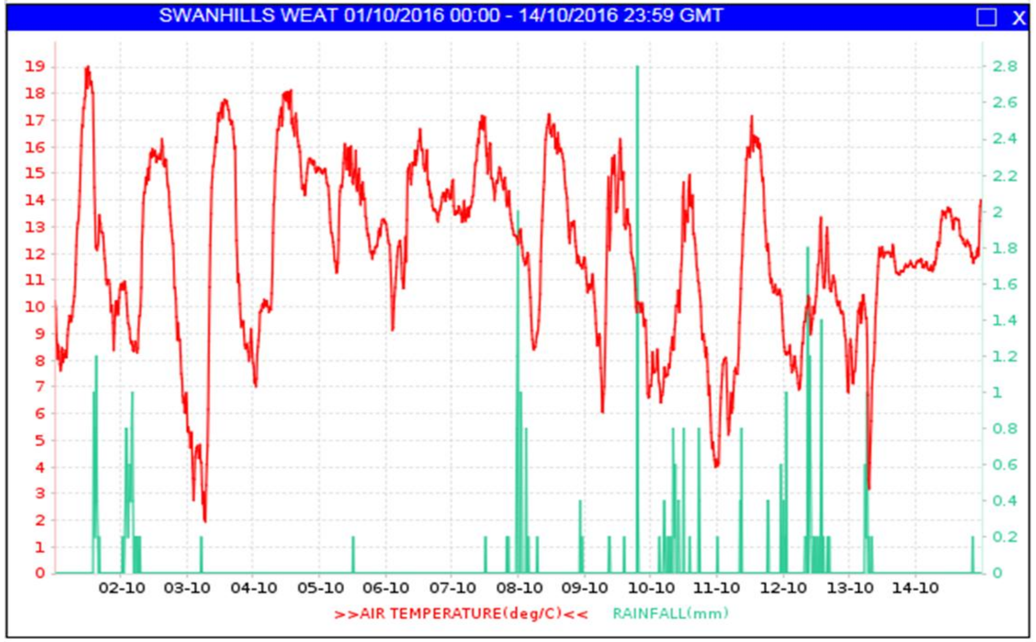
Designing a monitoring platform | Meteorological parameters

As the primary input of water to a catchment, the amount of precipitation will ultimately determine the quantity of surface water and groundwater resources. Precipitation is also closely linked to the delivery of pollutants to watercourses and therefore any water quality monitoring programme must also include meteorological measurements. Other parameters such as air temperature and solar radiation will impact upon biotic process within surface waters.

Parameter *	Method/specification	Lifespan	Purpose
Precipitation (mm)	Tipping bucket rain gauge, 0.2 mm resolution, telemetered 15-min interval	5-10 years	Understanding pollution mobilisation, hydrological response times, and calculating catchment water balances
Temperature (°C)	Thermometer, 0.1°C resolution, telemetered 15-min interval	5-10 years	Calculating evapotranspiration rates and understanding impacts upon water quality
Relative humidity (%)	Hygrometer, 0.1% resolution, telemetered 15-min interval	5-10 years	Calculating evapotranspiration rates
Net solar radiation (W/m²)	Radiometer, 0.1 W/m² resolution, telemetered 15-min interval	5-10 years	Understanding impact on crop growth and aquatic biotic processes and calculating evapotranspiration rates

* Link to met-office information


Weather station | Salle, Norfolk.
Photo credit: Wensum DTC



Example of high-resolution (15 minute) precipitation and air temperature data recorded by a telemetered weather station. Salle, Norfolk.

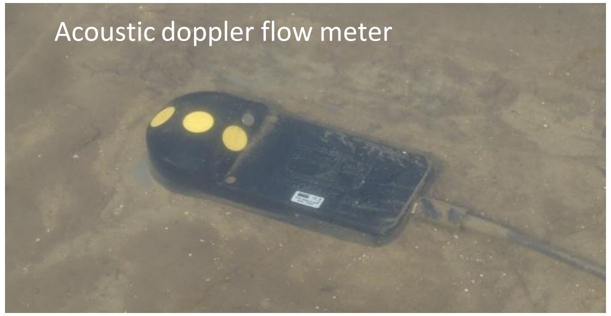
Designing a monitoring platform | Hydrological parameters

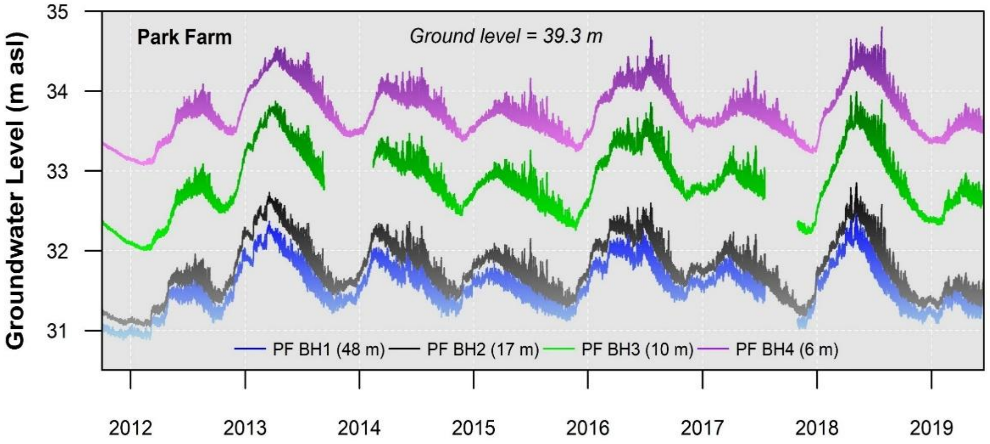
Monitoring the quantity of surface and subsurface water resources is essential for calculating catchment water balances, quantifying storage, and determining flood and drought risk. The delivery of pollutants to watercourses is also closely linked to hydrological processes and is therefore essential to include within any NbS monitoring programme. The relative contribution of surface vs subsurface water transport can vary substantially between study locations, and this has implications for the type of environmental monitoring that is required.

Parameter *	Method/specification	Lifespan	Purpose
River stage (m)	Pressure transducer in stilling well, automatic barometric correction, 0.1 cm resolution, telemetered 15-min interval	5-10 years	Understanding hydrological responses to rainfall events. Can be converted to discharge via manual flow gauging calibration.
River discharge (m^3/s)	Acoustic doppler flow meter, 0.001 m/s resolution, telemetered 15-min interval; For very shallow channels with uneven bed use a v-notch weir** with a stilling well.	5-10 years	Calculating hydrochemical loads and catchment water balance
Groundwater level (m AOD)	Pressure transducer in piezometer / borehole, automatic barometric correction, 0.1 cm resolution, telemetered 15-min interval	5-10 years	Identifying groundwater flow direction. Calculating groundwater recharge and catchment water balance
Field drain discharge (m^3/s)	Graduated bucket (L) + stopwatch, repeated 3 times per site	-	Calculating agrochemical export from under-drained agricultural land

* Links point to references about these parameters.

** Note that an environmental permit of land drainage consent may be needed for the installation of an in-channel structure



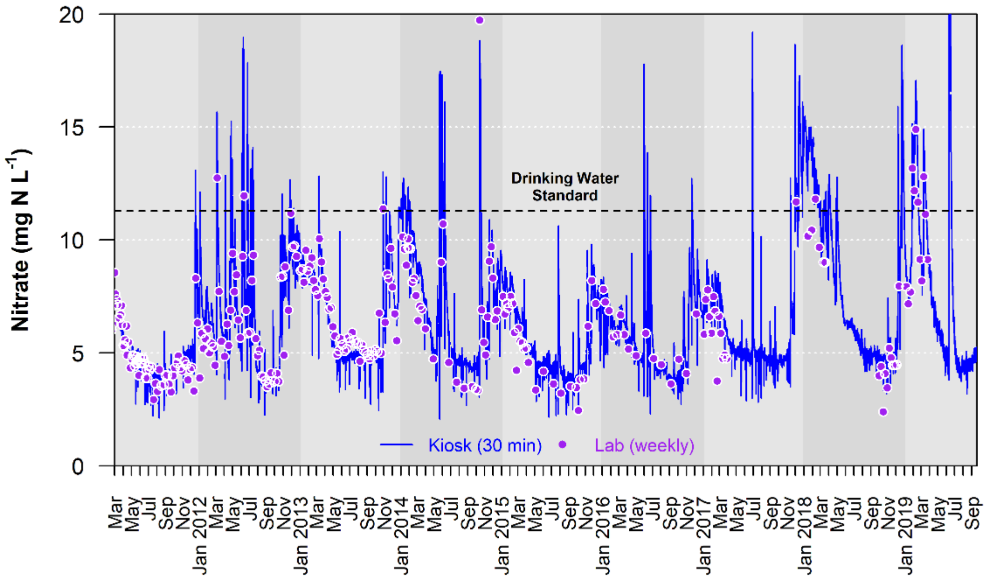


Example of high-resolution (15 minute) groundwater level data obtained from pressure transducers installed at four different depth boreholes. Salle, Norfolk.

Designing a monitoring platform | Hydrochemical parameters

Nutrients, sediment and carbon are core water quality parameters to monitor in surface and subsurface resources, although doing so at high-resolution using automated equipment entails considerable capital and maintenance costs. In-situ sensors can only measure a subset of key water quality parameters and have a higher inherent uncertainty associated with the data. Coupling with quality assured laboratory analysis ensures generation of robust datasets.


Riverine bankside monitoring station | Salle, Norfolk
Photo credit: Wensum DTC



Example high-resolution (30 minute) nitrate concentration data (blue) recorded by an in-situ bankside monitoring station, Salle, Norfolk. Weekly manual grab sampling and laboratory analysis data also shown (purple).

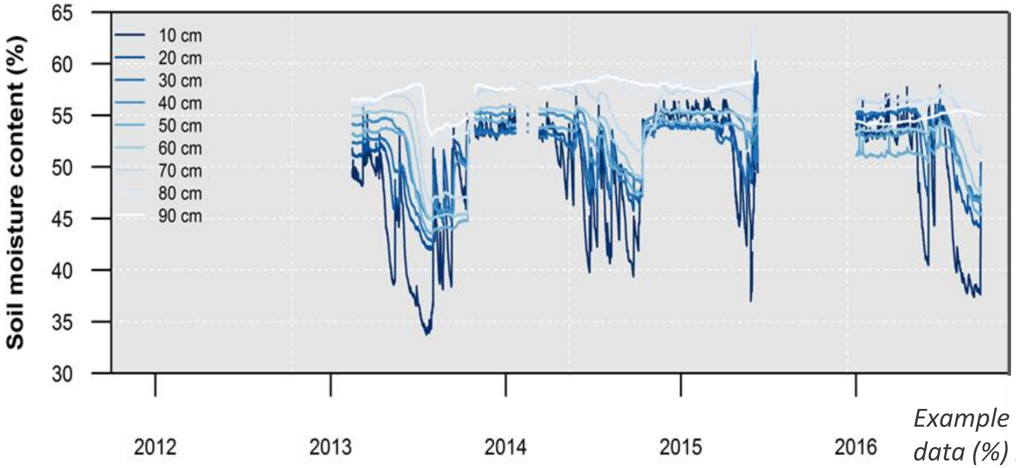
Parameter *	Species	Method/specification	Lifespan	Purpose
Nitrogen (mg N/L)	Nitrate	In-situ sensor, 0.01 mg/L resolution, telemetered 30-min interval	<2 years	Indicator of agricultural + sewage pollution
	Ammonia	In-situ sensor, 0.01 mg/L resolution, telemetered 30-min interval	<2 years	Indicator of agricultural + sewage pollution
	Total nitrogen	Lab analysis	-	Calculating nutrient loads
Phosphorus (mg P/L)	Phosphate	In-situ sensor, 0.01 mg/L resolution, telemetered 30-min interval	3-5 years	Indicator of agricultural + sewage pollution
	Total phosphorus	Lab analysis	-	Calculating nutrient loads
Carbon (mg C/L)	Dissolved organic	Lab analysis	-	Calculating carbon loads
Sediment (NTU or mg/L)	Turbidity	In-situ sensor, 0.01 NTU resolution, telemetered 30-min interval	3-5 years	Indicator of soil erosion
	Total suspended solids	Lab analysis	-	Calculating sediment loads
Dissolved oxygen (% or mg/L)	-	In-situ sensor, 0.1% saturation, telemetered 30-min interval	<2 years	Essential for aquatic respiration + measure of oxidation state
Temperature (°C)	-	In-situ sensor, 0.01°C resolution, telemetered 30-min interval	5-10 years	Impacts dissolved oxygen concentrations
Conductivity (µS/cm)	-	In-situ sensor, 1 µS/cm resolution, telemetered 30-min interval	3-5 years	Indicates origin of water + dissolved solids content
pH	-	In-situ sensor, 0.01 unit resolution, telemetered 30-min interval	<2 years	Impacts biogeochemical processes
Chlorophyll (µg/L)	Total algae	In-situ sensor, 0.01 µg/L resolution, telemetered 30-min interval	3-5 years	Indicator of eutrophication

* Links point to references about these parameters.

Designing a monitoring platform | Soil parameters

Soils represent the main pathway through which agricultural pollutants are transferred from land into the freshwater environment, via either surface runoff or subsurface leaching. Characterisation of soil health requires measurement of a suite of physical, chemical, hydrological and biological parameters. Some parameters, such as soil moisture content, can be made using in-situ telemetered sensors, whereas others require the manual collection of soil samples followed by laboratory analysis.

Telemetered soil moisture probe | Photo credit: Wensum DTC



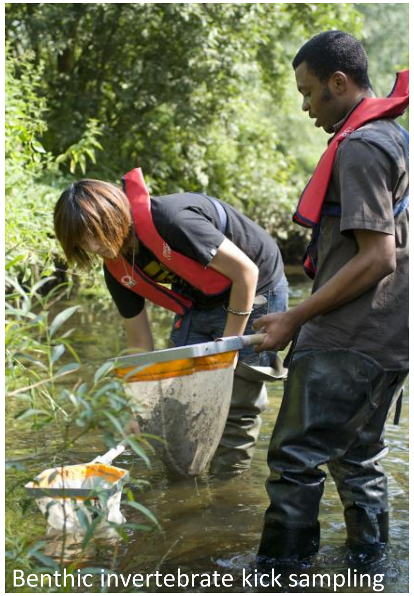
Example high-resolution (15 minute) soil moisture content data (%) recorded at 10-90 cm depth by an in-situ telemetered soil moisture probe, Salle, Norfolk.

Category *	Parameter(s)	Method/specification	Lifespan	Purpose
Hydrological	Soil moisture content (%)	In-situ, capacitance soil moisture probes, 10-100 cm depth, 10 cm intervals, 0.1% resolution, telemetered 15-min interval	3-5 years	Determine water availability for crops and potential for surface runoff and groundwater recharge generation
Physical	Bulk density (g/cm^3)	Lab analysis	-	Impacts structural stability and infiltration capacity
	Infiltration capacity (mm/hour)	Field infiltrometer	>10 years	Determine flood risk and groundwater recharge potential
Chemical	Soil water nutrients (mg/L)	In-situ porous pots (90 cm depth)	2-3 years	Determine nutrient leaching to groundwater
	Soil nutrients (N, P, K, S, Mg) (mg/kg)	Lab analysis	-	Determine soil nutrient status and calculation of catchment nutrient budgets.
	Soil carbon (mg/kg)	Lab analysis	-	Calculating carbon storage
Biological	Earthworms (count per m^3)	Manual count	-	General indicator of soil health
	Respiration rate (mg/kg)	Lab analysis CO_2 burst test	-	Indicator of soil microbial health

* Links point to references on how to do these tests.

Designing a monitoring platform | Ecological parameters

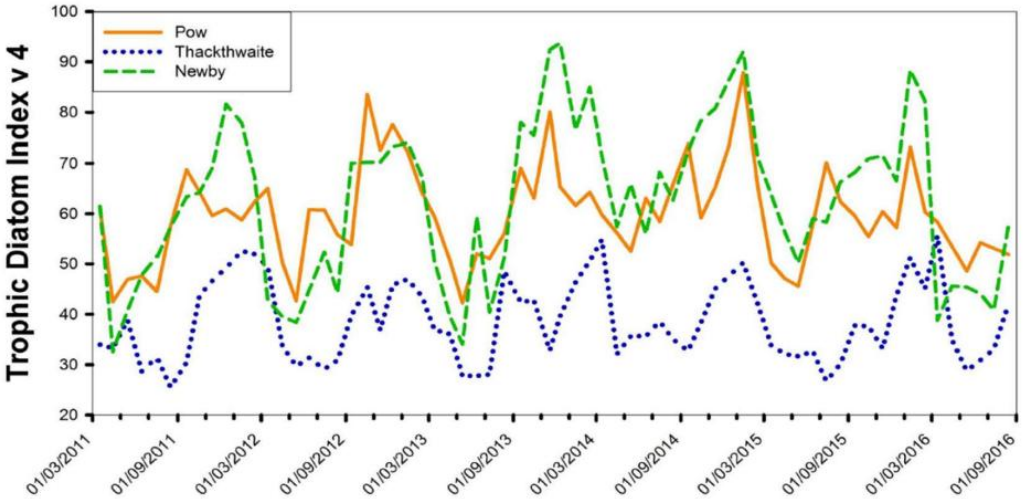
Ecological monitoring should be conducted across food webs and include key aquatic (diatoms, invertebrates, macrophytes, fish) and terrestrial (plants, birds, pollinators, mammals) taxa. Aligning ecological monitoring with hydrological and water quality monitoring provides a complementary assessment of ecosystem health to inform management of Nature-based Solutions.



Benthic invertebrate kick sampling
Photo credit: UEA

Category	Parameter	Method *	Purpose
Aquatic	Diatoms	DARLEQ	Indicator of trophic status (nutrient pollution)
	Invertebrates	Benthic kick sampling	Indicator of pollution and habitat status
	Macrophytes	LEAFPACS2	Indicator of trophic status (nutrient pollution)
	Fish	Electrofishing; eDNA	Indicator of pollution and habitat status
Terrestrial	Plants	Habitat mapping; species survey (quadrat/transect)	Indicator of habitat complexity
	Birds	Visual point count survey; acoustic recorders	Indicator of habitat status
	Pollinators	Netting bees & hoverflies	Indicator of habitat status
	Mammals	Longworth traps (small mammals); camera traps	Indicator of habitat status

* Links point to references on how to do these tests.



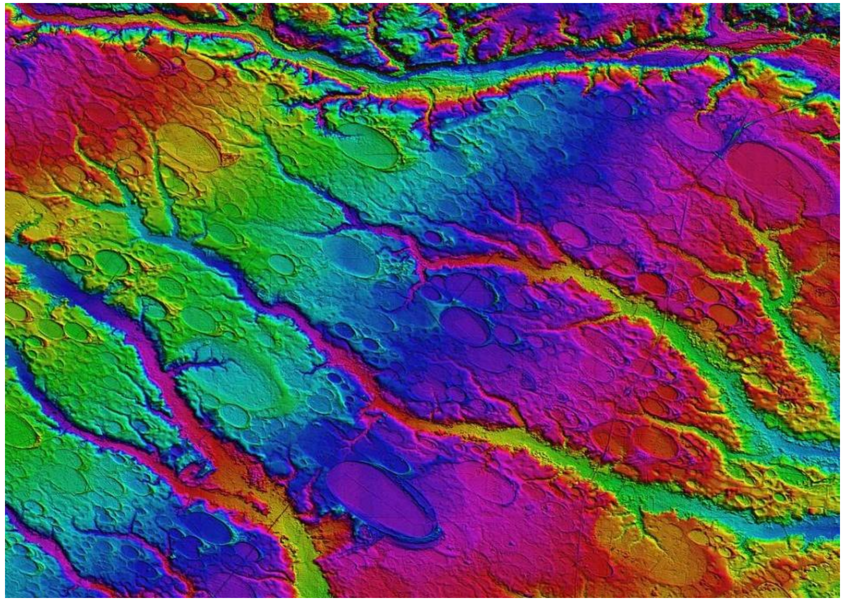
Example weekly resolution river diatom population data from three locations in the River Eden catchment, Cumbria. Credit: Eden DTC.

Designing a monitoring platform | Geomorphological parameters

Geomorphological monitoring involves tracking changes in landscapes, landforms, and surface processes over time. It helps to improve understanding of natural physical processes like erosion and sediment deposition, as well ecological processes such as vegetation evolution. Different in-situ and remote techniques are used depending on the scale, environment, and objectives.

Category	Method	Purpose
Topographic survey	LiDAR, total station theodolite	Provides detailed elevation mapping; particularly useful for floodplain restoration schemes
River morphology	Manual river habitat survey (RHS)	Assessing river physical characteristics and habitat types
Spatial changes	Drone survey (visual)	Provides aerial survey capability for large-scale NbS features
Temporal changes	Fixed point photography	Assessing visual changes in a site over time at a single location

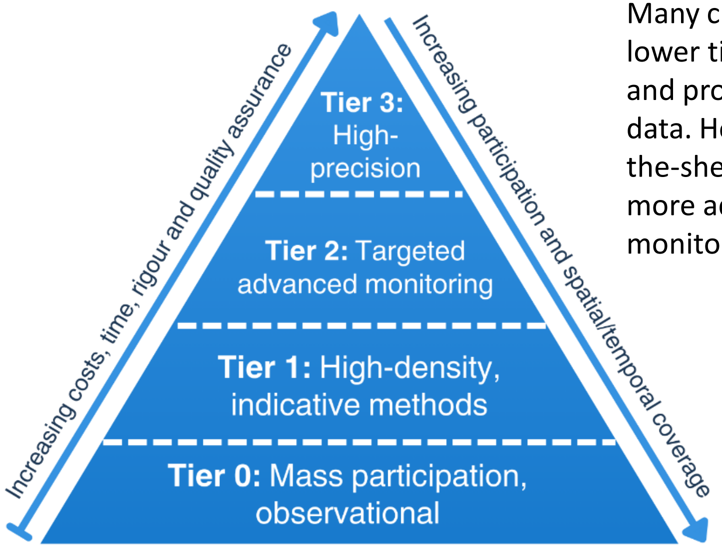
Topographic site survey for runoff attenuation feature construction | Salle, Norfolk
Photo credit: Wensum DTC



Example LiDAR topographic survey output.

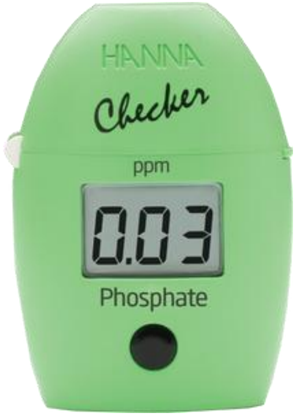
Designing a monitoring platform | Citizen Science

Citizen science monitoring involves engaging with non-professional volunteers in the systematic collection, analysis, and reporting of environmental data to assess NbS effectiveness. Utilising basic monitoring equipment and access to a large number of people, it can enable the generation of monitoring data at a higher spatial and temporal resolution than would otherwise be possible without complex and expensive equipment.



© CaSTCo

Many citizen science programmes focus on the lower tiers (0-1) of environmental monitoring and produce observational and qualitative data. However, with training and access to off-the-shelf test kits, citizen scientists can deliver more advanced targeted quantitative monitoring (tier 2) of NbS performance.



Basic nutrient test strips (left) or off-the-shelf handheld nutrient checkers (right) are low-cost solutions that can be used by citizen scientists for generating water quality data with relatively little training.

Case study | Wensum Citizen Science platform
https://castco.org/case-study/wensum-catchment
Volunteers seen here (right) water sampling in the upper River Wensum catchment to identify the source of phosphorus pollution.

Photo credit: Wensum DTC

Catchment Systems Thinking Cooperative (CaSTCo)

A full list of citizen science based monitoring approaches, including a demonstration project in the Wensum catchment can be found here:

castco.org

Designing a monitoring platform | Tiered monitoring framework

Basic monitoring regime

Attributes: low cost, minimal resources, community-led, monthly – yearly data resolution.

Purpose: Provides essential insights into NbS performance with limited equipment and expertise. Ideal for small-scale or community-driven projects involving citizen science groups.

Key components

- **Meteorology:** use existing Environment Agency or Met Office data.
- **Hydrology:** simple water level logger; extrapolation from Environment Agency datasets.
- **Water quality:** occasional manual grab sampling and analysis using handheld probes for basic parameters such as pH, dissolved oxygen, and some nutrients.
- **Biodiversity:** simple species presence/absence surveys for major taxonomic groups (e.g., birds, plants).
- **Geomorphology:** fixed point photography; qualitative sediment deposition observations.
- **Soils:** annual assessment of nutrients and carbon.

Estimated annual cost per site: < £10,000

Standard monitoring regime

Attributes: medium cost, moderate scientific rigor, mixed methods, weekly – monthly data resolution.

Purpose: Provides robust data for evaluation, suitable for research collaborations, local government projects, and NGOs.

Key components

- **Meteorology:** tipping bucket rain gauge.
- **Hydrology:** automated water level loggers in stilling wells/shallow piezometers.
- **Water quality:** regular manual grab sampling and laboratory analysis for a wider suite of priority pollutants (e.g., nitrate, phosphate, ammonia) and water quality parameters.
- **Biodiversity:** habitat mapping and seasonal surveys of key indicator species (e.g., fish, macrophytes, diatoms, benthic invertebrates).
- **Geomorphology:** topographic surveys; erosion pins; river habitat survey.
- **Soils:** seasonal assessment of physical, chemical and biological properties.

Estimated annual cost per site: £10,000 – £100,000

Gold Standard monitoring regime

Attributes: high cost, comprehensive, scientifically rigorous data collection, minute – daily data resolution.

Purpose: Provides long-term, high-resolution data suitable for policy impact, large-scale research, and government-funded projects.

Key components

- **Meteorology:** telemetered weather stations.
- **Hydrology:** telemetered water level sensors and flow meters; groundwater borehole observations.
- **Water quality:** real-time, telemetered, in-situ monitoring stations; pollutant tracing.
- **Biodiversity:** DNA metabarcoding for species identification; automated acoustic monitoring; camera traps.
- **Geomorphology:** drone surveys; LiDAR floodplain mapping.
- **Soils:** comprehensive monthly assessment of full suite of physical, chemical and biological properties.

Estimated annual cost per year: >£100,000

Options for Nature-based Solutions

This section outlines '**basic**', '**standard**' and '**gold standard**' monitoring regimes for the following NbS, with relevant example case studies.

Edge-of-field measures to attenuate and store runoff under high-flow events. These may include scrapes, sediment traps and ditch blocking. Features attenuate runoff, encourage infiltration, settle out sediment and absorb nutrients.

Conversion of intensively managed agricultural land to more natural landscapes. This could include arable or pasture conversion to native, species-rich grassland or woodland. Priority species and grassland type depend on the location of implementation.

In-field measures to decrease runoff and encourage infiltration. Measures could include minimum tillage, tramline disruption, or the introduction of winter cover crops.

Re-planting and restoration of habitats along riparian areas to intercept runoff before it enters river channels and/or to prevent pollutants moving further downstream. May include grassland or woodland dependent on location.

Restoration of over-straightened and over-deepened river channels into a more sinuous natural form connected with the floodplain. This may be done through diverting a river into newly created meanders and scrapes, or a 'Stage Zero' approach where the straightened, deepened channel is filled in and the river allowed to find its own course.

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

Retention pond | Salle Park Estate, Norfolk
Photo credit: Wensum DTC

Ecosystem Services provided

Approximate monitoring costs

Basic
Capital £250 **I** Annual £700 - £1500

Standard
Capital £20,000- £70,000 **I** Annual £1000 - £5000

Gold Standard
Capital £45,000 - £120,000 **I** Annual £20,000 - £80,000

Case study

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

Overview

Runoff Attenuation Features (RAFs) are natural or soft-engineered landscape interventions designed to intercept, slow, and temporarily store surface water runoff with the aim of reducing downstream flood risk, increasing infiltration and improving water quality.

Primary goals

Reduce downstream flood risk

Reduce particulate pollution

Example approaches

- **Leaky dams** | small barriers constructed in streams and ditches that slow water flow during storm events. Often constructed of woody debris.
- **Retention ponds** | engineered or natural depressions that collect and store surface runoff resulting in the creation of a permanent standing body of water.
- **Swales** | shallow, broad, vegetated channels designed to store and convey surface runoff. Commonly used alongside roads.
- **Wetlands** | densely vegetated permanent standing body of water into which surface runoff can be directed.

Objectives

- **Reduce flood risk** | RAFs capture and temporarily store excess rainwater, gradually releasing it to reduce peak downstream flow.
- **Enhance water quality** | by slowing water movement, sediment and particulate-bound pollutants settle out of suspension, improving water quality before reaching surface watercourses. Biological activity within the RAF can also act to reduce water pollutants (e.g., plant nutrient uptake).
- **Promote groundwater recharge** | RAFs can increase infiltration of surface runoff, enhancing recharge of groundwater.
- **Support biodiversity** | creation of permanent wetland and pond habitats can improve local biodiversity.

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

Retention pond in field corner | Salle Park Estate, Norfolk.
Photo credit: Wensum DTC

Leaky dam in ditch | Upper River Nar, Norfolk.
©Norfolk Rivers Trust

Wetland | River Mun, Norfolk. ©Norfolk Rivers Trust

Roadside swale | Broadland Northway, Norwich, Norfolk.

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

Conceptual monitoring design

Monitoring goals

The primary focus for monitoring runoff attenuation features should be to assess the impacts upon downstream flood risk, erosive surface runoff and groundwater recharge.

A **basic monitoring regime** should therefore aim to assess:

1. Water storage volume within the RAF
2. Nutrient and sediment concentrations within the RAF and surface water

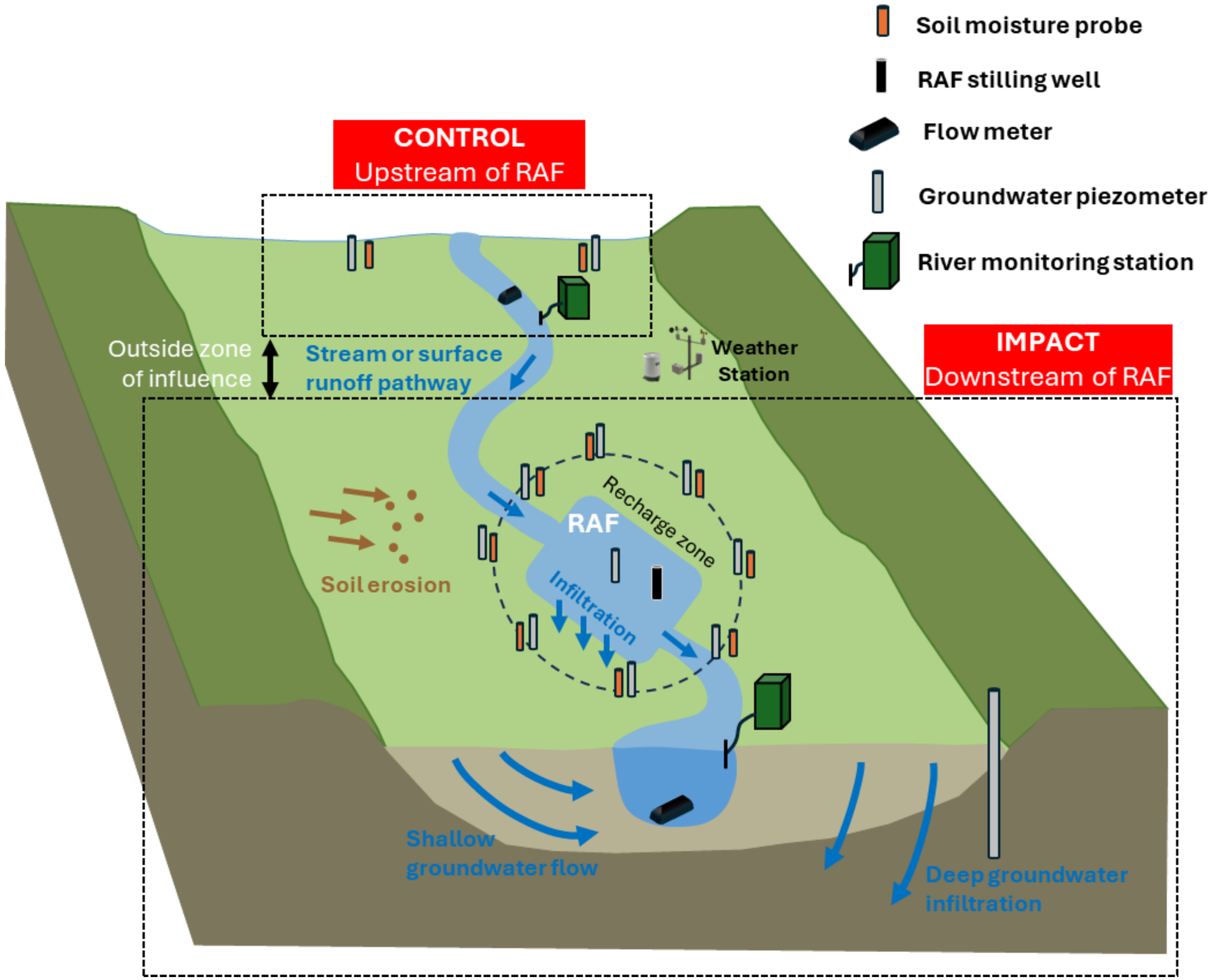
In addition to the basic regime, a **standard monitoring regime** should aim to assess:

1. Shallow groundwater recharge rates
2. Storm event hydrological responses

In addition to the standard regime, a **gold standard monitoring regime** should aim to assess:

1. Deep groundwater recharge rates
2. Soil moisture content
3. Complete water balance

Outline monitoring requirements for these basic, standard, and gold standard regimes are presented on the following pages.



Example gold standard control-impact monitoring design for an 'online' RAF constructed along an existing watercourse. This design would principally enable assessment of RAF impacts upon surface water storage, stream discharge, and groundwater recharge. Control site could be either upstream of the restored section or on a separate neighbouring tributary with similar catchment characteristics.

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

Basic monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	Obtain from EA Hydrology Data Explorer	Daily	1 = local	-	Free
Surface water	Hydrological	Water level	In-situ telemetered stilling well pressure transducer	Near-continuous	1 = within RAF	Essential for Replenish	£250 - £1000 per unit
	Chemical	Nitrate, orthophosphate	Citizen scientist sampling + basic colorimetric test strips or handheld nutrient checkers	Monthly	3 = upstream + downstream + RAF	-	<£2 per test (test strips); £50-£100 per unit + <£2 per test (Hanna Checker)
Geomorphology	Physical	RAF evolution over time	Fixed point photography	Monthly-biannual	1 = RAF	Essential for NN and Replenish	<£100 per visit
				Estimated capital cost (one off)			**£250 - £1000**
				Estimated annual running cost			**£700 - £1500**

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	In-situ telemetered rain gauge	Near-continuous	1 = near RAF	-	£500 - £1500 per unit
Surface water	Hydrological	Water level within RAF; river stage with manual stage-discharge calibration	In-situ telemetered stilling well pressure transducer	Near-continuous	3 = upstream+ downstream + RAF	Essential for NN and Replenish	£250 - £1000 per unit
	Chemical	Nitrate, orthophosphate, total nitrogen, total phosphorus, total suspended solids, accumulated sediment, biological oxygen demand	Manual sampling + laboratory analysis	Monthly	3 = upstream+ downstream + RAF	Essential for NN and Replenish	£25 - £75 per sample
Groundwater	Hydrological	Shallow groundwater levels (up to 10 m depth)	In-situ telemetered pressure transducers in piezometers	Near-continuous	10 = 8 impact + 2 control	-	£1500 - £5000 per hole £250 - £1000 per transducer
Soils	Physical	Infiltration capacity	Infiltrometer test	Annual	1 = within RAF	Essential for Replenish	£300 – £500 per day for field technician
Geomorphology	Physical	RAF dimensions (3D)	Topographic survey (total station)	Annual	1 = RAF	Essential for Replenish	£500 - £1500 per site
				Estimated capital cost (one off)			**£20,000 – £70,000**
				Estimated annual running cost			**£1000 - £5000**

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation, air temperature, humidity, wind speed	In-situ telemetered weather station	Near-continuous	1 = near RAF	-	£1000 – £2500 per unit
Surface water	Hydrological	Water level within RAF; river discharge	In-situ telemetered pressure transducer in stilling well; in-situ telemetered flow meter	Near-continuous	3 = upstream + downstream + RAF	Optional for NN and Replenish	£250 - £1000 per unit; £2500 - £7500 per flow meter
	Chemical	Nitrate, orthophosphate, turbidity, dissolved oxygen, temperature, pH, conductivity	In-situ telemetered sensors	Near-continuous	2 = upstream + downstream	Optional for NN and Replenish	£1000 - £10,000 per sensor
		Nitrate, orthophosphate, total nitrogen, total phosphorus, total suspended solids, dissolved organic carbon, accumulated sediment, biological oxygen demand	Manual sampling + laboratory analysis	Weekly	3 = upstream + downstream + RAF	Optional for NN and Replenish	£25 - £75 per sample
Soil water (up to 100 cm depth)	Hydrological	Soil moisture content	In-situ telemetered soil moisture probes (100 cm)	Near-continuous	10 = 8 impact + 2 control	-	£500 - £1000 per probe
Groundwater	Hydrological	Shallow groundwater levels (up to 10 m depth)	In-situ telemetered pressure transducers in piezometers/boreholes	Near-continuous	10 = 8 impact + 2 control	-	£1500 - £5000 per hole £250 - £1000 per transducer
		Deeper groundwater levels (10 - 50 m depth, if required)	In-situ telemetered pressure transducers in piezometers/boreholes	Near-continuous	10 = 8 impact + 2 control	-	£10,000 - £50,000 per hole £250 - £1000 per transducer

Continued on next page …

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Continued…							
Soils	Physical	Infiltration capacity	Infiltrometer test	Seasonal	1 = within RAF	Essential for Replenish	£300 – £500 per day for field technician
Geomorphology	Physical	RAF dimensions (3D)	Topographic survey (LiDAR)	Annual	1 = RAF	Optional for Replenish	£1000 – £2000 per site
Telemetry	Data	Real-time data visualisation/ management	Cloud-based platform	Near-continuous	All	Optional for NN	£500 - £1500 per year
Equipment maintenance	Data	-	Instrument cleaning	Weekly	All	Optional for NN	£300 - £500 per day for field technician
			Water quality instrument servicing	3-6 months	2 = control + impact	Optional for NN	£1000 - £10,000 per visit
				Estimated capital cost (one off)			**£45,000 - £ 120,000**
				Estimated annual running cost			**£20,000 - £80,000**

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

Pickering Beck, North Yorkshire I Monitoring the effectiveness of RAFs for natural flood management

Case study

©Forest Research

Source: www.forestresearch.gov.uk/research/slowing-the-flow-at-pickering/

Initiated in 2009, the Pickering Beck '**slowing the flow**' project aimed to reduce downstream flood risk in the historically flood-impacted town of Pickering by slowing and storing surface runoff in RAFs before it reached the main river channel. This multi-stakeholder project led by Forest Research saw the installation of a large number of RAFs and other catchment inventions across the Pickering Beck catchment. These included:

- 167 semi-permeable, leaky, **woody debris dams** constructed from felled trees to slow the flow in headwater stream channels and extend catchment lag times.
- 187 **heather bale check dams** constructed in moorland drains and gullies to slow upland runoff.
- A large bunded **flood storage basin** (120,000 m^3) excavated in a flood-prone area to temporarily store surface runoff and prevent it entering the main river channel.
- Planting of 44 ha of **riparian and farm woodland** to increase catchment tree cover.
- Creation of 5.9 ha of **riparian buffer strips** along field margins to intercept surface runoff from agricultural land, thereby reducing nutrient and sediment ingress into waterbodies.

Options for Nature-based Solutions | Runoff Attenuation Features (RAFs)

(continued)

Pickering Beck, North Yorkshire I Monitoring the effectiveness of RAFs for natural flood management

Case study

Monitoring design

A basic monitoring programme was delivered consisting of:

- 10 x water level loggers installed upstream and downstream of RAFs along four stream reaches
- Discharge data from 4 x pre-existing Environment Agency gauging stations.
- Fixed point time-lapse photography of RAFs.
- Two tipping bucket rain gauges.

The monitoring data were subsequently used to support rainfall-runoff modelling on the impact of all catchment interventions.

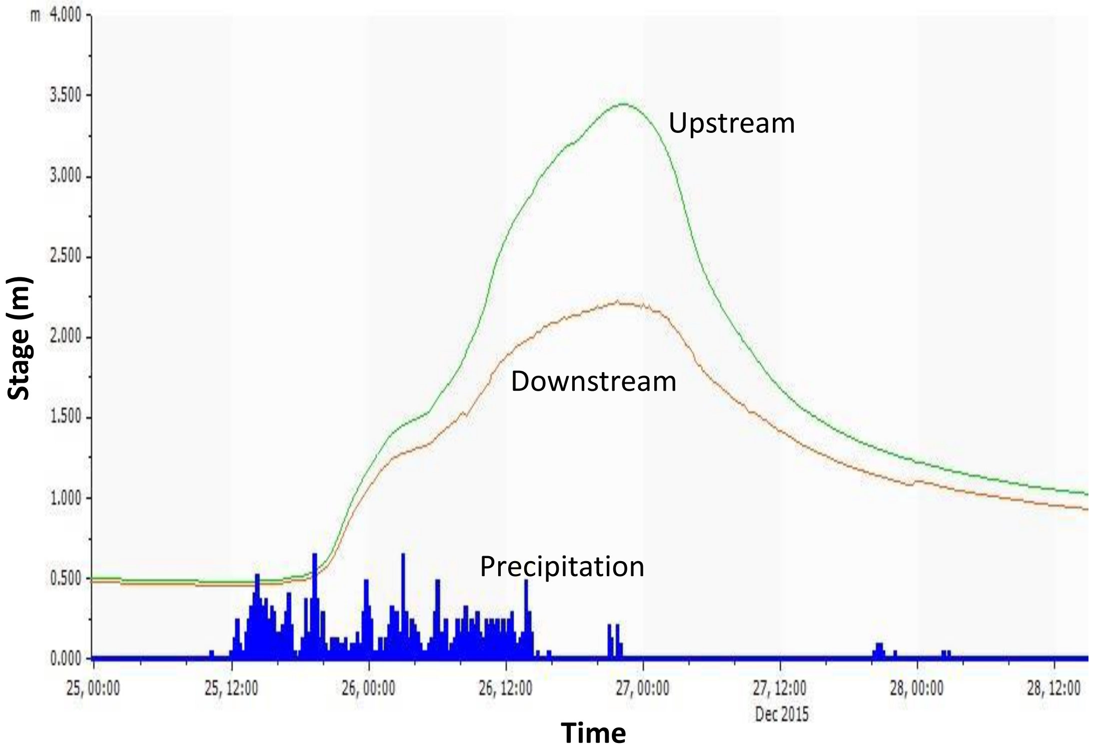
Results

Modelling predicted these RAF measures would:

- Protect Pickering from a 1 in 25-year flood.
- Reduce downstream flood risk from 25% to 4%.
- Reduced downstream peak flows by 15-20%.
- Create ~20,000 m^3 of additional flood water storage from woodland and farm measures.

Key monitoring finding

A lack of pre-intervention baseline data, coupled with a lack of monitoring of overbank flows, made accurate impact assessment difficult.



Water level recorded upstream (green) and downstream (brown) of the Pickering flood storage basin in December 2015 (Slowing the Flow Partnership, 2016).

Options for Nature-based Solutions | Land use change

Native species-rich grassland | Wendling Beck, Norfolk. ©WRE

Ecosystem Services provided

Approximate monitoring costs

Basic
Capital £0 I Annual £4000 - £8000

Standard
Capital £1500 - £5000 I Annual £18,000 - £38,000

Gold Standard
Capital £50,000 - £130,000 I Annual £75,000 - £200,000

Case study

Options for Nature-based Solutions | Land use change

Overview

NbS approaches to land use change are most commonly associated with the conversion of human-dominated landscapes with limited ecosystem service potential, to more naturalised landscapes with lower human disturbance that provide a broader suite of ecosystem services.

Primary goals
Reduce water pollution
Increase biodiversity

Example approaches

- **Arable or pasture conversion to species-rich grassland** | intensively cultivated arable crop monocultures or improved livestock pastures are converted to native species-rich wildflower meadows.
- **Arable or pasture conversion to native woodland** | intensively cultivated arable crop monocultures or improved livestock pastures are converted to permanent native deciduous or mixed-species woodland.
- **Arable or pasture conversion to peatland** | conversion of drained, carbon-depleted, agricultural land to permanently wet, carbon-rich, lowland or upland peatland.

Objectives

- **Improve water quality** | conversion away from agriculture reduces agrochemical input (fertilisers, pesticides) into surface water and groundwater resources.
- **Reduce soil erosion** | replacement of seasonally cultivated crops with permanent native vegetation minimises soils disturbance, improves soil structure and reduces soil erosion risk.
- **Increase biodiversity** | replacement of single species monocultures with multi-species native vegetation mixes, increases floral and associated faunal diversity.

Options for Nature-based Solutions | Land use change

Species-rich grassland | Bintree, Norfolk. ©WRE

Wet floodplain meadow | Dillington, Norfolk. ©WRE

Woodland creation | ©Forestry Commission

Peatland restoration | Buttle Marsh, Norfolk. ©Broads Authority

Land use change: Conceptual monitoring design

Monitoring goals

The primary focus for monitoring land use change should be to assess the impacts upon soil health, water quality, water balance and biodiversity.

A **basic monitoring regime** should therefore aim to assess:

1. Soil nutrient leaching into field drainage
2. Soil nutrient and carbon concentrations
3. Pollinator presence/absence
4. Surface water nutrient and sediment concentrations

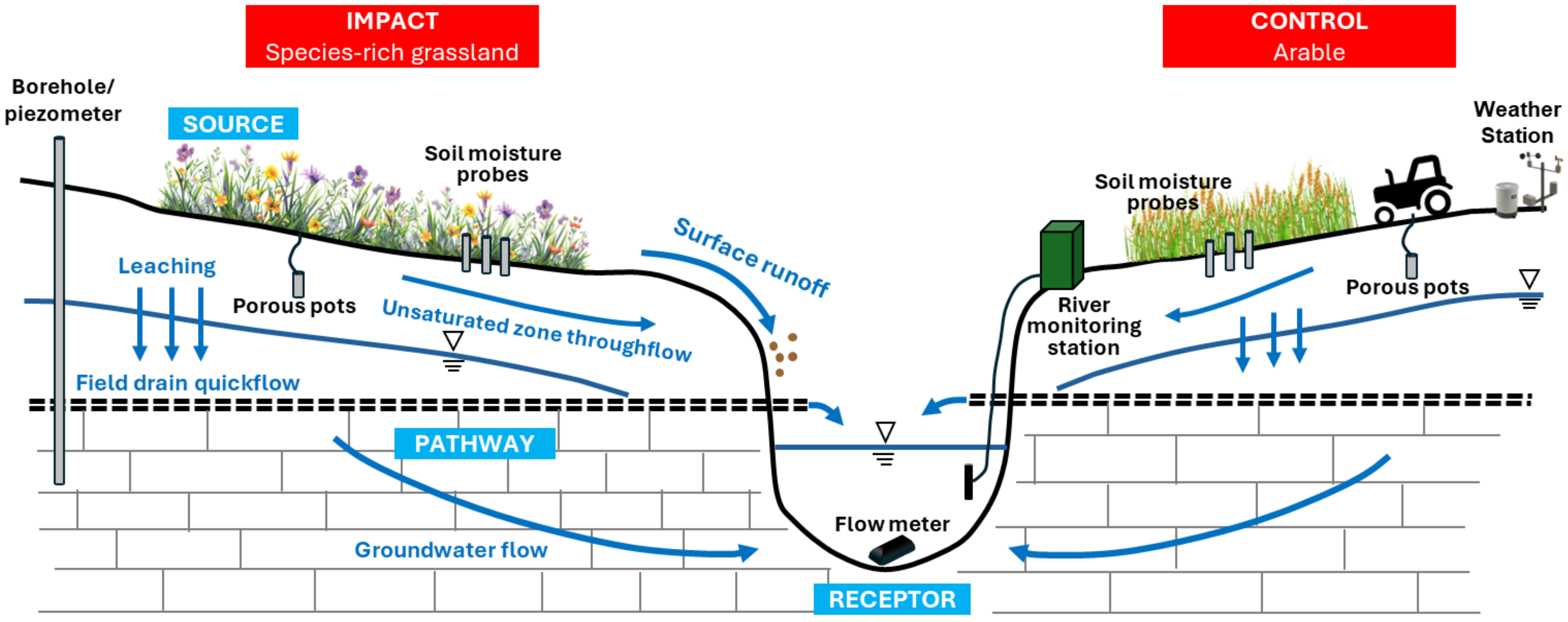
In addition to the basic regime, a **standard monitoring regime** should aim to assess:

1. Nutrient leaching into deeper soil water
2. Soil physical, chemical and biological status
3. Terrestrial species abundance

In addition to the standard regime, a **gold standard monitoring regime** should aim to assess:

1. Soil moisture content
2. Groundwater recharge rates
3. Comprehensive species assessment

Outline monitoring requirements for these basic, standard, and gold standard regimes are presented on the following pages.



Example gold standard monitoring train design for assessing conversion of arable land to species-rich grassland. This design would principally focus on the soil zone and enable assessment of water quality along the source-pathway-receptor continuum (blue).

Options for Nature-based Solutions | Land use change

Basic monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	Obtain from EA Hydrology Data Explorer	Daily	1 = local	-	Free
Surface water	Hydrological	River discharge spatially extrapolated from closest gauging station	Obtain from EA Hydrology Data Explorer	Daily	1 = local	-	Free
	Chemical	Nitrate, orthophosphate	Citizen scientist sampling + basic colorimetric test strips or handheld nutrient checkers	Monthly	2 = control + impact	-	<£2 per test (test strips); £50-£100 per unit + <£2 per test (Hanna Checker)
Soils (top 30 cm)	Chemical	N, P, organic carbon	Manual sampling + laboratory analysis	Annual	10 = 5 control + 5 impact	Essential for carbon credits	£30 - £50 per sample
Field drainage (commonly 100-150 cm depth)	Chemical	Nitrate, orthophosphate	Citizen scientist sampling + basic colorimetric test strips or handheld nutrient checkers	Monthly	10 = 5 control + 5 impact	-	<£2 per test (test strips); £50-£100 per unit + <£2 per test (Hanna Checker)
	Hydrological	Drain flow	Manual measurement with graduated bucket	Monthly	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
Biodiversity	Terrestrial	Birds	Manual species survey (visual point counts)	Annual	2 = control + impact	Optional for BNG	<£200 per day to support citizen scientists
Geomorphology	Physical	Landscape evolution over time	Fixed point photography	Monthly-biannual	2 = control + impact	Essential for Replenish	<£100 per visit
				Estimated capital cost (one off)			**£0**
				Estimated annual running cost			**£4000 - £8000**

Options for Nature-based Solutions | Land use change

Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	In-situ telemetered rain gauge	Near-continuous	1 = study site	-	£500 - £1500 per unit
Surface water	Hydrological	River stage with manual stage-discharge calibration	In-situ telemetered stilling well pressure transducer	Near-continuous	2 = control + impact	Essential for NN and Replenish	£250 - £1000 per unit
	Chemical	Nitrate, total nitrogen, orthophosphate, total phosphorus, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Monthly	2 = control + impact	Essential for NN	£25 - £75 per sample
Soil water (up to 100 cm depth)	Chemical	Total nitrogen, nitrate, total phosphorus, orthophosphate, dissolved organic carbon	In-situ porous pot sampling + laboratory analysis	Seasonal	10 = 5 control + 5 impact	-	£25 - £75 per sample; £50 - £100 per porous pot
Soils (top 30 cm)	Chemical	N, P, organic carbon	Manual sampling + laboratory analysis	Seasonal	10 = 5 control + 5 impact	Optional for carbon credits	£30 - £50 per sample
	Physical	Bulk density; infiltration capacity	Manual sampling + laboratory analysis; infiltrometer test	Seasonal	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
	Biological	Earthworms	Manual sampling	Seasonal	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician

Continued on next page …

Options for Nature-based Solutions | Land use change

Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Continued…							
Field drainage (commonly 100-150 cm depth)	Chemical	Total nitrogen, nitrate, total phosphorus, orthophosphate, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Monthly	10 = 5 control + 5 impact	-	£25 - £75 per sample
	Hydrological	Drain flow	Manual measurement with graduated bucket	Monthly	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
Biodiversity	Terrestrial	Pollinators, birds, plants	Manual species survey (e.g., sweep netting, point counts)	Seasonal	2 = control + impact	Plants essential for BNG, others optional	£500 – £1000 per day per ecological type for field ecologist
Geomorphology	Physical	Landscape evolution over time	Fixed point photography	Monthly-biannual	2 = control + impact	Essential for Replenish	<£100 per visit
				Estimated capital cost (one off)			**£1500 - £5000**
				Estimated annual running cost			**£18,000 - £38,000**

Options for Nature-based Solutions | Land use change

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation, air temperature, humidity, wind speed	In-situ telemetered weather station	Near-continuous	1 = study site	-	£1000 – £2500 per unit
Surface water	Hydrological	River discharge	In-situ telemetered flow meter	Near-continuous	2 = control + impact	Optional for NN and Replenish	£2500 - £7500 per unit
	Chemical	Nitrate, orthophosphate, turbidity, dissolved oxygen, temperature, pH, conductivity	In-situ telemetered sensors	Near-continuous	2 = control + impact	Optional for NN	£1000 - £10,000 per sensor
		Nitrate, total nitrogen, orthophosphate, total phosphorus, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Weekly	2 = control + impact	Optional for NN	£25 - £75 per sample
Soil water (up to 100 cm depth)	Chemical	Total nitrogen, nitrate, total phosphorus, orthophosphate, dissolved organic carbon	In-situ porous pot sampling + laboratory analysis	Monthly	10 = 5 control + 5 impact	-	£25 - £75 per sample; £50 - £100 per porous pot
	Hydrological	Soil moisture content	In-situ telemetered soil moisture probes (100 cm)	Near-continuous	10 = 5 control + 5 impact	-	£500 - £1000 per probe
Soils (top 30 cm)	Chemical	N, P, K, S, Mg, organic carbon	Manual sampling + laboratory analysis	Monthly - seasonal	10 = 5 control + 5 impact	Optional for carbon credits	£50 - £80 per sample
	Physical	Bulk density; infiltration capacity	Manual sampling + laboratory analysis; infiltrometer test	Monthly - seasonal	10 = 5 control + 5 impact		£300 – £500 per day for field technician
	Biological	Earthworms; respiration	Manual sampling; laboratory analysis	Monthly - seasonal	10 = 5 control + 5 impact		£300 – £500 per day for field technician; £25 - £75 per sample

Continued on next page …

Options for Nature-based Solutions | Land use change

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Continued…							
Field drainage (commonly 100-150 cm depth)	Chemical	Total nitrogen, nitrate, total phosphorus, orthophosphate, total suspended solids, dissolved organic carbon	Manual sampling, laboratory analysis	Weekly	10 = 5 control + 5 impact	-	£25 - £75 per sample
	Hydrological	Drain flow	Manual measurement with graduated bucket	Weekly	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
Groundwater	Hydrological	Shallow groundwater levels (up to 10 m)	In-situ telemetered pressure transducers in piezometers	Near-continuous	10 = 5 control + 5 impact	-	£1500 - £5000 per hole £250 - £1000 per transducer
Biodiversity	Terrestrial	Birds, insects, mammals, plants	Manual species survey; Longworth traps; camera traps; acoustic recorders	Seasonal	2 = control + impact	Plants essential for BNG, others optional	£500 – £1000 per day per ecological type for field ecologist; £50 - £100 per camera trap; £250 - £750 per acoustic recorder
Geomorphology	Physical	Landscape evolution over time	Fixed point photography	Monthly-biannual	2 = control + impact	Essential for Replenish	<£100 per visit
Telemetry	Data	Real-time data visualisation/management	Cloud-based platform	Near-continuous	All	Optional for NN	£500 - £1500 per year
Equipment maintenance	Data	-	Instrument cleaning	Weekly	All	Optional for NN	£300 - £500 per day for field technician
			Water quality instrument servicing	3-6 months	2 = control + impact	Optional for NN	£1000 - £10,000 per visit
				Estimated capital cost (one off)			**£50,000 - £130,000**
				Estimated annual running cost			**£75,000 - £200,000**

Options for Nature-based Solutions | Land use change

Haweswater, Cumbria I Hydrological impacts of broadleaved woodland vs pasture

Case study

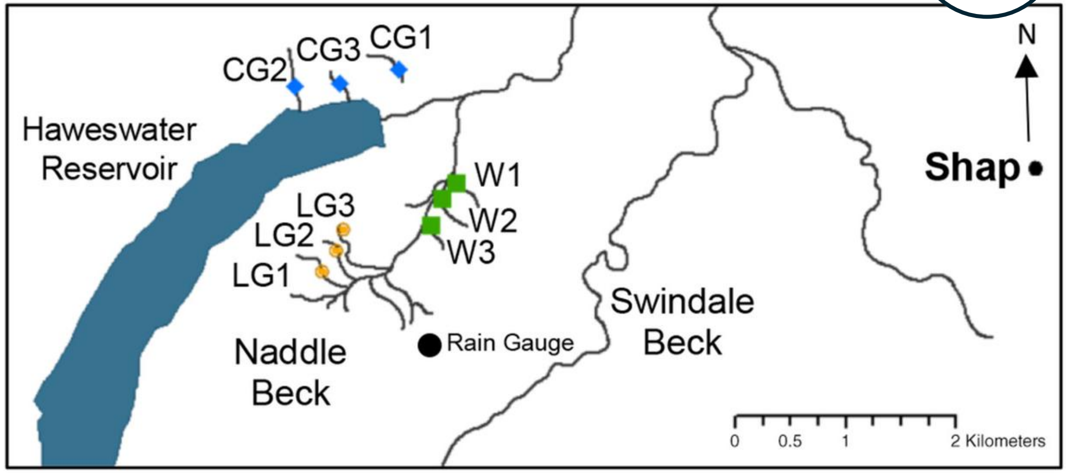
Source: https://onlinelibrary.wiley.com/doi/full/10.1002/hyp.14453

This study conducted during 2018 - 2020 around Haweswater reservoir in the Lake District, aimed to compare the hydrological impacts of semi-native broadleaved woodland versus two types of grazing pasture: year-round 'commons grazing' and seasonal 'low-density grazing'.

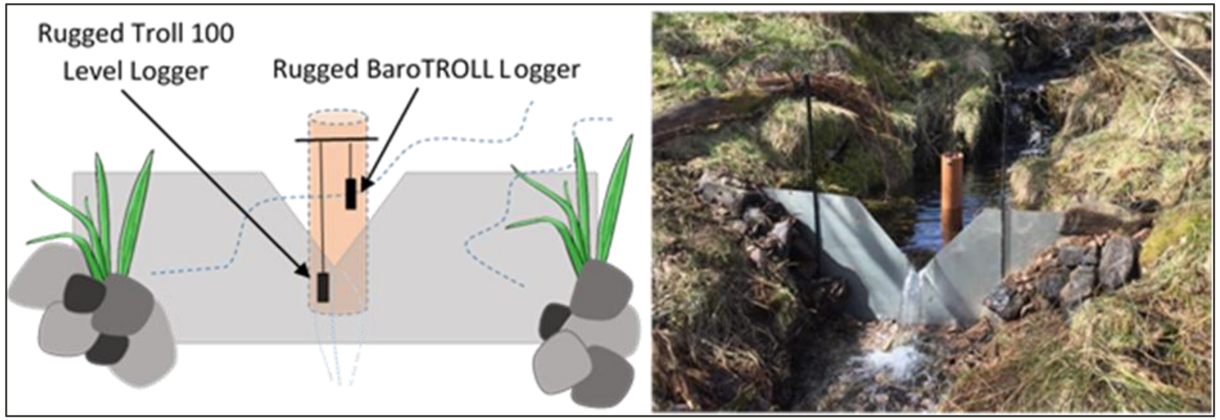
Monitoring design

The study area was divided into 9 x small sub-catchments (<20 ha), with 3 x sub-catchments representing each land use type. The in-field monitoring programme consistent of:

- Manual monthly soil assessment (0-5 cm depth) of bulk density, permeability and soil moisture content.
- Stream stage (5-minute resolution) recorded via stilling well pressure transducers installed at sub-catchment outlets. This was converted to discharging using a stage-discharge equation for V-notch weirs.
- Precipitation data (5-minute resolution) recorded via a tipping bucket rain gauge.



Map of field sites around Haweswater reservoir, divided into sub-catchments dominated by woodland (W), commons grazing (CG) and low-density grazing (LG) pasture.



V-notch weir constructed in a stream channel with a stilling well pressure transducer upstream recording stream stage at 5-minute resolution.

Options for Nature-based Solutions | Land use change

(continued)

Haweswater, Cumbria I Hydrological impacts of broadleaved woodland vs pasture

Case study

Results

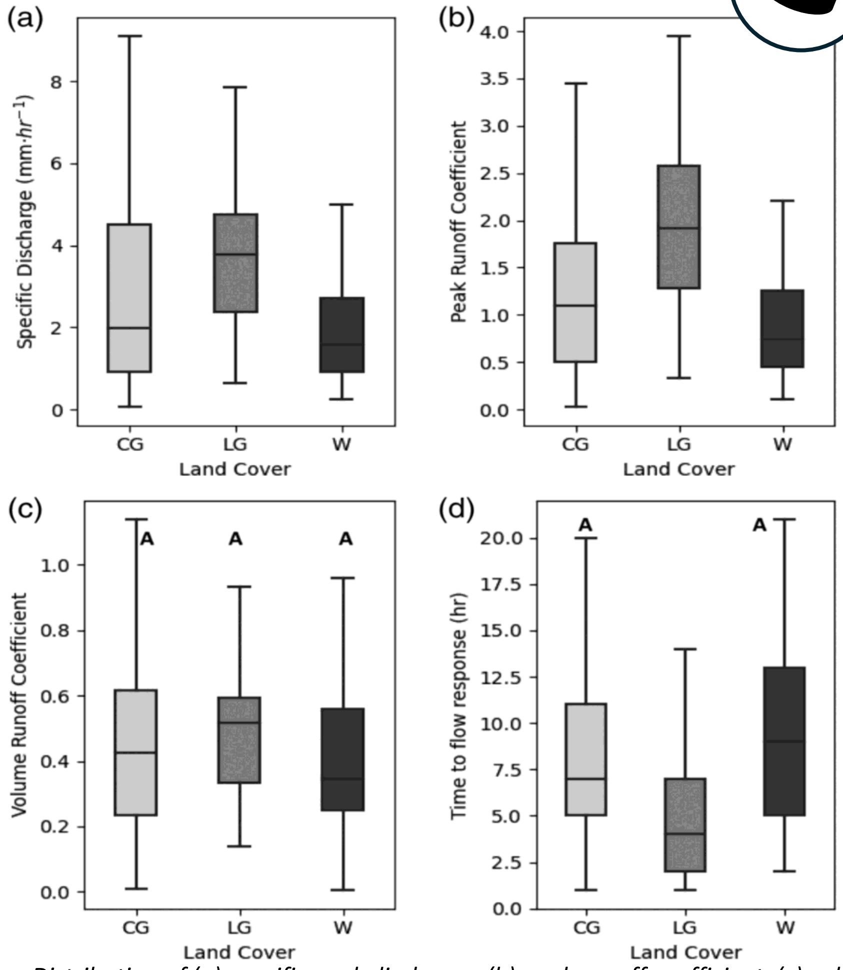
The results of the study revealed that compared to pasture, semi-natural broadleaf woodlands:

- Reduced downstream specific peak discharge by 23-60%
  [discharge (m^3 s^{-1}) / catchment area (m^2)]
- Reduced peak runoff coefficients by 30-60%
  *[peak discharge (m^3 s^{-1}) / maximum rainfall intensity (m s^{-1}) * catchment area (m^2)]*
- Reduced volume runoff coefficients by 21-35%
  [total surface runoff (m^3) / total rainfall (m^3)]
- Increased stream rainfall response time by 14-50%

These changes were found to primarily be driven by woodland soil having a permeability 11-20 times greater than pasture soil, thereby increasing infiltration and decreasing surface runoff. The conversion of pasture to broadleaved woodland can therefore significantly reduce downstream flood risk.

Key monitoring finding

Data was based on small catchments (<20 ha) and storm events with short return periods (<10 years). Hydrological modelling would be required to extrapolate results to larger catchments and bigger storm events.



Distribution of (a) specific peak discharge, (b) peak runoff coefficient, (c) volume runoff coefficient, (d) time to flow response for woodland (W), commons grazing (CG) and low-density grazing (LG) pasture. Median (line), 25% to 75% of data (box), 5% to 95% of data (whiskers). Sites which were not statistically different share a letter.

Options for Nature-based Solutions | Soil management practices

Reduced tillage | Salle Park Estate, Norfolk.
Photo credit: Wensum DTC

Ecosystem Services provided

Approximate monitoring costs

Basic
Capital £0 I Annual £4000 - £8000

Standard
Capital £2000- £8000 I Annual £12,000 - £27,000

Gold Standard
Capital £50,000 - £130,000 I Annual £70,000 - £190,000

Case study

Options for Nature-based Solutions | Soil management practices

Overview

NbS approaches to soil management are most commonly associated with conservation agriculture - a farming system that encompasses a range of sustainable, in-field, soil husbandry techniques that aim to reduce soil erosion, minimise nutrient losses, and improve infiltration across arable farmland.

Primary goals

Reduce agrochemical pollution

Reduce soil erosion

Example approaches

- **Cover cropping** | planting of a non-cash crop over winter to protect the soil from erosive surface flows and to capture residual soil nutrients.
- **Reduced tillage** | reducing the intensity of ploughing, or stopping completely (no-till), to minimise soil disturbance and preserve soil structure.
- **Riparian buffer strips** | strips of permanent natural vegetation (typically grass) planted alongside a watercourse to restrict surface runoff ingress.
- **Contour cultivation** | sowing crops and tilling the soil parallel to the natural contours of the land to slow surface runoff.
- **Tramline disruption** | decompacting in-field tramlines left by heavy farm machinery to prevent the creation of preferential pathways for surface runoff.

Objectives

- **Reduce agrochemical pollution** | winter cover crops reduce soil nitrate leaching into groundwater, whilst riparian buffer strips limit particulate bound pollutants in surface runoff.
- **Reduce soil erosion** | maintaining permanent soil vegetation cover and reducing soil disturbance improves soil structural stability and reduces soil losses.
- **Increase infiltration** | improved soil husbandry reduces soil compaction and increases infiltration rates.
- **Improve fertility** | improved nutrient and organic matter management benefits soil biology and boosts fertility.

Options for Nature-based Solutions | Soil management practices

Winter cover crop | Salle Park Estate, Norfolk.
Photo credit: Wensum DTC

Riparian buffer strips | Salle Park Estate, Norfolk.
Photo credit: Wensum DTC

Tramline disruption | Norfolk.
©Norfolk Rivers Trust

Reduced tilled land | Salle Park Estate, Norfolk.
Photo credit: Wensum DTC

Conceptual monitoring design

Monitoring goals

The primary focus for monitoring soil management techniques should be to assess the impacts upon agrochemical pollutant mobilisation through soils and on soil health.

A basic monitoring regime should therefore aim to assess:

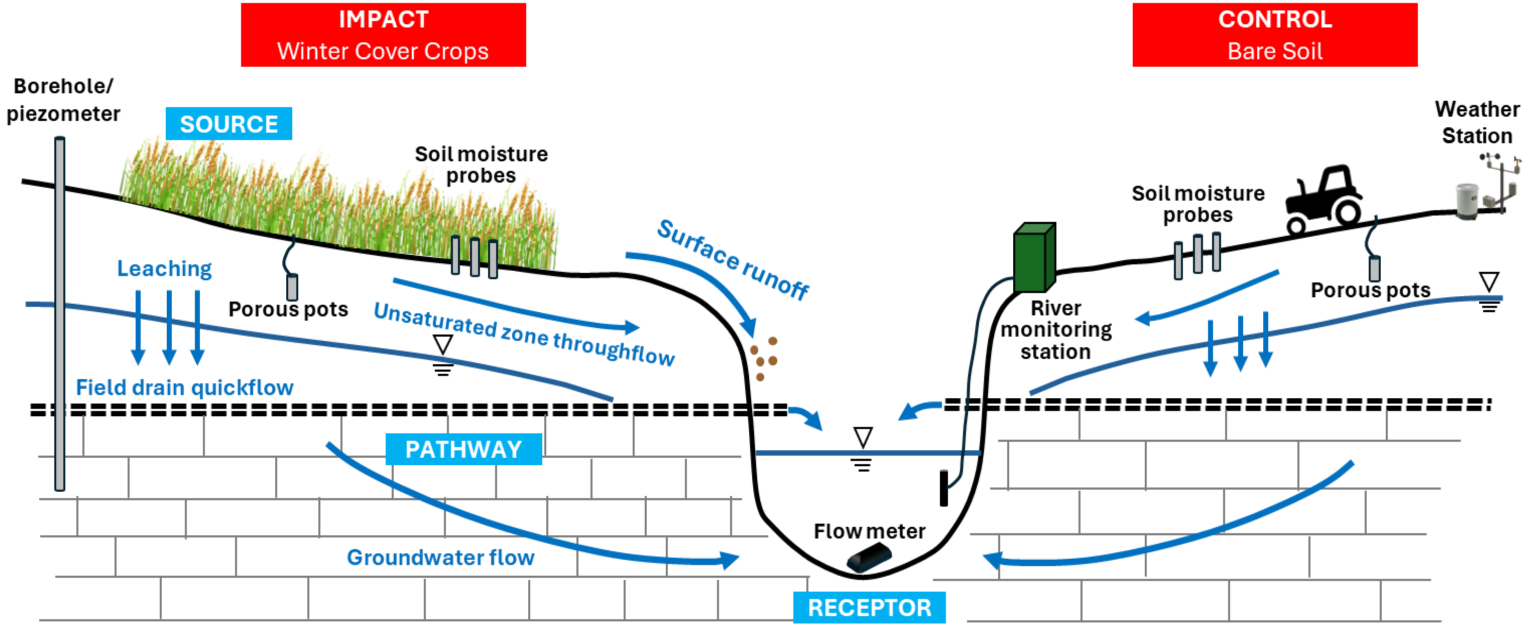
1. Soil nutrient leaching into field drainage
2. River nutrient and sediment concentrations
3. Soil carbon and nutrient concentrations

In addition to the basic regime, a standard monitoring regime should aim to assess:

1. Nutrient leaching to deeper soil water
2. Soil physical, chemical and biological status
3. Storm event pollution mobilisation

In addition to the standard regime, a gold standard monitoring regime should aim to assess:

1. Soil moisture content
2. Groundwater recharge rates
3. Monitor in-situ at high temporal resolution



Example gold standard monitoring train design for assessing winter cover cropping. This design would principally focus on the soil zone and enable assessment of water quality along the source-pathway-receptor continuum (blue).

Outline monitoring requirements for these basic, standard, and gold standard regimes are presented on the following pages.

Options for Nature-based Solutions | Soil management practices

Basic monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	Obtain from EA Hydrology Data Explorer	Daily	1 = local	-	Free
Surface water	Hydrological	River discharge spatially extrapolated from closest gauging station	Obtain from EA Hydrology Data Explorer	Daily	1 = local	-	Free
	Chemical	Nitrate, orthophosphate	Citizen scientist sampling + basic colorimetric test strips or handheld nutrient checkers	Monthly	2 = control + impact	-	<£2 per test (test strips); £50-£100 per unit + <£2 per test (Hanna Checker)
Soils (top 30 cm)	Chemical	N, P, organic carbon	Manual sampling + laboratory analysis	Annual	10 = 5 control + 5 impact	Essential for carbon credits	£30 - £50 per sample
Field drainage (commonly 100-150 cm depth)	Chemical	Nitrate, orthophosphate	Citizen scientist sampling + basic colorimetric test strips or handheld nutrient checkers	Monthly	10 = 5 control + 5 impact	-	<£2 per test (test strips); £50-£100 per unit + <£2 per test (Hanna Checker)
	Hydrological	Drain flow	Manual measurement with graduated bucket	Monthly	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
Farm Business	Socioeconomic	Practicality of management	Anecdotal evidence from farmer	Annual	1 = study site	-	Free
				Estimated capital cost (one off)			**£0**
				Estimated annual running cost			**£4000 - £8000**

Options for Nature-based Solutions | Soil management practices

Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	In-situ telemetered rain gauge	Near-continuous	1 = study site	-	£500 - £1500 per unit
Surface water	Hydrological	River stage with manual stage-discharge calibration	In-situ telemetered stilling well pressure transducer	Near-continuous	2 = control + impact	Essential for NN and Replenish	£250 - £1000 per unit
	Chemical	Nitrate, total nitrogen, orthophosphate, total phosphorus, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Monthly	2 = control + impact	Essential for NN	£25 - £75 per sample
Soil water (up to 100 cm depth)	Chemical	Total nitrogen, nitrate, total phosphorus, orthophosphate, dissolved organic carbon	In-situ porous pot sampling + laboratory analysis	Seasonal	10 = 5 control + 5 impact	-	£25 - £75 per sample; £50 - £100 per porous pot
Soils (top 30 cm)	Chemical	N, P, organic carbon	Manual sampling + laboratory analysis	Seasonal	10 = 5 control + 5 impact	Optional for carbon credits	£30 - £50 per sample
	Physical	Bulk density, infiltration capacity	Manual sampling + laboratory analysis; infiltrometer test	Seasonal	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
	Biological	Earthworms	Manual sampling	Seasonal	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
Field drainage (commonly 100-150 cm depth)	Chemical	Total nitrogen, nitrate, total phosphorus, orthophosphate, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Monthly	10 = 5 control + 5 impact	-	£25 - £75 per sample
	Hydrological	Drain flow	Manual measurement with graduated bucket	Monthly	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
Farm Business	Socioeconomic	Fertiliser input, yields, costs, gross margins	Manual, desk-based	Annual	1 = study site	-	£500 – £1000 per day for data analyst
				Estimated capital cost (one off)			**£2000 - £8000**
				Estimated annual running cost			**£12,000 - £27,000**

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation, air temperature, humidity, wind speed	In-situ telemetered weather station	Near-continuous	1 = study site	-	£1000 – £2500 per unit
Surface water	Hydrological	River discharge	In-situ telemetered flow meter	Near-continuous	2 = control + impact	Optional for NN and Replenish	£2500 - £7500 per flow meter
	Chemical	Nitrate, orthophosphate, turbidity, dissolved oxygen, temperature, pH, conductivity	In-situ telemetered sensors	Near-continuous	2 = control + impact	Optional for NN	£1000 - £10,000 per sensor
		Nitrate, total nitrogen, orthophosphate, total phosphorus, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Weekly	2 = control + impact	Optional for NN	£25 - £75 per sample
Soil water (up to 100 cm depth)	Chemical	Total nitrogen, nitrate, total phosphorus, orthophosphate, dissolved organic carbon	In-situ porous pot sampling + laboratory analysis	Monthly	10 = 5 control + 5 impact	-	£25 - £75 per sample; £50 - £100 per porous pot
	Hydrological	Soil moisture content	In-situ telemetered soil moisture probes (100 cm)	Near-continuous	10 = 5 control + 5 impact	-	£500 - £1000 per probe
Soils (top 30 cm)	Chemical	N, P, K, S, Mg, organic carbon	Manual sampling + laboratory analysis	Monthly / seasonal	10 = 5 control + 5 impact	Optional for carbon credits	£50 - £80 per sample
	Physical	Bulk density; infiltration capacity	Manual sampling + laboratory analysis; infiltrometer test	Monthly / seasonal	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
	Biological	Earthworms; respiration	Manual sampling; laboratory analysis	Monthly / seasonal	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician; £25 - £75 per sample

Continued on next page …

Options for Nature-based Solutions | Soil management practices

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Continued…							
Field drainage (commonly 100-150 cm depth)	Chemical	Total nitrogen, nitrate, total phosphorus, orthophosphate, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Weekly	10 = 5 control + 5 impact	-	£25 - £75 per sample
	Hydrological	Drain flow	Manual measurement with graduated bucket	Weekly	10 = 5 control + 5 impact	-	£300 – £500 per day for field technician
Groundwater	Hydrological	Shallow groundwater levels (up to 10 m)	In-situ telemetered pressure transducers in piezometers	Near-continuous	10 = 5 control + 5 impact	-	£1500 - £5000 per hole £250 - £1000 per transducer
Farm Business	Socioeconomic	Fertiliser input, yields, costs, gross margins	Manual, desk-based	Annual	1 = study site	-	£500 – £1000 per day for data analyst
Telemetry	Data	Real-time data visualisation/management	Cloud-based platform	Near-continuous	All	Optional for NN	£500 - £1500 per year
Equipment maintenance	Data	-	Instrument cleaning	Weekly	All	Optional for NN	£300 - £500 per day for field technician
			Water quality instrument servicing	3-6 months	2 = control + impact	Optional for NN	£1000 - £10,000 per visit
				Estimated capital cost (one off)			**£50,000 - £130,000**
				Estimated annual running cost			**£70,000 - £190,000**

Options for Nature-based Solutions | Soil management practices

Salle, Norfolk I Monitoring the impact of cover crops and conservation tillage on water quality and soil health

Case study

Source: www.sciencedirect.com/science/article/pii/S0167880916306168

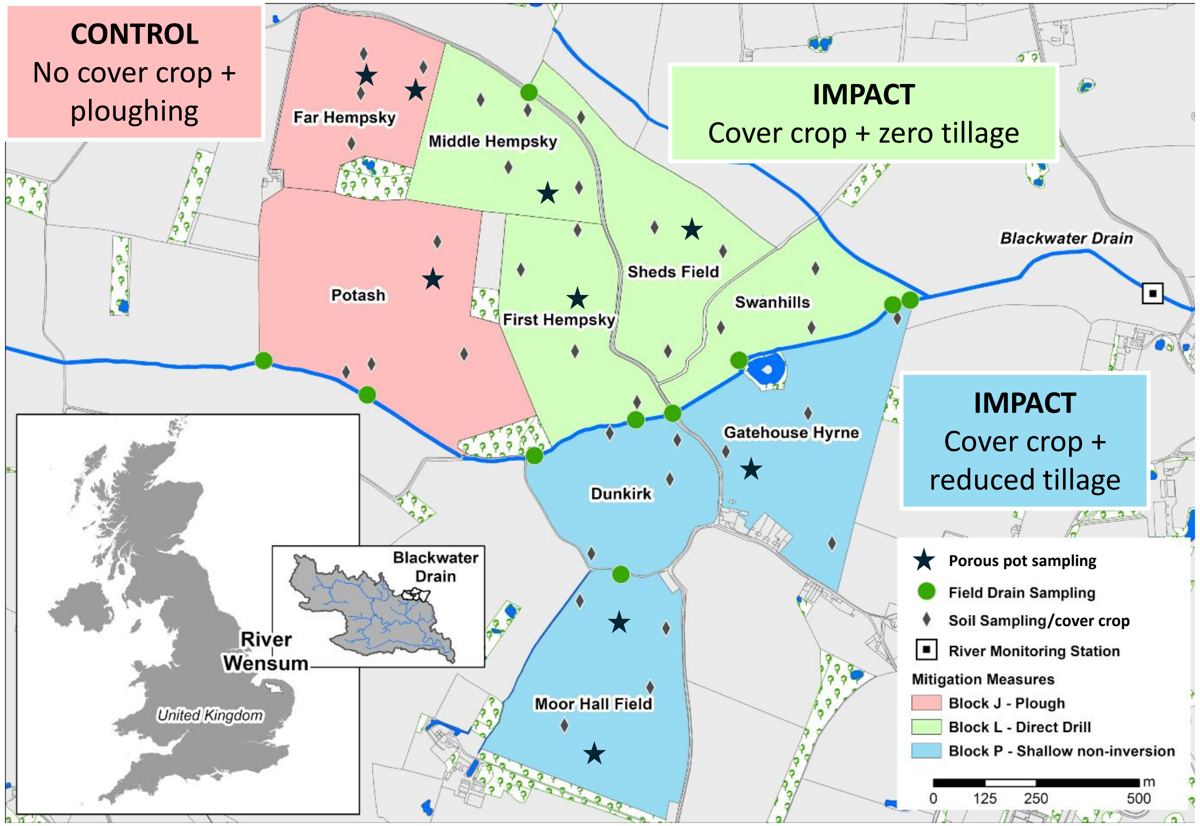
The effectiveness of cover crops and conservation tillage at minimising farm-scale nutrient leaching losses and improving soil health was assessed during 2013/14 on the Salle Park Estate. Adopting a control-impact approach, the trial area consisted of nine arable fields (143 ha) and was divided into three contrasting mitigation blocks:

- **Control Block J** (42 ha) = standard farm practice (plough, no cover crop)
- **Impact Block P** (52 ha) = reduced tillage (shallow non-inversion) and winter cover crop.
- **Impact Block L** (53 ha) = direct drill (zero tillage) and winter cover crop

Monitoring design

Adopting a monitoring train design, a 12-month sampling programme was conducted:

1. **Soil and cover crop vegetation:** sampled monthly from 4 x locations within each field and analysed for nutrient content.
2. **Soil water:** sampled monthly using porous pots buried 90 cm deep across 3 x locations within each trial block and analysed for nutrient concentrations in the laboratory.
3. **Field drains:** sampled weekly via grab sampling at 2-3 x drainage outfalls per trial block and analysed for nutrient concentrations in the laboratory.
4. **River water:** monitored at 30-minute resolution via an in-situ telemetered bankside monitoring station located 700 m downstream of the trial area.



Control-impact monitoring design for the Salle Park Estate cover crop and conservation tillage farm trial in 2013/14.

Options for Nature-based Solutions | Soil management practices

(continued)

Salle, Norfolk I Monitoring the impact of cover crops and conservation tillage on water quality and soil health

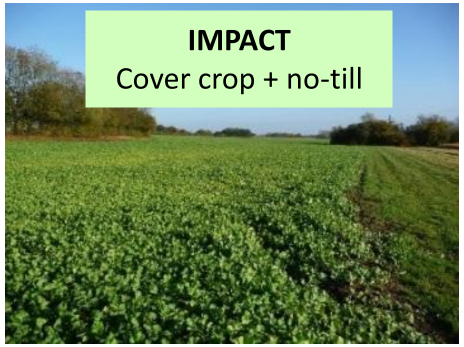
Case study

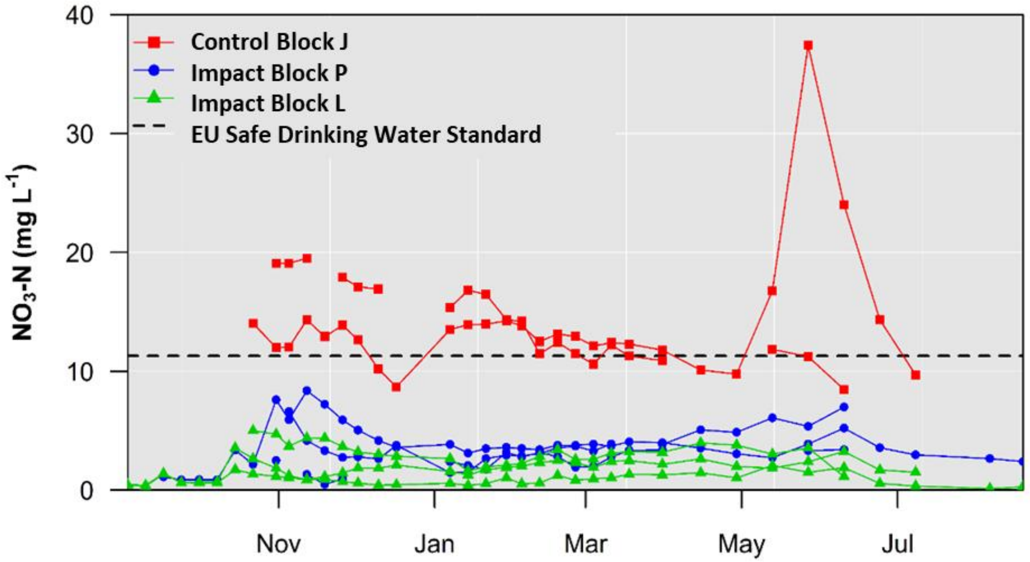
Results

- Weekly field drain monitoring revealed the winter oilseed radish cover crop successfully reduced nitrate leaching losses discharging into the river by 75% under impact Block P and by 88% under impact Block L, relative to the fallow control Block J during the 2013/14 farm year.
- Analysis of porous pot soil water samples revealed that soil nitrate concentrations were reduced by an average of 77% at 60–90 cm depth beneath the cover crop and conservation tillage blocks, highlighting the ability of the long-rooted cover crop to scavenge nutrients from deep within the soil profile and thus mitigate leaching losses.
- However, significant reductions in riverine nitrate concentrations downstream of the trial area were not observed, despite the trial area covering 20% of the catchment.
- Similarly, results revealed that conservation tillage did not significantly alter the soil physical (bulk density, infiltration capacity), chemical (N, P, K, Mg) or biological (worm counts, microbial respiration) condition relative to conventional ploughing, even after 5 years (2013-2018) of adoption.

Key monitoring finding

Monitoring of field drain outflows beneath soil management NbS was the easiest and most reliable method for directly assessing the impact upon water quality. It was also found that more than 5 years of monitoring would likely be required before significant improvements in river water quality or soil health can be detected due to legacy effects arising from decades of intensive agricultural practice.





Field drain nitrate concentrations recorded across the control and impact blocks between September 2013 and August 2014

Options for Nature-based Solutions | Riparian restoration

Species-rich riparian planting | Wendling Beck, Norfolk
Photo credit: Richard Cooper

Ecosystem Services provided

Approximate monitoring costs

Basic
Capital £0 I Annual £900 - £1800

Standard
Capital £1000- £4000 I Annual £17,000 - £35,000

Gold Standard
Capital £30,000 - £55,000 I Annual £35,000 - £125,000

Case study

Options for Nature-based Solutions | Riparian restoration

Overview

Riparian restoration involves the re-naturalisation of fluvial geomorphological processes by restoring riparian habitats both within and immediately adjacent to the river channel.

Primary goals

Improve water quality
Increase biodiversity

Example approaches

- **Bank top revegetation** | planting of natural vegetation immediately adjacent to the watercourse along the line of the riverbank.
- **Instream revegetation** | establishing marginal habitat through the planting of aquatic plants within the river channel and sides of the riverbanks.
- **Bioengineering** | use of coir logs or brushwood rolls to stabilise riverbanks and create low-level vegetated flood berms. Can also be used to narrow over-widened channels and increase water velocity.

Objectives

- **Reduce riverbank erosion** | planting of riparian vegetation helps to stabilise exposed riverbanks and reduce channel erosion.
- **Improve water quality** | shading by riparian trees keeps water cooler during the summer, whilst also acting as a physical barrier to restrict sediment and phosphorus ingress from surface runoff.
- **Increase biodiversity** | revegetation of the riparian zone provides new and improved habitats for both aquatic and terrestrial species in the river corridor.
- **Increase flow diversity** | establishment of instream vegetation and creation of flood berms increases flow heterogeneity which helps to scour deposited bed sediments and provide a greater range of habitats for aquatic organisms.

Options for Nature-based Solutions | Riparian restoration

Berm creation with coir rolls | River Gaywood, Norfolk.
©Norfolk Rivers Trust

Riparian tree planting | Flakebridge, Cumbria.
©River Eden Trust

Channel narrowing | River Heacham, Norfolk.
©Norfolk Rivers Trust

Instream marginal vegetation | River Nar, Norfolk.
Photo credit: Wensum DTC

Conceptual monitoring design

Monitoring goals

The primary focus for monitoring riparian restoration should be to assess the impacts upon riverbank erosion, river water quality and biodiversity.

A **basic monitoring regime** should therefore aim to assess:

1. River nutrient and sediment concentrations
2. Aquatic and terrestrial species presence/absence
3. River morphological complexity

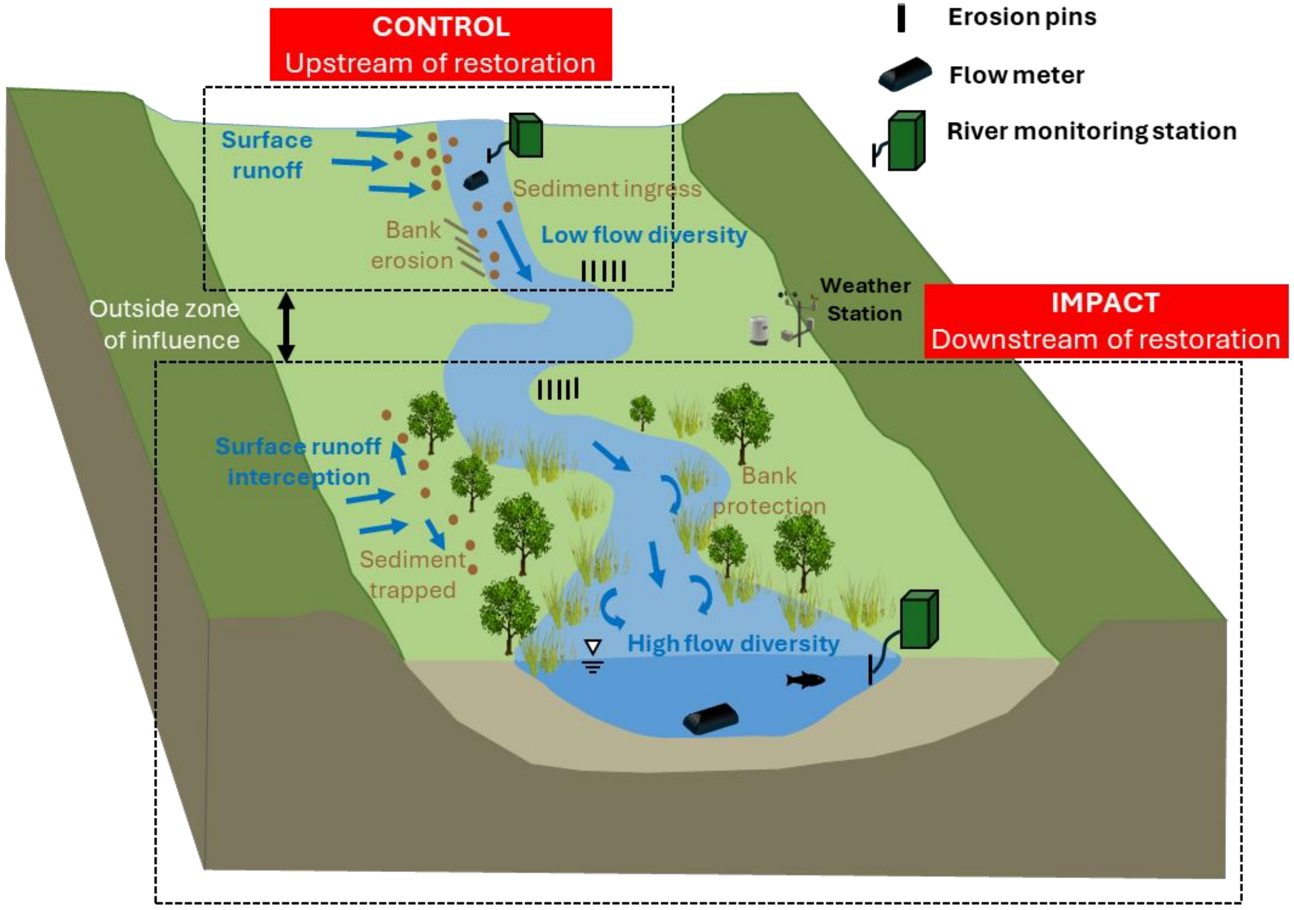
In addition to the basic regime, a **standard monitoring regime** should aim to assess:

1. Riverbank erosion rates and temporal change in channel morphology
2. Aquatic and terrestrial species abundance

In addition to the standard regime, a **gold standard monitoring regime** should aim to:

1. Provide comprehensive species assessment
2. Monitor in-situ at high-temporal resolution

Outline monitoring requirements for these basic, standard, and gold standard regimes are presented on the following pages.



Example gold standard control-impact monitoring design for assessing riparian restoration. This design would principally enable assessment of surface water quality and riverbank erosion. Control site could be either upstream of the restored section or on a separate neighbouring tributary with similar catchment characteristics.

Options for Nature-based Solutions | Riparian restoration

Basic monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	Obtain from EA Hydrology Data Explorer	Daily	1 = Local	-	Free
Surface water	Hydrological	River discharge spatially extrapolated from closest gauging station	Obtain from EA Hydrology Data Explorer	Daily	1 = Local	-	Free
	Chemical	Nitrate, orthophosphate	Citizen scientist sampling + basic colorimetric test strips or handheld nutrient checkers	Monthly	2 = upstream + downstream	-	<£2 per test (test strips); £50-£100 per unit + <£2 per test (Hanna Checker)
Geomorphology	Physical	Riparian habitat	Fixed point photography	Monthly	2 = control + impact	Essential for NN	<£100 per time
Biodiversity	Aquatic	Invertebrates; macrophytes	Benthic kick sampling; visual observations	Annual	2 = control + impact	Essential for BNG	<£200 per day to support citizen scientists
	Terrestrial	Birds	Manual species survey (visual point counts)	Annual	2 = control + impact	Optional for BNG	<£200 per day to support citizen scientists
				Estimated capital cost (one off)			**£0**
				Estimated annual running cost			**£900 - £1800**

Options for Nature-based Solutions | Riparian restoration

Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	In-situ telemetered tipping bucket rain gauge	Near-continuous	1 = study site	-	£500 - £1500 per unit
Surface water	Hydrological	River stage with manual stage-discharge calibration	In-situ telemetered stilling well pressure transducer	Near-continuous	2 = upstream + downstream	Essential for NN	£250 - £1000 per unit
	Chemical	Nitrate, orthophosphate, total nitrogen, total phosphorus, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Monthly	2 = upstream + downstream	Essential for NN	£25 - £75 per sample
Geomorphology	Physical	Riparian habitat; riverbank erosion;	River habitat survey (RHS); erosion pin measurements	Annual; monthly	2 = control + impact; 10 pin sites = 5 control + 5 impact	RHS essential for BNG	£500 – £1000 per day for field ecologist; £10-£20 per pin
Biodiversity	Aquatic	Invertebrates; fish; macrophytes; diatoms	Benthic kick sampling; electrofishing; LEAFPACS; DARLEQ	Seasonal	2 = control + impact	Macrophytes essential for BNG, others optional	£500 – £1000 per day per ecological type for field ecologist
	Terrestrial	Habitat types; birds; pollinators; mammals	Manual habitat survey; visual point surveys; sweep netting; Longworth traps	Seasonal	2 = control + impact	Habitat types essential for BNG, others optional	£500 – £1000 per day per ecological type for field ecologist
				Estimated capital cost (one off)			**£1000 - £4000**
				Estimated annual running cost			**£17,000 - £35,000**

Options for Nature-based Solutions | Riparian restoration

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation, air temperature, humidity, wind speed	In-situ telemetered weather station	Near-continuous	1 = study site	-	£1000 – £2500 per unit
Surface water	Hydrological	River discharge	In-situ telemetered flow meter	Near-continuous	2 = upstream + downstream	Optional for NN	£2500 - £7500 per flow meter
	Chemical	Nitrate, orthophosphate, turbidity, dissolved oxygen, temperature, pH, conductivity	In-situ telemetered sensors in river monitoring station	Near-continuous	2 = upstream + downstream	Optional for NN	£1000 - £10,000 per sensor
		Nitrate, orthophosphate, total nitrogen, total phosphorus, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Weekly	2 = upstream + downstream	Optional for NN	£25 - £75 per sample
Geomorphology	Physical	Riparian habitat evolution	Drone survey (photographic)	Seasonal	2 = control + impact	-	£500 - £1500 per visit
Biodiversity	Aquatic	Invertebrates; fish; macrophytes; diatoms	eDNA	Seasonal	2 = control + impact	Macrophytes essential for BNG, others optional	£200 - £400 single species; £1000 - £1500 multispecies
	Terrestrial	Habitat types; birds; pollinators; mammals	Manual habitat survey; acoustic recorders; sweep netting; camera traps	Seasonal	2 = control + impact	Habitat types essential for BNG, others optional	£500 – £1000 per day per ecological type for field ecologist; £50 - £100 per camera trap; £250 - £750 per acoustic recorder

Continued on next page …

Options for Nature-based Solutions | Riparian restoration

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Continued…							
Telemetry	Data	Real-time data visualisation/management	Cloud-based platform	Near-continuous	All	Optional for NN	£500 - £1500 per year
Equipment maintenance	Data	-	Instrument cleaning	Weekly	All	Optional for NN	£300 - £500 per day for field technician
			Water quality instrument servicing	3-6 months	2 = upstream + downstream	Optional for NN	£1000 - £10,000 per visit
				Estimated capital cost (one off)			**£30,000 - £55,000**
				Estimated annual running cost			**£35,000 - £125,000**

Options for Nature-based Solutions | Riparian restoration

Eddleston Water Project, Scotland I Catchment restoration programme

Case study

Source: tweedforum.org/our-work/projects/the-eddleston-water-project

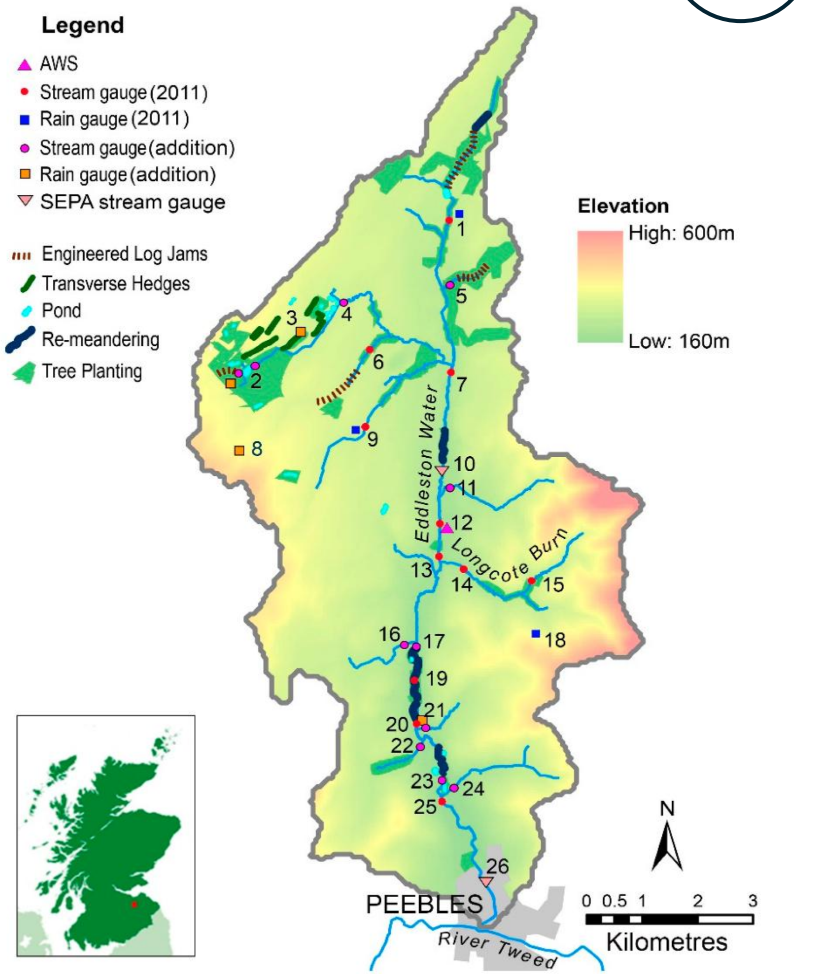
The Eddleston Water Project is a long running (2012 -) Scottish Government funded empirical study into the impact of natural flood management (NFM) techniques on flood risk and habitat restoration. Conducted across a 69 km^2 sub-catchment of the River Tweed, the project has delivered a wide range of habitat restoration and NFM measures, including:

- 207 hectares of woodland planting with over 330,000 native trees
- 116 high-flow log structures positioned on upper tributary streams
- 36 flow-attenuation ponds located in the headwaters and 2 larger ones on the lower floodplain
- 3 km of channel re-meandering

Monitoring design

Adopting a before-after, control-impact approach, the monitoring strategy aimed to develop a comprehensive hydrometry network to form the underpinning hydrological dataset, whilst also monitoring changes in fluvial hydrogeomorphology and ecology. The following monitoring equipment was installed:

- 24 x water level pressure transducers to record surface water levels (15-min resolution)
- 1 x telemetered weather station (15-min resolution)
- 10 x piezometers with loggers to record groundwater levels (1-10 m depth)
- 1 x downstream water quality monitoring site (manual) for nitrate, phosphate, suspended solids, pH, temperature and dissolved oxygen.
- Ecological surveys for aquatic invertebrates (eDNA), macrophytes (LEAFPACS), fish (electrofishing)
- Habitat mapping (aerial photography) and geomorphological survey (LiDAR).



In-field monitoring setup in the Eddleston Water catchment. Location of NbS measures also shown. AWS = automatic water sampler.

Options for Nature-based Solutions | Riparian restoration

(continued)

Eddleston Water Project, Scotland I Catchment restoration programme

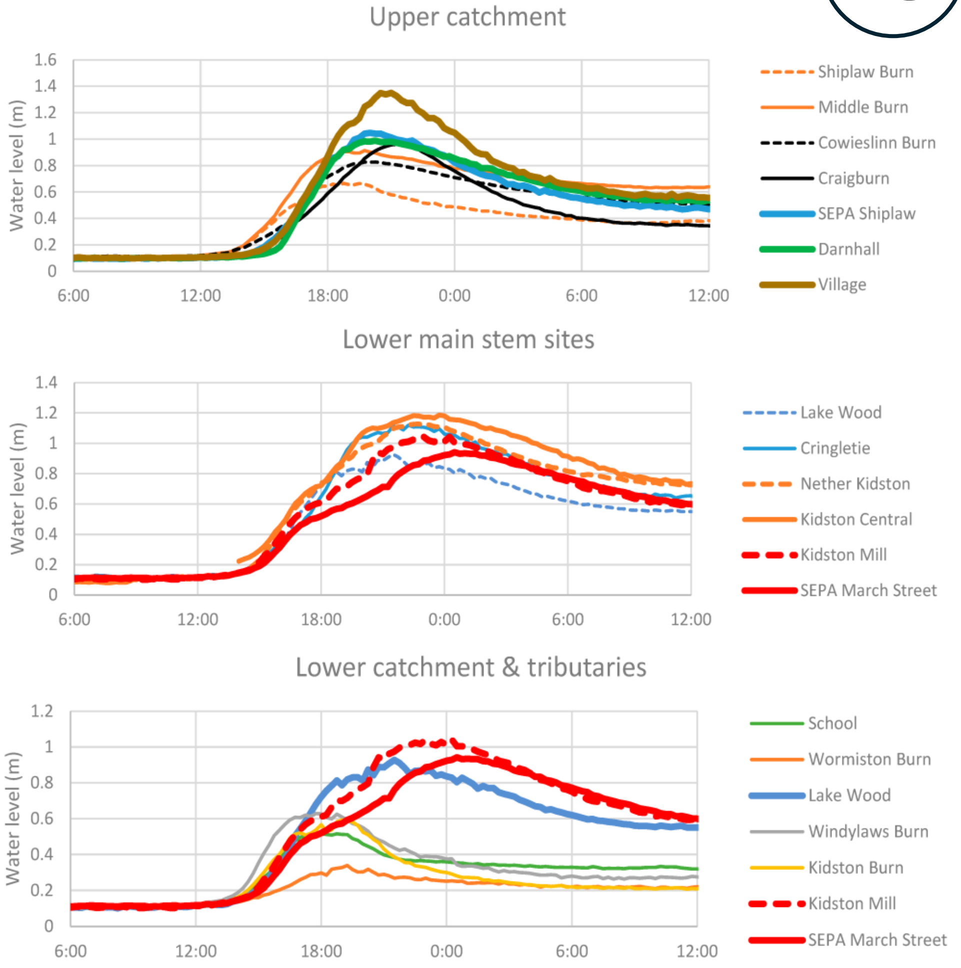
Case study

Results

- Significant increases in hydrological response times of between 2–7 hours were found in sub-catchments with combinations of leaky dams, retention ponds and riparian woodland planting, thus reducing downstream flood risk.
- However, in catchments with only riparian woodland planting, no significant increases in lag time were recorded and therefore no improvement in downstream flood risk was realised.
- The immaturity of the riparian trees was believed to be responsible, with the hydraulic impacts of riparian vegetation strongly controlled by planting density, stem diameter, height, structure and phenological phase.
- An up to 25-year delay might be expected in achieving an empirical understanding of the effects of riparian afforestation interventions.

Key monitoring finding

Working at larger temporal and spatial scales brings challenges in terms of increasing complexity and 'noise' from external drivers of environmental change unrelated to the NbS interventions. Whilst a before-after, control-impact design may mitigate these issues, control sites may show significant change over time and therefore require continued assessment.



Example temporal water level data used to determine rainfall response lag times in different sub-catchments with different NbS interventions. Source: www.mdpi.com/2073-4441/14/15/2305

Options for Nature-based Solutions | Floodplain reconnection

Floodplain reconnection | River Stiffkey, Norfolk
©Norfolk Rivers Trust

Ecosystem Services provided

Approximate monitoring costs

Basic
Capital £250 - £1000 **I** Annual £1500 - £3500

Standard
Capital £10,000- £35,000 **I** Annual £22,000 - £46,000

Gold Standard
Capital £45,000 - £120,000 **I** Annual £40,000 - £120,000

Case study

Options for Nature-based Solutions | Floodplain reconnection

Overview

Floodplain reconnection aims to restore the hydrological connection between river channels and the adjacent low-lying floodplains so that water, sediment, and biological material inundate the floodplains and store water during times of high river flow. This can involve removing flood embankments and other barriers to floodplain connectivity.

Primary goals

Reduce downstream flood risk

Increase wetland habitat

Example approaches

- **Bank lowering** | lowering the riverbanks to enable more frequent occurrence of overbank flows onto the floodplain.
- **Channel re-meandering** | restoring a river's natural sinuosity through the floodplain by creating meander loops.
- **Controlled flooding** | creating designated overflow zones to absorb excess water during storm events.
- **Wetland restoration** | re-establishing floodplain wetlands alongside the river channel to store surface water and create new wetland habitat.
- **Side channel/backwater creation** | constructing side channels and backwaters to increase connectivity between the river and floodplain.

Objectives

- **Flood mitigation** | reconnected floodplains act as natural storage areas, absorbing excess floodwater and reducing peak flows downstream.
- **Improved water quality** | slow moving water on floodplains allows sediments to settle, whilst floodplain biota assimilate nutrients, improving downstream water quality.
- **Enhanced groundwater recharge** | infiltration through floodplain soils can help sustain river baseflows downstream.
- **Restored biodiversity** | reconnected floodplains can restore large-scale wetland ecosystems, providing new habitats for fish, amphibians, birds, and wetland plants.
- **Climate resilience** | helps buffer against extreme weather events by absorbing and storing excess rainfall, reducing the impact of droughts and floods.

Options for Nature-based Solutions | Floodplain reconnection

Channel re-meandering | River Glaven, Norfolk.
©Norfolk Rivers Trust

Beaver wetland creation | River Glaven, Norfolk.
Photo credit: Richard Cooper

Backwater creation | River Glaven, Norfolk.
©Norfolk Rivers Trust

Riverbank lowering | River Glaven, Norfolk.
©Norfolk Rivers Trust

Conceptual monitoring design

Monitoring goals

The primary focus for monitoring floodplain reconnection should be to assess the impacts upon downstream flood risk, river water quality and biodiversity.

A **basic monitoring regime** should therefore aim to assess:

1. Floodplain surface water levels
2. River nutrient concentrations
3. Habitat types and species presence/absence

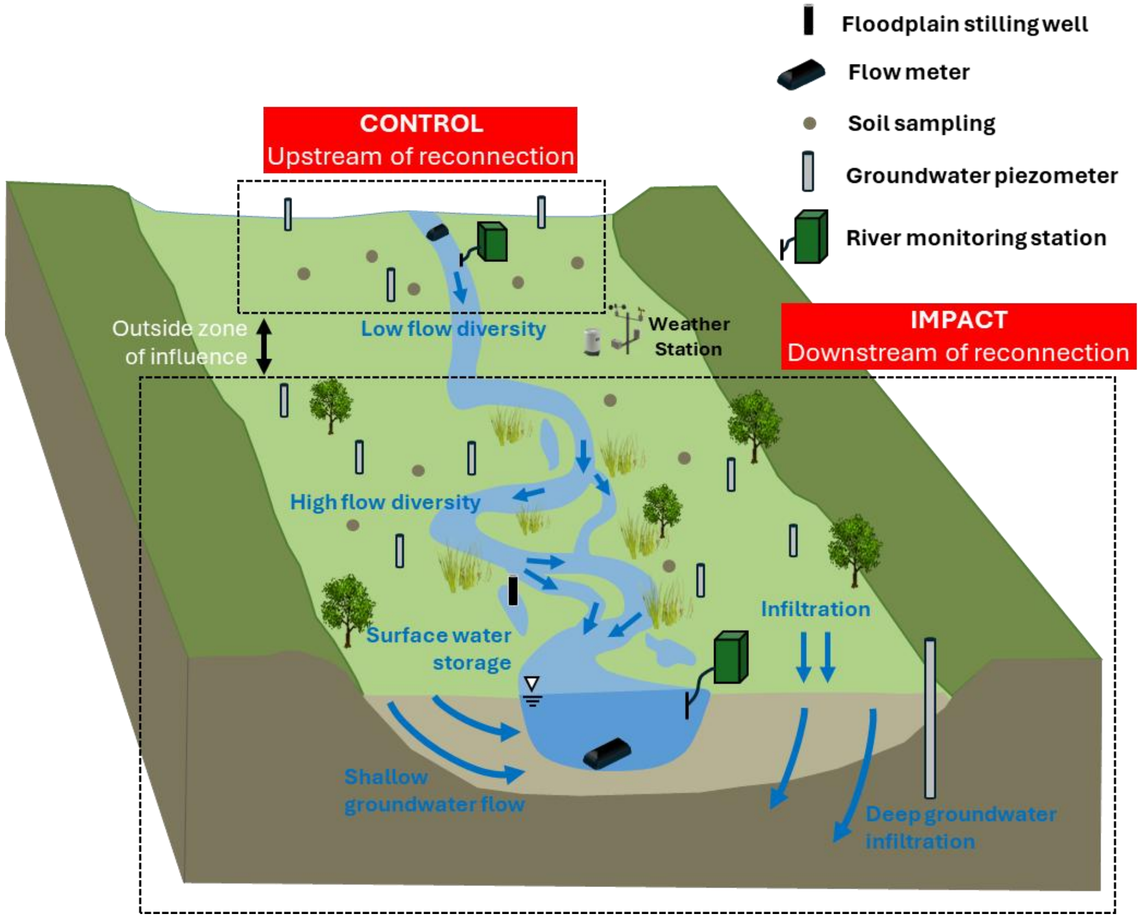
In addition to the basic regime, a **standard monitoring regime** should aim to assess:

1. Impact on downstream river flows
2. Shallow groundwater recharge rates
3. Floodplain carbon and nutrient storage in soils
4. River sediment and carbon concentrations
5. Terrestrial and aquatic species abundance

In addition to the standard regime, a **gold standard monitoring regime** should aim to assess:

1. Deeper groundwater recharge rates
2. Wider suite of water quality parameters measured in-situ
3. Full catchment water balance

Outline monitoring requirements for these basic, standard, and gold standard regimes are presented on the following pages.



Example gold standard control-impact monitoring design for assessing floodplain reconnection. This design would principally enable assessment of changes in river discharge, surface water storage, and groundwater infiltration. Control site could be either upstream of the restored section or on a separate neighbouring tributary with similar catchment characteristics.

Options for Nature-based Solutions | Floodplain reconnection

Basic monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	Obtain from EA Hydrology Data Explorer	Daily	1 = local	-	Free
Surface water	Hydrological	Floodplain surface water level	In-situ telemetered pressure transducer in stilling well	Near-continuous	1 = impact floodplain	-	£250 - £1000 per unit
	Chemical	Nitrate, orthophosphate	Citizen scientist sampling + basic colorimetric test strips or handheld nutrient checkers	Monthly	2 = upstream + downstream	-	<£2 per test (test strips); £50-£100 per unit + <£2 per test (Hanna Checker)
Geomorphology	Physical	Floodplain evolution	Fixed point photography	Monthly	2 = control + impact	Essential for NN and Replenish	<£100 per visit
Biodiversity	Aquatic	Invertebrates; macrophytes	Benthic kick sampling; visual observations	Seasonal	2 = control + impact	Macrophytes essential for BNG	<£200 per day to support citizen scientists
	Terrestrial	Birds	Manual species survey (point counts)	Annual	2 = control + impact	Optional for BNG	<£200 per day to support citizen scientists

Estimated capital cost (one off)	**£250 - £1000**
Estimated running cost (annual)	**£1500 - £3500**

Options for Nature-based Solutions | Floodplain reconnection

Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation	In-situ telemetered rain gauge	Near-continuous	1 = study site	-	£500 - £1500 per unit
Surface water	Hydrological	River stage with manual stage-discharge calibration; floodplain surface water level	In-situ telemetered pressure transducers in stilling wells	Near-continuous	3 = upstream + downstream + floodplain	Essential for NN	£250 - £1000 per unit
	Chemical	Nitrate, orthophosphate, total nitrogen, total phosphorus, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Monthly	2 = upstream + downstream	Essential for NN	£25 - £75 per sample
Soils (top 30 cm)	Chemical	N, P, organic carbon	Manual sampling + laboratory analysis	Seasonal	10 = 5 control + 5 impact	Essential for carbon credits	£30 - £50 per sample
Groundwater	Hydrological	Shallow groundwater levels (up to 10 m depth)	In-situ telemetered pressure transducers in piezometers	Near-continuous	5 = 1 control + 4 impact	-	£1500 - £5000 per hole £250 - £1000 per transducer
Geomorphology	Physical	Floodplain dimensions (3D)	Topographic survey (total station)	Annual	2 = control + impact	Optional for Replenish	£5000 - £10,000 per survey
Biodiversity	Aquatic	Invertebrates; fish; macrophytes; diatoms	Benthic kick sampling; electrofishing; LEAFPACS; DARLEQ	Seasonal	2 = control + impact	Macrophytes essential for BNG, others optional	£500 – £1000 per day per ecological type for field ecologist
	Terrestrial	Habitat types; birds; pollinators; mammals	Manual habitat survey; visual point surveys; sweep netting; Longworth traps	Seasonal	2 = control + impact	Habitat types essential for BNG, others optional	£500 – £1000 per day per ecological type for field ecologist
				Estimated capital cost (one off)			**£10,000 - £35,000**
				Estimated running cost (annual)			**£22,000 – £46,000**

Options for Nature-based Solutions | Floodplain reconnection

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Weather	Meteorological	Precipitation, air temperature, humidity, wind speed	In-situ telemetered weather station	Near-continuous	1 = study site	-	£1000 – £2500 per unit
Surface water	Hydrological	River discharge; floodplain surface water level	In-situ telemetered flow meter; In-situ telemetered pressure transducer in stilling well	Near-continuous	3 = upstream + downstream + floodplain	Optional for NN	£2500 - £7500 per flow meter; £250 - £1000 per unit
	Chemical	Nitrate, orthophosphate, turbidity, dissolved oxygen, temperature, pH, conductivity	In-situ telemetered sensors in river monitoring station	Near-continuous	2 = upstream + downstream	Optional for NN	£1000 - £10,000 per sensor
		Nitrate, orthophosphate, total nitrogen, total phosphorus, total suspended solids, dissolved organic carbon	Manual sampling + laboratory analysis	Weekly	2 = upstream + downstream	Optional for NN	£25 - £75 per sample
Soils (top 30 cm)	Chemical	N, P, organic carbon	Manual sampling, laboratory analysis	Monthly	10 = 5 control + 5 impact	Optional for carbon credits	£30 - £50 per sample
Groundwater	Hydrological	Shallow groundwater levels (up to 10 m depth)	In-situ telemetered pressure transducers in piezometers	Near-continuous	10 = 3 control + 7 impact	-	£1500 - £5000 per hole £250 - £1000 per transducer
		Deeper groundwater levels (10 - 50 m depth, if required)	In-situ telemetered pressure transducers in piezometers/boreholes	Near-continuous	10 = 3 control + 7 impact	-	£10,000 - £50,000 per hole £250 - £1000 per transducer

Continued on next page …

Options for Nature-based Solutions | Floodplain reconnection

Gold Standard monitoring regime

Component	Type	Parameters	Method	Resolution	Locations	Scheme	Approximate cost
Continued…							
Geomorphology	Physical	Floodplain dimensions (3D)	Topographic drone survey (LiDAR)	Annual	2 = control + impact	Essential for Replenish	£5000 – £10,000 per survey
Biodiversity	Aquatic	Invertebrates; fish; macrophytes; diatoms	eDNA	Seasonal	2 = control + impact	Macrophytes essential for BNG, others optional	£200 - £400 single species; £1000 - £1500 multispecies
	Terrestrial	Habitat types; birds; pollinators; mammals	Manual habitat survey; acoustic recorders; sweep netting; camera traps	Seasonal	2 = control + impact	Habitat types essential for BNG, others optional	£500 – £1000 per day per ecological type for field ecologist; £50 - £100 per camera trap; £250 - £750 per acoustic recorder
Telemetry	Data	Real-time data visualisation/management	Cloud-based platform	Near-continuous	All	Optional for NN	£500 - £1500 per year
Equipment maintenance	Data	-	Instrument cleaning	Weekly	All	Optional for NN	£300 - £500 per day for field technician
			Water quality instrument servicing	3-6 months	2 = upstream + downstream	Optional for NN	£1000 - £10,000 per visit
				Estimated capital cost (one off)			**£45,000 - £120,000**
				Estimated running cost (annual)			**£40,000 - £120,000**

Options for Nature-based Solutions | Floodplain reconnection

River Aller, Holnicote Estate, Somerset I Stage Zero approach

Case study

Source: www.nationaltrust.org.uk/visit/somerset/bossington/stage-0-one-year-on

The National Trust's Riverlands Project on the Holnicote Estate (2018-) was the first large-scale 'stage zero' floodplain restoration project conducted in the UK. Focussed on the River Aller, the project aimed to return the river to a pre-human disturbance state by fully reconnecting the river with its surrounding floodplain along a 1.2 km stretch of previously over-straightened and over-deepened channel. Restoration involved the lowering of riverbanks, creation of scapes and ponds, and addition of large quantities of woody debris to increase flow diversity. Additionally, floodplain wildflowers were sown and 25,000 native trees were planted to enrich the habitat. This resulted in the creation of a multithread channel meandering through seven hectares of newly created floodplain wetland environment.


www.restorerivers.eu/wiki/index.php?title=Case_study%3ARiverlands_Porlock_Vale_Streams

Monitoring design

Building on from an earlier DEFRA-funded natural flood management project (2009-2015) the project has yielded 15 years of comprehensive before-after monitoring data for the following parameters:

- Hydrology – discharge, stage, groundwater levels (15-min resolution)
- Meteorology – precipitation (15-min resolution)
- Water quality - turbidity
- Hydromorphology - high-resolution drone footage to provide river form baseline
- Ecology - key indicators including fish, aquatic invertebrates, bats, nesting birds, grass snakes, water vole and butterfly.

Options for Nature-based Solutions | Floodplain reconnection

(continued)

River Aller, Holnicote Estate, Somerset I Stage Zero approach

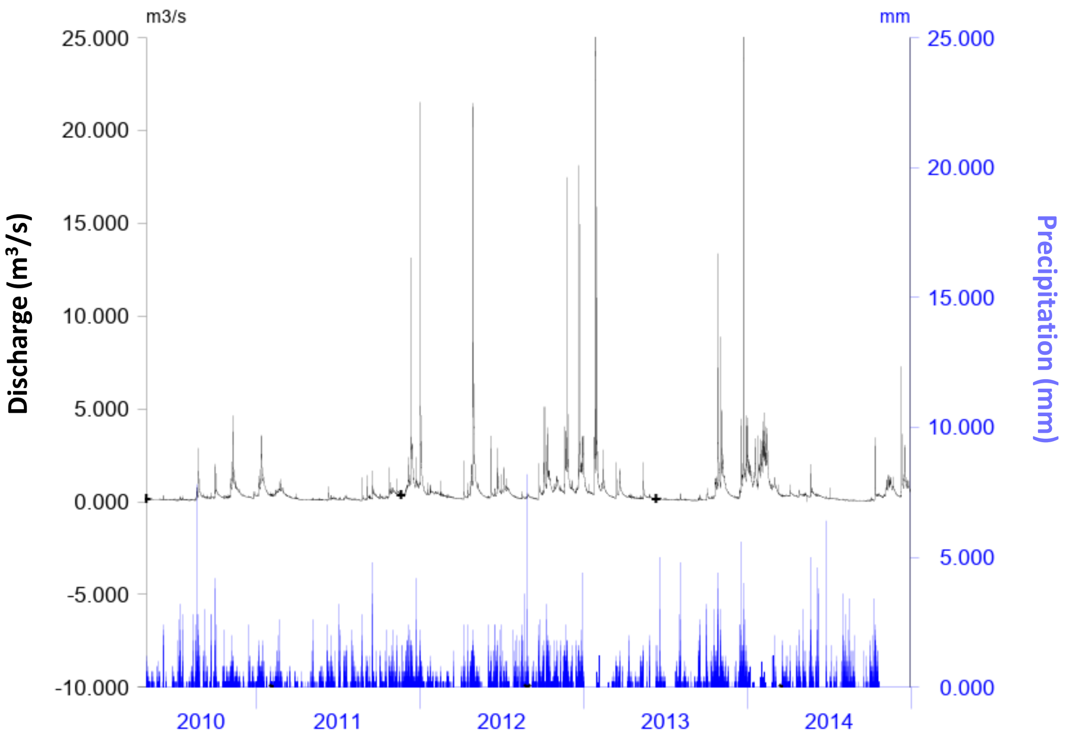
Case study

Results

- Average reduction in downstream peak flood flows of 38%.
- Increase in lag time between peak rainfall and peak discharge.
- Increase in groundwater levels by >1 m across the floodplain.
- Reduction in downstream water turbidity of 41%.
- Increase of 1780% aquatic habitat area (0.18 ha to 3.42 ha), with a diverse mosaic of wetland types providing refuge for wildlife including water voles, eels, lamprey, grass snakes, trout, and various bird species.
- Increase in geomorphological diversity with the development of pools, riffles, ponds, and gravel stream bed.

Key monitoring finding

Data telemetry proved problematic in several locations due to the hilly topography, whilst equipment reliability, power outages and the logistics of on-going equipment maintenance also proved challenging.



Example of the high-resolution (15-min) hydrological and meteorological data recorded by in-situ monitoring on the Holnicote Estate (National Trust, 2015).
stagezeroriverrestoration.com/docs/resources/holnicote%20report_final.pdf

Permissions and regulations

Overview

A range of permits, regulations and approvals may apply when implementing Nature-based Solutions, e.g., wetlands, buffer strips, rewetting, land use change and other natural interventions as outlined in the table below. This section introduces these regulations and looks more specifically at those controlling alterations to watercourses and land use change (e.g., arable to grassland).

Permission/Regulation/Approval	Description
1. Environmental Permitting Regulations (EPR) 2016	Administered by the Environment Agency, these apply to discharges or modifications to rivers, groundwater or wetlands. Common permits include a Water Discharge Activity Permit, Groundwater Activity Permit and Flood Risk Activity Permit. Permits are required for most discharges or engineering works (for example flow gauging structures) in or near water bodies.
2. Land Drainage Consents	If working in or near an ordinary watercourse (e.g., ditch or stream), a consent under the Land Drainage Act 1991 may be required as issued by Lead Local Flood Authorities (LLFAs) or Internal Drainage Boards (IDBs).
3. Town and Country Planning Act 1990	Planning permission may be required if the NbS project includes land use changes, engineering works or habitat creation. Local Planning Authorities determine if permission is needed or if the works fall under permitted development
4. Water Framework Directive (WFD) Objectives	Projects must comply with WFD standards to ensure no deterioration in water body status and may form part of permit applications.
5. Habitats Regulations 2017 (HRA)	If the project is near a Special Area of Conservation (SAC), Special Protection Area (SPA) or Ramsar site, a Habitats Regulations Assessment (HRA) may be required. Natural England should be consulted in these cases.
6. Catchment Sensitive Farming & Farming Rules for Water	Agricultural NbS must comply with Farming Rules for Water (2018). Natural England supports best practices through Catchment Sensitive Farming (CSF) advice.
7. Biodiversity Net Gain (BNG) & Local Nature Recovery Strategies (LNRS)	Nature-based water quality projects may also qualify for BNG credits if they deliver long-term biodiversity improvement. Therefore, ensure that projects meet habitat quality standards and are secured for at least 30 years.
8. Legal Agreements and Covenants	To formalise and secure long-term delivery of NbS, the project may need Section 106 Agreements, Conservation Covenants and land management contracts with mitigation providers.

Permissions and regulations | Altering a watercourse

Altering a watercourse

In England, altering a watercourse requires compliance with specific permits and regulations, which vary depending on the classification of the watercourse and the nature of the proposed work. Before altering any watercourse in England, it's crucial to identify the type of watercourse and consult the appropriate regulatory body to obtain the necessary permits or consents, ensuring compliance with all relevant regulations.

Main rivers

For activities on or near main rivers, which are typically larger watercourses, the Environment Agency regulates such works under the Environmental Permitting (England and Wales) Regulations 2016. This regulation mandates obtaining an environmental permit, formerly known as a flood defence consent, for activities that could affect flood risk, such as:

- Working in, over, under, or near a main river
- Constructing or altering structures that may impede water flow
- Activities within a floodplain or near a sea defence

For guidance on permitting of works and where to find further information and support, refer to the Environment Agency's guide: Your watercourse: rights and roles.

Note that operating without the necessary permit is a legal offence and can result in enforcement actions, including fines and orders to remove or modify unauthorised works.

To determine if your activity is on a main river, you can consult the main rivers map available from the Environment Agency.

Ordinary watercourses

For smaller watercourses, such as streams, ditches and drains not designated as main rivers, the responsibility for regulation falls to local authorities or Internal Drainage Boards (IDB). In these cases, you may need to apply for an Ordinary Watercourse Land Drainage Consent. This consent is required for works that might affect the flow or storage of water within the watercourse, including:

- Building or altering bridges, culverts or weirs
- Changing the alignment of the watercourse
- Erecting any obstruction that could impede water flow

For example, Norfolk County Council is responsible for consenting works that affect the flow of an ordinary watercourse. Councils typically charge £50 per structure or change, with the total cost depending on the proposed works.

To determine if your activity is on an ordinary watercourse managed by the Internal Drainage Board, you can, for example, consult the ordinary watercourse map for Norfolk available from the Water Management Alliance.

Permissions and regulations | Altering a watercourse

Legislative framework

The primary legislation governing alterations to watercourses includes:

- Water Resources Act 1991 | Provides the framework for water resource management, including abstraction and impoundment licensing.
- Land Drainage Act 1991 | Addresses the duties of drainage authorities and the regulation of ordinary watercourses.
- Flood and Water Management Act 2010 | Enhances flood risk management and assigns responsibilities to various authorities.

Local variations

Notice that regulations and application processes can vary by region. Therefore, it's essential to consult your local Environment Agency office, council or internal drainage board for guidance tailored to your area.

Fish pass creation, River Tiffey, Wymondham I © Norfolk Rivers Trust

Permissions and regulations | Land use change

Land use change

Land use change (e.g., from arable to grassland) while often environmentally beneficial must comply with a range of planning, agricultural and environmental laws

1. Town and Country Planning Act 1990 | In general, changing agricultural land from arable to grassland does not require planning permission. However, permission may be needed if the land is in a protected area (e.g., AONB, SSSI), involves engineering works, or is part of a larger development.

2. Environmental Impact Assessment (Agriculture) Regulations 2006 | If the land is uncultivated or semi-natural and the project is over 2 hectares, you may need Environmental Impact Assessment (EIA) screening or consent from Natural England. This applies particularly to projects that could affect biodiversity, landscape or soil structure.

3. Farming Rules for Water | These apply if you are part of an agri-environment scheme. Even when converting to grassland, you must comply with buffer zones, nutrient management rules, and avoid causing soil erosion or runoff.

4. Nitrate Vulnerable Zones (NVZs) | If the land is in an NVZ, you must follow strict rules on when and how fertilisers and manures are applied. Changing from arable to grassland may reduce nitrogen losses, but you still need to observe application limits and closed periods.

5. Protected Sites and Designations | Additional permissions may be needed if your land is in or near a Site of Special Scientific Interest (SSSI), Special Area of Conservation (SAC) or similar designation. Natural England must be consulted for consent in these cases.

Section 106 Agreements

What is a Section 106 Agreement?
A Section 106 agreement is a legal promise between a developer or landowner and the local council. The agreement ensures that the development reduces its impact on the local area, e.g., by constructing a wetland to improve water quality.

How long does it last?
The agreement usually lasts as long as the development exists. If for an environmental project (e.g., wetland creation), it may last for 80–120 years or more. The agreement stays with the land and applies to any new owner.

Section 106 and Nutrient Neutrality
If the development is in a protected catchment area, e.g., Broadland, a Section 106 agreement enables the developer to legally commit to using a nutrient credit or supporting a nature-based project to offset the development's impact.

Funding sources for Nature-based Solutions

Overview

Funding sources to support Nature-based Solutions include public schemes, developer contributions and emerging natural capital markets. Many NbS projects can blend (stack) multiple sources of funding (e.g., agri-environment payments, developer offsets, and biodiversity or carbon credits). The following provides a list of example funding sources.

Funding source	Description	Useful Links
Environmental Land Management Scheme (ELM)	Administered by Defra and the Rural Payments Agency, ELM includes: - Countryside Stewardship (CS): Capital grants for buffer strips, fencing and wetlands. - Landscape Recovery: Supports large-scale catchment restoration.	www.gov.uk/government/publications/environmental-land-management
Water Company Investment & Catchment Partnerships	Water companies (e.g., Anglian Water) fund NbS within regulated catchment partnerships and through WINEP (Water Industry National Environment Programme). Support includes funding for constructed wetlands, land management for runoff reduction, and riparian restoration.	broadlandcatchmentpartnership.org.uk engageenvironmentagency.uk.engagementhq.com/case-study-anglian-water
Nutrient Mitigation Funds & Developer Contributions	Where nutrient neutrality applies, developers may pay into mitigation schemes. Landowners who deliver wetlands, buffer zones or low-input grassland may receive payments per kg of nitrogen or phosphorus removed. Payments are usually secured by legal agreements.	www.nmfnorfolk.co.uk publications.naturalengland.org.uk/publication/5031421117988864
Biodiversity Net Gain (BNG) Credits	From 2024, BNG is mandatory for most developments. NbS that improve habitats (e.g. wetlands, meadows) may qualify for BNG credits if maintained for 30+ years. These can be sold to developers needing offsets.	www.gov.uk/government/collections/biodiversity-net-gain
Natural Environment Investment Readiness Fund (NEIRF)	Grants of up to £100,000 support project development (not capital works). NEIRF funds business models, contracts, and legal structures to help prepare NbS projects for private investment or blended finance.	www.gov.uk/government/publications/apply-for-a-grant-from-the-natural-environment-investment-readiness-fund

Continued on next page…

Funding sources for Nature-based Solutions

Continued from previous page…

Funding source	Description	Useful Links
Green Finance & Blended Investment	Private investors, ESG (Environmental, Social & Governance) funds and banks are increasingly funding natural capital projects, particularly where NbS generate carbon, biodiversity, water (e.g. Replenish Credits) or nutrient credits. Projects must usually demonstrate a return via credit sales or service payments.	www.gov.uk/guidance/green-finance hive.greenfinanceinstitute.com/wp-content/uploads/2024/10/NEIRF-case-study-The-Rivers-Trust-Replenish.pdf
Additional Funding Sources	Water Environment Improvement Fund (WEIF) capital budget for catchment partnerships in support of various objectives including habitat creation and restoration, and flood risk and natural flood management.	www.gov.uk/government/publications/water-environment-improvement-fund-projects
	Farming in Protected Landscapes (FiPL): For projects in National Parks and AONBs.	www.gov.uk/guidance/funding-for-farmers-in-protected-landscapes
	UK Shared Prosperity Fund (UKSPF): Local projects, some may support green infrastructure.	www.gov.uk/government/publications/uk-shared-prosperity-fund-prospectus
	Woodland Creation Grants: Support riparian or wet woodland creation.	www.gov.uk/government/publications/woodland-grants-and-incentives-overview-table/woodland-grants-and-incentives-overview-table
	UK Research and Innovation (UKRI): funds fundamental, solutions-oriented research into building a green future and a secure and resilient world. Includes opportunities to bid for capital equipment.	www.ukri.org/opportunity
	EU Horizon: facilitates research in developing, supporting and implementing EU policies while tackling global challenges. The EU Life Programme includes funding for nature and biodiversity.	https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls_en
	WRAP (Waste and Resources Action Programme): supply chain investor bringing together businesses, NGOs and governments to reduce waste and restore nature.	www.wrap.ngo/what-we-do
	LENs (Landscape Enterprise Networks): a system for organising the buying and selling of nature-based solutions through brokering negotiations, and eventually transactions, between buyers and groups of landowners.	landscapeenterprisenetworks.com

Funding sources for Nature-based Solutions | Replenish Credits

Overview

Replenish Credits provide a new income stream for landowners and catchment project developers. Replenish Credits align with corporate Environmental, Social and Governance (ESG) targets, River Basin Management Plans (RBMPs) and Local Nature Recovery Strategies (LNRS).

What are Replenish Credits?

Replenish Credits are verified units that quantify the volume of water (in cubic metres) returned to or saved in a catchment through interventions such as wetlands, floodplain restoration or water efficiency improvements. Replenish Credits support water resilience and river health and are often tied to catchment-based water stewardship programmes.

Relevance to River catchments

Within river catchments, Replenish Credits aim to restore the natural water cycle, offset freshwater use, support biodiversity and enhance climate resilience. Projects must be located in the same river basin where water use occurs, making them catchment-specific.

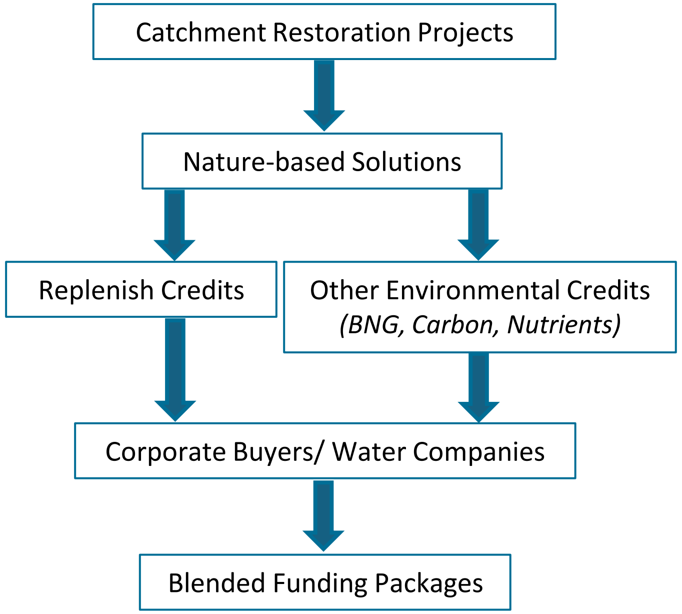
Who sells Replenish Credits?

Farmers/landowners and local authorities.

Who buys Replenish Credits?

- Corporations with science-based water targets (e.g., food and drink manufacturers, technology companies and supermarkets).
- Water companies seeking to improve catchment water balances.
- Philanthropic funders supporting freshwater ecosystems.

Replenish Credits as part of a Catchment Funding Strategy



Funding sources for Nature-based Solutions | Replenish Credits

Example interventions generating Replenish Credits

Intervention	Credit outcome
Wetland creation	Water retention and filtration
Floodplain reconnection	Seasonal flood flow restoration
River meandering	Slower flow and groundwater recharge
Crop switching	Lower abstraction pressure
Precision irrigation	Freshwater savings
Sustainable Drainage Systems (SuDS)	Aquifer recharge and peak flow reduction

Purchasing Water Benefit Certificates delivers impact towards the UN Sustainable Development Goals

Measurement and verification

Replenish Credits are measured using according to the The Rivers Trust's Replenish Toolbox, which incorporates the Volumetric Water Benefit Accounting (VWBA) methodology.

Projects must show baseline water status, additional water returned or saved, and long-term monitoring.

Buyers and sellers will be responsible for maintaining and monitoring interventions, typically over 10 years, or the length of time that buyers wish to claim Replenish values.

Other schemes funding water resource NbS projects:

- Water Benefit Certificates (WBC) use a methodology more aligned to a Gold standard approach,
- The Alliance for Water Stewardship (AWS) standard has a site-based accreditation system.

Alliance for Water Stewardship Standard's five-step continual improvement framework

Funding sources for Nature-based Solutions | Replenish Credits

Monitoring requirements*

The type of in-field monitoring required to earn Replenish Credits varies depending on the type of NbS feature being delivered:

Runoff attenuation features (RAFs)

- Storage capacity of the feature (m^3)
- Water flow into feature (m^3/s) under range of hydrological conditions
- Inlet and outlet total phosphorus, total nitrogen and biological oxygen demand (BOD) concentrations collected fortnightly over 3-month period
- Soil infiltration rate (mm/hr)
- Fixed-point photography (biannual)
- Observational wetness index – days wet per year
- Sediment settlement (mm/year)
- Operational walkover survey (daily-annual)

Land use change

- Fixed point photography (biannual)
- Surface runoff volume (m^3/year) before and after land use change
- Modelled catchment runoff data where primary data collection not feasible
- Remote sensing evidence of land use change (optional)

Soil management practices

- Surface runoff volume (m^3/year) before and after soil management change
- Modelled catchment runoff data where primary data collection not feasible

Floodplain reconnection

- Fixed point photography (biannual)
- Change in surface water area (m^2) and/or river channel length (m)

** Based on Replenish Monitoring Principles v1.1 in development by The Rivers Trust (Draft document January 2025)*

Funding sources for Nature-based Solutions | Replenish Credits

The Rivers Trust Replenishment Toolbox I Example project

Case study

Source: storymaps.arcgis.com/stories/70c7ce9c852c41feab4f5e5bd7d59172

Norfolk Rivers Trust identified a river restoration project that included the diversion of an existing channel into meandered channels and the creation of earth bunds resulting in a wetland habitat. The project will deliver a water quality benefit and was identified in the toolbox as an online ponds, wetlands and bunded areas for water quality. The calculations assume that the water flowing into the online feature is failing a locally relevant water quality target, such as those set out in the EU Water Framework Directive, and that the water leaving the feature is below the target threshold.

Nar valley wetland © The Rivers Trust

Key learning points

Ensure that projects/interventions are led by the needs of the catchment and the local environmental threats/opportunities. Achieving optimal outcomes also provides confidence to buyers.

Ensure messaging around the ecosystem service(s) being sold, and its purpose, is clear to build buyers' confidence. Events with buyers can be a useful engagement mechanism, though trust will require time to develop.

Funding sources for Nature-based Solutions | Nutrient Neutrality

Overview

Nutrient neutrality, an example of water quality trading, is an economical and efficient mechanism for controlling excess nutrient loads (phosphorus and nitrogen) in catchments through the generation of 'credits' from nutrient management solutions that are sold to buyers facing restrictions imposed by environmental quality standards.

In the UK, under the Habitats Regulations, local planning authorities and the Environment Agency in England and Wales must assess the environmental impacts of planning applications that affect protected habitat sites. For sites in unfavourable condition due to excess nutrient pollution, the intention is that development plans can only proceed if the increase in wastewater that is produced by the projected population increase will not cause additional pollution, in other words maintaining 'nutrient neutrality'.

Nutrient neutrality involves mitigating the nutrient load from a new development either onsite or elsewhere within the same catchment as the protected habitat. Potential nutrient management options include:

(i) Nature-based Solutions (e.g., reforesting marginal, often unprofitable cropland, creating new wetlands to strip nutrients from water, and creating nutrient buffer zones along rivers and other watercourses)

(ii) agricultural runoff management solutions (e.g., retiring agricultural land to reduce fertiliser and manure applications and the use of post-harvest cover crops to reduce residual nutrient losses)

(iii) wastewater management solutions (e.g., improving existing wastewater treatment infrastructure and upgrading existing private sewage systems);

(iv) demand management solutions (e.g., retrofitting water-saving measures in existing properties).

Funding sources for Nature-based Solutions | Nutrient Neutrality

Monitoring requirements

Unless Natural England has predefined nitrogen and phosphorus removal efficiency values for a specific NbS, then either in-field monitoring or use of secondary datasets is required to estimate the baseline nutrient load entering a defined river reach, whilst additional monitoring will be required to prove the nutrient load reduction that has been achieved through deployment of the NbS option.

(1) Baseline monitoring

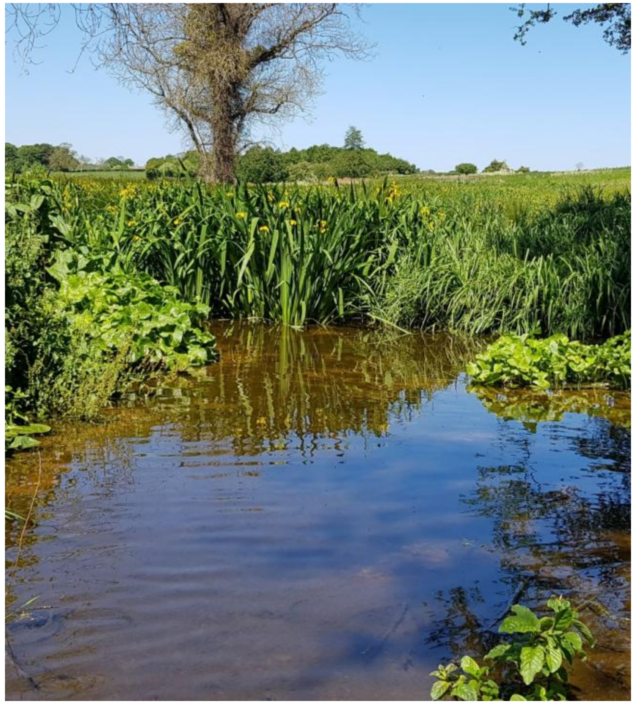
- Total nutrient (N + P) concentrations and water flows upstream and downstream of the NbS feature should be generated.
- Must be conducted for at least 1 year at monthly resolution or higher to characterise nutrient loads under all seasonal conditions.
- Should specifically target monitoring of rainfall events when nutrient mobilisation is greatest.
- Deployment of in-situ nutrient sensors and calibrated water level loggers should be considered to provide continuous data.

(2) Post-implementation monitoring to gain credits

- Must include total nutrient (N + P) concentrations and flow data upstream and downstream of the feature.
- Carried out for a minimum of 3 years to capture seasonal variability in NbS performance.
- Should continue at least until the system has reached quasi-equilibrium with stable nutrient removal performance.
- More frequent monitoring during the initial years is recommended.
- Can use secondary datasets if available, robust, and fully documented.

(3) Post-implementation monitoring to support adaptive management focusing on scheme function

- Required to ensure the NbS function is maintained.
- Regular visual inspections and repeat photography should begin as soon as the scheme has been implemented.
- Frequency of inspections will vary depending upon the nature of the feature, but must be reviewed annually for at least 3 years.
- Future monitoring plan and timelines should be determined to ensure the in-perpetuity benefits of the scheme.



Ingoldisthorpe integrated constructed wetland
Photo credit: Richard Cooper

Funding sources for Nature-based Solutions | Nutrient Neutrality

Mitigation measures create nutrient credits that are traded in private markets, although statutory credits have been created by Natural England for the Poole Harbour and Tees catchments in which credits are typically created through wildlife trusts buying land to develop mitigation measures.

Case studies

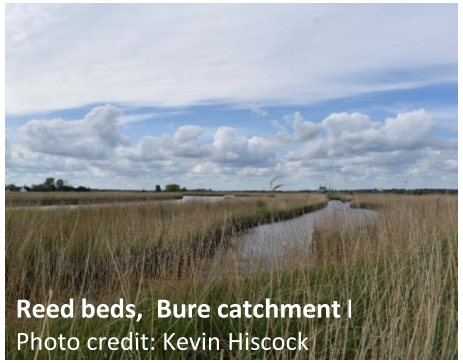
In the Poole Harbour catchment, the purchase of Dorset Wildlife Trust's 170-hectare Wild Woodbury site near Bere Regis, supported by a grant from local councils, will mitigate the impacts of increased nitrogen inputs from the development of over 2000 homes at a cost of £3250 per 1 kg nitrogen-credit. The community rewilding project at Bere Regis includes landscape-changing Stage Zero river restoration work for wetland wildlife and improvement in water quality.

Stage Zero river restoration, Bere Regis I ©Dorset Wildlife Trust

In the Tees catchment, Natural England has secured almost 440 ha of land for nature recovery through its Nutrient Mitigation Scheme and has offered credits for over 6000 new homes at a cost of £2700 per 1 kg nitrogen-credit. An example project is the purchase by the Durham Wildlife Trust of Morden Carr for nature recovery from low-grade farmland to more natural fenland with benefits for biodiversity, carbon capture and flood mitigation.

Teesmouth and Cleveland Coast SPA I ©Natural England

In Norfolk, Norfolk Environmental Credits (NEC), a non-profit collaboration between district councils, manages mitigation credits in the Bure, Wensum and Yare catchments through changes in land use, most commonly through a Section 106 agreement with landowners. NEC seeks a range of offset solutions that generate temporary (short-term mitigation for five years, e.g., arable to grassland conversion) and permanent (long-term mitigation for 80-plus years, e.g., woodland and wetland creation) nutrient credits. Funding is available through the Norfolk Mitigation Fund to support feasibility and capital schemes including nature-based solutions (riparian buffer strips and constructed wetlands). NEC sells nutrient neutrality credits for the Broadland catchments at a cost of £5900+VAT. These costs are for 0.1kg/year total phosphorus, inclusive of the nitrogen mitigation needed for site development.



Reed beds, Bure catchment I Photo credit: Kevin Hiscock

Key learning point

Generating nutrient credits through nature-based solutions, such as creating new wetlands, requires a full consideration of the administrative, legal and practical costs of mitigation and the associated monitoring and maintenance costs.

Funding sources for Nature-based Solutions | Biodiversity Net Gain

Overview

Biodiversity Net Gain (BNG) is an approach to development that ensures a project leaves the natural environment in a measurably better state than before the development began. It requires developers to not only replace lost habitats but also enhance them, resulting in a minimum 10% increase in biodiversity value. This is achieved through various methods, including on-site habitat creation or enhancement, off-site habitat projects, or by purchasing biodiversity credits

Delivery mechanisms

Biodiversity net gain can be achieved in three main ways:

- **On-site:** Enhancing or creating new habitats within the development's boundary. For example, planting a wildflower meadow, creating a pond, or integrating green roofs.
- **Off-site:** Enhancing or creating habitats on land outside the development site, either on the developer's own land or by purchasing "biodiversity units" from land managers. These gains need to be legally secured for at least 30 years.
- **Statutory Biodiversity Credits:** As a last resort, if on-site and off-site options are not feasible, developers can purchase statutory biodiversity credits from the government. The revenue from these credits is invested in habitat creation elsewhere in England.

Legal requirement

In England, BNG is now mandatory for most new developments under the Environment Act 2021. It became mandatory for major developments on 12 February 2024, and for small sites on 2 April 2024.

Management

Any habitats created or enhanced for BNG must be managed and monitored for at least 30 years to ensure the intended biodiversity gains are achieved and maintained. This is usually secured through planning conditions, obligations (Section 106 agreements), or conservation covenants.

Biodiversity Gain Plan

Developers are required to submit a Biodiversity Gain Plan to the local planning authority, detailing how they will achieve the required net gain. This plan outlines the pre-development biodiversity value and how the post-development value will be at least 10% higher. It also outlines the monitoring that will be conducted to establish whether the uplift has been achieved.

Photo credit: Kevin Hiscock

Funding sources for Nature-based Solutions | Biodiversity Net Gain

Monitoring requirements

Monitoring for Biodiversity Net Gain (BNG) is a mandatory requirement under the Environment Act 2021 to ensure that developers deliver and maintain at least a 10% biodiversity uplift for a minimum of 30 years. Monitoring primarily involves habitat condition assessments and species surveys conducted before (baselining) and after development. Whilst there is no prescriptive monitoring scheme applicable to all habitat types, it is recommended that surveys are carried out during the peak botanical season (typically April to August depending on habitat type) and conducted every 1-5 years.

Natural England provides a Habitat Management and Monitoring Plan (HMMP) which must be completed for each BNG site to outline how the land will be managed and monitored, completed under the guidance of a professional ecologist. The type of in-field monitoring required to earn BNG credits varies depending on the type of NbS feature being delivered:

Land use change (species-rich grassland creation)

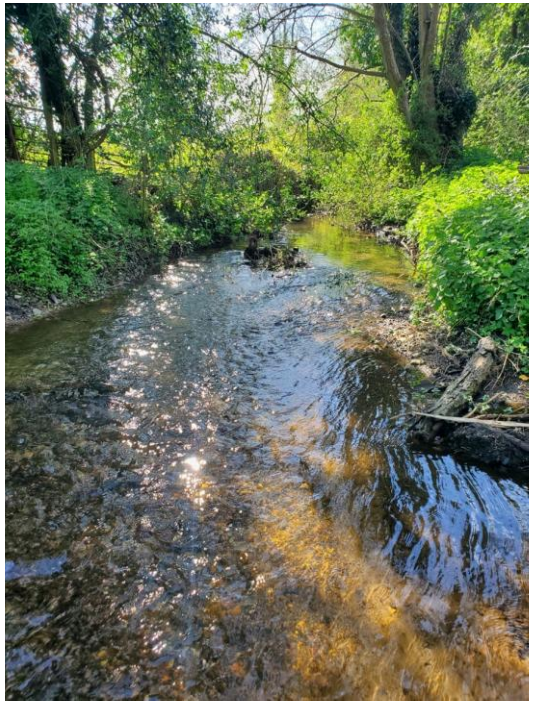
- Diversity of vascular plant species per m^2
- Sward height variability
- Presence of scrub (%)
- Presence of bare ground (%)
- Presence of physical damage (%)

Floodplain reconnection (wetland)
* will also include watercourse measures

- Height of water table
- Vascular and non-vascular plant composition
- Water quality (principally turbidity)
- Scrub and tree coverage (%)
- Bare ground coverage (%)
- Presence of non-native species
- Dead vegetation coverage (%)
- Coverage of sphagnum moss, cottongrass and ericaceous dwarf shrubs
- Reedbed diversity
- Drainage ditch habitat condition

Riparian restoration (watercourse)

- Bank top and face vegetation structure
- Bank top and face tree richness
- Bank face material
- Channel margin aquatic vegetation
- Channel margin aquatic morphotype
- Channel aquatic morphotype richness
- Channel bed hydraulic features richness
- Channel bed natural features richness
- Channel bed material richness



Wendling Beck Environment Project
Photo credit: Richard Cooper

Funding sources for Nature-based Solutions | Carbon credits

Overview

The UK carbon market comprises two primary components: (1) the government regulated UK Emissions Trading Scheme (UK ETS) which is designed to tackle carbon emissions from power generation and heavy industry; and (2) the unregulated and market-driven Voluntary Carbon Market (VCM) where businesses, organisations, and individuals voluntarily purchase carbon credits to offset their greenhouse gas emissions and support sustainability goals. The VCM is the most relevant in relation to obtaining funding for the delivery of Nature-based Solutions.

Current Voluntary Carbon Markets

Woodland Carbon Code | quality assurance standard for woodland carbon projects in the UK managed by the Forestry Commission and Scottish Forestry.

Peatland Code | quality assurance standard for peatland restoration projects in the UK managed by the IUCN.

Soil Carbon Code | emerging scheme that currently lacks a unified verification standard. Soil carbon credits have the greatest risks associated with sequestration due to uncertainty around the long-term stability of carbon within the soil. However, soil carbon is the most relevant for the NbS options of land use change, soil management practices, and floodplain reconnection.

Because these schemes are voluntary and market-driven, there is no fixed price for carbon sequestration. Prices vary widely from £10 - £100 per tonne of carbon sequestered. A lack of government regulation raises concerns around the potential for 'double counting' and corporate 'greenwashing', and so robust monitoring of any scheme is essential.

Monitoring requirements

Soil Carbon | No fixed requirement, but advisable that soil samples be collected (0-30 cm depth) from across control and impact areas and analysed for organic carbon content (%) prior to NbS implementation (baselining) and annually thereafter to assess temporal changes. Soil bulk density (kg/m^3) should also be measured and multiplied by the carbon content to determine the total mass of carbon sequestered across the NbS area.

Woodland Carbon | Carbon stocks in tree biomass, leaf litter, non-tree biomass, and woodland soils must be first baselined (kg/ha). These carbon stocks can then be projected forward over future years based on established tree growth rates using certified Carbon Lookup Tables.

Funding sources for Nature-based Solutions | Biodiversity Net Gain and soil carbon

Biodiversity Net Gain and soil carbon I Wendling Beck Environment Project

Case studies

The Wendling Beck Environment Project (WBEP) is an exemplar of efforts to protect and enhance the natural environment, while generating revenue from ecosystem services. The project steering group (the Wendling Beck Alliance) is a collaboration between farmers, Norfolk Wildlife Trust, Norfolk County Council, NGOs (Norfolk Rivers Trust, Norfolk Farming and Wildlife Advisory Group, and The Nature Conservancy (TNC)), and Anglian Water. The project aims to create a blueprint to leverage private finance for the delivery of NbS at a landscape-scale.

Wendling Beck catchment

The Wendling Beck is a tributary of the River Wensum in Norfolk and lies within a strategic corridor for nature recovery. The WBEP aims to transform around 800 ha of arable land through the creation of species-rich grasslands, heathlands, wetlands and woodlands along with the restoration of chalk streams. Habitat interventions will also include nitrogen and phosphate removal from soil and water, natural flood management (NFM), carbon sequestration and storage, and reducing carbon emissions from farming.

Financing

The WBEP is looking to sell multiple ecosystem services. The project will raise revenue through the sale of environmental credits via a new Limited Liability Partnership (LLP) and focus primarily on BNG, with a secondary focus on nutrient credits and NFM solutions. Selling voluntary biodiversity credits via environmental and social governance (ESG) markets could also play a part in generating income. Carbon sequestration will be measured but is unlikely to form a future revenue stream under current standards.

Key learning point

Employ good measurement and data management practices. Establish baseline measurements early and measure as much as possible. Ensure that control data are also captured so that outcomes can be compared and correctly attributed. A good data management strategy and system is essential.

Monitoring and modelling

Key outcomes of the WBEP will be measured through a detailed monitoring framework, focusing on species presence and abundance, carbon stores (both in soils and above-ground biomass) and water quality. Monitoring will deploy novel techniques and include:

- Monitoring habitat transition and species recovery using novel techniques such as bioacoustics monitoring, eDNA and remote sensing.
- Using new technology such as artificial intelligence for measuring the amount of carbon sequestered and stored in above-ground biomass.
- Employing the regenerative **soil food web approach** to restore agricultural soils.
- Spatial modelling of BNG demand by habitat type, in order to quantify market opportunities.

Dillington Hall Estate, Wendling Beck I
Photo credit: Emli Bendixen

Integrated implementation | Credit stacking

Overview

Landowners, farmers and project developers can integrate NbS to improve soil and water environments by combining multiple funding schemes and credit markets with a focus on 'credit stacking'.

What is credit stacking?

Credit stacking involves combining different environmental funding streams or credit markets (e.g., carbon, biodiversity, nutrient, public subsidies) on the same land or project. It is a way to maximise both environmental and financial returns while ensuring that benefits are not double-counted.

Stackable opportunities

Examples of what can be stacked include:

Environmental Outcome	Example NbS	Revenue Streams
Soil carbon	Reduced tillage, cover crops	Soil carbon credits, SFI payments
Water quality	Wetlands, buffer strips	Nutrient credits, CS grants
Biodiversity	Grasslands, woodland	BNG credits, FiPL
Carbon sequestration	Agroforestry, woodland	Woodland Carbon Code units, BNG
Flood mitigation	Rewetting, storage basins	Payment for Ecosystem Services (PES) schemes, water company funds

River Glaven beaver dam I
Photo credit: Richard Cooper

Integrated implementation | Credit stacking

Key steps to integrate stacking in a business

A. Map natural capital potential

Use baseline tools to identify opportunities for stacking such as soil sampling, habitat mapping and nutrient loss modelling.

B. Design a layered credit strategy

Align compatible credits on the same land without overlap. Use spatial and temporal separation where necessary.

C. Secure legal & contractual clarity

Use separate contracts per credit stream and ensure clarity on exclusivity, verification and payment terms.

D. Develop a business case

Model costs and returns across schemes and factor in verification, permanence and long-term management.

E. Use intermediaries

Work with organisations who can bundle credits, manage delivery and match with buyers (e.g., Environment Bank, Rivers Trusts).

Rules, risks and safeguards

Rule / Risk	Explanation
No double counting	Each credit must represent a unique environmental benefit
Additionality	Benefits must be over and above business as usual
Compatibility	Some schemes allow stacking, others restrict it
Permanence mismatch	Schemes may require 30- to 100-year commitments
Admin/verification burden	More credits = more documentation and audits

Step-by-step integration strategy

Step 1 | Baseline and map opportunities using natural capital tools

Step 2 | Select compatible schemes (e.g., SFI + BNG + Carbon)

Step 3 | Structure clear legal agreements for each credit stream

Step 4 | Engage partners and buyers early (e.g., brokers, LPAs, utilities)

Integrated implementation | Credit stacking

Credit Stacking I Worked example of a stacked credit model for a constructed wetland

Case study

Project overview

Element	Details
Location	Norfolk (e.g., Broadland catchments)
Size	3 hectares (constructed wetland with buffer grassland)
Current land use	Low-grade arable land
Proposed intervention	Creation of surface-flow wetland + 10m buffer zones
Management period	30+ years (minimum requirement for most credits)

Regulatory & legal framework

Requirement	Mechanism
Planning permission	May be required for earthworks / habitat change
EPR permit	Needed for discharge to surface water
BNG registration	Register habitat bank with Natural England
Nutrient credits	50 kg N/year reduction sold to developers in the Norfolk Nutrient Mitigation Scheme
Management obligations	Minimum 30 years, ideally 80–120 years

Business model

Element	Details
Capital cost	£200,000 for design, excavation, planting
Annual management	£1000–£2000/year for inspections, mowing
Main income sources	Developer-funded credits, SFI payments
Delivery partner	Local Rivers Trust + ecology consultant
Monitoring	Water sampling, habitat surveys, photo records

Environmental outcomes

Outcome Type	Benefits Provided
Water quality	Filters agricultural runoff, reduces nitrogen & phosphorus
Biodiversity	New wetland habitat for birds, amphibians, pollinators
Carbon sequestration	Organic matter build-up in wetland soils & biomass
Flood mitigation	Slows overland flow, reduces peak discharge

Stacked funding and credit streams

Credit / Payment Type	Basis	Est. Revenue (over 30 years)
Nutrient credits	50 kg N/year reduction sold to developers in the Norfolk Nutrient Mitigation Scheme	£150,000
BNG units	3 habitat units (wetland + grassland) at £15,000 each	£45,000
SFI payment	SAM2 (buffer zones), SAM3 (low-input grassland)	£25,000
Capital grant	CS or water company co-funding (one-off)	£30,000

Total estimated revenue: approximately £250,000 over 30 years.

Summary

Category	Value
Upfront cost	£200,000
Total revenue	£250,000+ (over 30 years)
Net benefit	£50,000+
Primary credits	Nutrient, Biodiversity, SFI

Useful resources

Biodiversity Net Gain

- DEFRA | https://www.gov.uk/government/collections/biodiversity-net-gain
- DEFRA | https://www.gov.uk/government/publications/nature-markets-framework-progress-update-march-2024/nature-markets-framework-progress-update-march-2024

Carbon Codes

- Soil carbon code | https://sustainablesoils.org/soil-carbon-code/about-the-code
- UKCCC | https://ukcarboncode.org
- Woodland carbon code | https://woodlandcarboncode.org.uk

Citizen Science

- CaSTCo citizen science monitoring platforms | https://castco.org
- CEH | www.ceh.ac.uk/our-science/citizen-science/citizen-science-best-practice-guide
- Wensum citizen science group | https://castco.org/case-study/wensum-catchment

Environment Agency datasets

- Catchment Data Explorer | https://environment.data.gov.uk/catchment-planning
- Ecology & Fish Data Explorer | https://environment.data.gov.uk/ecology/explorer
- Hydrology Explorer | https://environment.data.gov.uk/hydrology/explore
- Water Quality Archive | https://environment.data.gov.uk/water-quality/view/explore

For farmers and land managers

- Rules for farmers and land managers | https://www.gov.uk/guidance/rules-for-farmers-and-land-managers
- Farming rules for water | https://www.gov.uk/government/publications/applying-the-farming-rules-for-water/applying-the-farming-rules-for-water

Useful resources | Continued…

Floodplain reconnection

- River Restoration Centre | https://www.therrc.co.uk/stage-0-floodplain-reconnection
- Environment Agency | www.gov.uk/government/publications/natural-flood-management-evidence/river-and-floodplain-management
- Knepp | https://knepp.co.uk/rewilding/river-restoration

Land use change

- British Geological Survey | https://nora.nerc.ac.uk/id/eprint/533586/1/OR22076.pdf
- Catchment based Approach | https://treehub.catchmentbasedapproach.org
- Farm Wildlife | https://farmwildlife.info/how-to-do-it/farmed-area/arable-reversion
- Natural England | https://publications.naturalengland.org.uk/publication/624404

Monitoring guidance

- Freshwater Habitats Trust | https://freshwaterhabitats.org.uk/our-work/research-and-monitoring
- Nature-based Solutions Initiative | https://nbshub.naturebasedsolutionsinitiative.org/wp-content/uploads/2024/01/Biodiversity-soil-health-metrics-user-guide.pdf
- River Restoration Centre | www.therrc.co.uk/monitoring-guidance

Nutrient Neutrality

- DEFRA | Tools and resources for calculating nutrient neutrality. Available at: https://www.gov.uk/government/collections/tools-and-resources-for-calculating-nutrient-neutrality
- Natural England | https://publications.naturalengland.org.uk/publication/5031421117988864
- Natural England | Strategic Solutions: Nutrient Neutrality. Available at: https://publications.naturalengland.org.uk/publication/6687601766694912
- Norfolk Environmental Credits | https://www.norfolkenvironmentalcredits.co.uk
- Royal haskoningDHV | Norfolk Nutrient Guidance: Nutrient Mitigation Solutions. Available at: https://www.north-norfolk.gov.uk/media/9754/ex016-norfolk-nutrient-guidance-nutrient-mitigation-solutions-updated-october-2023.pdf

Useful resources | Continued…

Natural Flood Management

- Catchment Based Approach | https://catchmentbasedapproach.org/learn/nfm-handbook-to-support-nfm-hub
- Environment Agency | https://assets.publishing.service.gov.uk/media/6036c730d3bf7f0aac939a47/Working_with_natural_processes_one_page_summaries.pdf

Nature-based Solutions

- IUCN | https://iucn.org/our-work/nature-based-solutions
- UNEP | www.unep-wcmc.org/en/nature-based-solutions
- Nature-based Solutions Initiative | https://nbshub.naturebasedsolutionsinitiative.org

Replenish Credits

- Catchment Based Approach | https://catchmentbasedapproach.org/learn/the-water-sensitive-farming-initiative-a-case-study
- Green Finance Institute | https://hive.greenfinanceinstitute.com/wp-content/uploads/2024/10/NEIRF-case-study-The-Rivers-Trust-Replenish.pdf
- The Rivers Trust Replenishment Toolbox |https://storymaps.arcgis.com/stories/70c7ce9c852c41feab4f5e5bd7d59172

Riparian restoration

- Environment Agency | www.gov.uk/government/publications/natural-flood-management-evidence/woodland-management
- Forestry Commission | https://cdn.forestresearch.gov.uk/2024/07/UKFSPG028_Riparian-woodland_web-compressed.pdf
- River Restoration Centre | https://www.therrc.co.uk/manual-river-restoration-techniques

Runoff Attenuation Features

- Catchment Based Approach | https://catchmentbasedapproach.org/learn/runoff-attenuation-features-guide
- Environment Agency | www.gov.uk/government/publications/natural-flood-management-evidence/run-off-management

Soil management practices

- Catchment Based Approach | https://aghub.catchmentbasedapproach.org
- Freshwater Habitats Trust | https://freshwaterhabitats.org.uk/projects/water-friendly-farming
- The Allerton Project | https://www.allertontrust.org.uk/research
- Westcountry Rivers Trust | https://wrt.org.uk/project/soils-and-natural-flood-management

Useful resources | Acronyms

Abbr.	In full	Abbr.	In full
AONB	Area of Outstanding Natural Beauty	NEC	Norfolk Environmental Credits
AWS	Alliance for Water Stewardship	NEIFR	Natural Environment Investment Readiness Fund
BNG	Biodiversity Net Gain	NFM	Natural Flood Management
CaBA	Catchment Based Approach	NGO	Non-governmental organisation
CSF	Catchment Sensitive Farming	NN	Nutrient Neutrality
CS	Countryside Stewardship	NVZ	Nitrate Vulnerable Zone
DTC	Demonstration Test Catchment	PES	Payments for Ecosystem Services
eDNA	Environmental DNA	RAF	Run-off Attenuation Feature
EIA	Environmental Impact Assessment	RBMP	River Basin Management Plan
ELM	Environmental Land Management Scheme	SAC	Special Area of Conservation
EPR	Environmental Permitting Regulations (2016)	SPA	Special Protection Area
ESG	Environmental, Social & Governance funds	SSSI	Site of Special Scientific Interest
FiPL	Farming in Protected Landscapes	SuDS	Sustainable Drainage Systems
HRA	Habitats Regulations Assessment	UKSPF	UK Shared Prosperity Fund
IDB	Internal Drainage Board	VWBA	Volumetric Water Benefit Accounting
KPI	Key Performance Indicator	WBC	Water Benefit Certificate
LEP	Local Enterprise Partnership	WBEP	Wendling Beck Environment Project
LLFA	Lead Local Flood Authorities	WFD	Water Framework Directive
LLP	Limited Liability Partnership	WRE	Water Resources East
LNRS	Local Nature Recovery Strategy	WEIF	Water Environment Improvement Fund
NbS	Nature-based Solution	WINEP	Water Industry National Environment Programme

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Disclaimer: all the information presented in this report is, to the best of our knowledge, accurate and up-to-date at the time of publication.

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