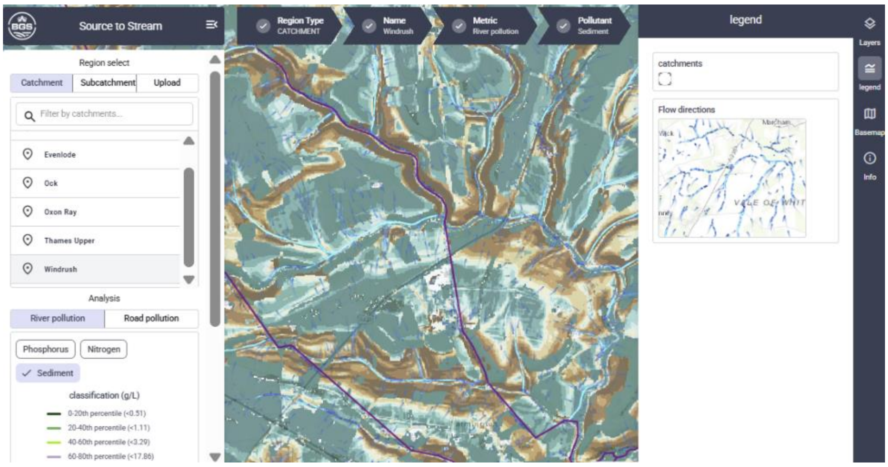
Source to Stream: technical summary

Environmental Change, Adaptation & Resilience programme

Commissioned report CR/26/046



Region Type: CATCHMENT
Name: Windrush
Metric: River pollution
Pollutant: Sediment

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL CHANGE, ADAPTATION & RESILIENCE PROGRAMME

COMMISSIONED REPORT CR/26/046

Keywords

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Source to Stream web application

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Source to Stream: technical summary

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Editor

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BRITISH GEOLOGICAL SURVEY

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Summary

The Source to Stream tool is a high-resolution, map-based application developed to support understanding of how pollutants originate within catchments, move across the landscape and potentially impact river-water quality. It integrates national datasets on terrain, land cover, soils, climate, agriculture and infrastructure to visualise the spatial distribution of key pollutants, sediment, sediment-bound phosphorus, nitrogen and road runoff, alongside the pathways by which they may be transported to rivers.

The tool applies established, empirical modelling approaches to estimate long-term average pollutant losses:

- sediment loss is calculated using the widely adopted ‘Revised Universal Soil Loss Equation’ (RUSLE)
- phosphorus loss is derived from sediment estimates combined with soil geochemistry
- nitrogen loss is estimated from atmospheric deposition and inorganic fertiliser inputs, with a representative proportion assumed to be lost via surface runoff

Road runoff pollution is characterised using an integrated pollution classification, which combines multiple pollutants into a single ranking to identify road segments with relatively higher pollution potential.

Sediment, sediment-bound phosphorus and nitrogen pollutant sources are routed across the landscape using a digital terrain model to represent surface flow pathways, enabling the tool to highlight both where pollution is generated and how it may reach rivers. Indicative pollutant concentrations in rivers are also visualised by combining modelled pollutant loads with estimates of surface runoff, providing a proxy representation of potential in-stream impacts.

The Source to Stream tool is designed as a screening and exploratory platform. It supports interpretation of spatial patterns, identification of pollution hotspots and evidence-based discussion of catchment pressures and potential interventions. However, it relies on simplified assumptions, including:

- the use of long-term average conditions
- representation of only surface transport pathways
- the assumption that all generated pollutants are delivered to rivers

As a result, outputs represent relative patterns and potential risks rather than absolute or observed values. They are not intended for regulatory, compliance or site-specific decision making.

Overall, the tool provides a coherent and accessible framework for integrating multiple sources of diffuse pollution into catchment-scale analysis, supporting improved understanding of environmental processes and helping to inform prioritisation of further investigation and management actions.

1 The Source to Stream tool

1.1 OVERVIEW OF THE TOOL

The Source to Stream tool has been developed to provide an accessible, high-resolution, map-based tool that helps users explore:

- where sediment, nutrient and road runoff pollution may originate within a catchment
- how pollution may be routed to rivers
- how these patterns relate to land use, terrain and other environmental features

More specifically, it aims to:

- identify and visualise potential landscape sources of sediment, phosphorus, nitrogen and pollution from roads within a river catchment
- support understanding of how landscape features influence pollution patterns
- enable exploration of flow pathways across the landscape using terrain-derived routing
- integrate multiple environmental datasets to support interpretation of pollution risks and drivers
- provide an accessible, map-based platform for exploring catchment pressures and processes
- support evidence-based discussions around catchment management and intervention targeting
- facilitate hypothesis generation rather than prediction by making assumptions and limitations explicit

Through the visualisation and interrogation of the displayed data, the tool supports exploration of:

- potential sources of pollution derived from roads and across rural landscapes
- surface pathways along which pollution could be transported to rivers
- potential contribution to the pollutant concentrations in rivers from the pollutants generated across rural and agricultural areas

The sources of pollution include:

- sediment due to soil erosion
- phosphorus bound to sediment
- nitrogen derived from two sources:
  - application of inorganic fertiliser
  - deposition of atmospheric nitrogen
- pollution in runoff from roads (represented by the 'Integrated pollutant classification' used in the BGS Road Pollution Solutions Tool[1])

1.2 VISUALISATION OF THE DATA

Rates of sediment, sediment-bound phosphorus and nitrogen loss across the landscape are visualised on a grid of 10 × 10 m pixels. Roads are coloured according to the 'Integrated pollutant classification' (Visanji, 2023):

- high priority
- moderate priority
- lower priority
- lowest priority
- unknown

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[1] https://mapapps.bgs.ac.uk/road-pollution-solutions/

The potential contribution of sediment, sediment-bound phosphorus and nitrogen (from the two specified sources) to the pollution in rivers is represented as a concentration in water along sections of rivers.

1.3 ASSUMPTIONS AND LIMITATIONS

1.3.1 Assumptions

1.3.1.1 Sources

- The losses of pollutants from across an area are estimated using simple, empirical methods rather than detailed, physically based models calibrated against observations of pollutant concentrations in rivers
- All estimates represent long-term average conditions: the calculation methods do not consider temporal variability in sources, pathways or receptors
- These empirical methods are based on accepted and widely applied approaches reported in the peer-reviewed, scientific literature
- Inputs of nitrogen from organic sources are not considered; potential sources therefore excluded include:
    - animal manures and slurries
    - organic fertilisers and soil amendments: for example, compost; sewage sludge; green waste compost; digestate
    - crop residues and plant litter
    - soil-derived organic nitrogen
    - agriculturally linked non-agricultural sources: for example, septic tanks; rural wastewater
- Land cover and crop types are based on static maps for specific years — land cover change and crop rotations are not considered
- Land cover, crop types, soils and road classes are assumed to behave uniformly within each mapped category, despite known within-class variability
- Land management practices (tillage; stocking densities; buffer strips, etc.) are not explicitly represented
- The classification of roads based on their pollutants loads is only provided for motorways, A and B roads; pollution from ‘minor roads’ is not estimated
- Estimated losses are assumed to reflect current landscape conditions, rather than the influence of legacy sediment or nutrient stores
- Other point or quasi-point sources (for example, waste-water treatment works) are not considered

1.3.1.2 Pathways

- Pollutants are transported downhill in surface water.
    - downhill directions are calculated using a gridded, 10 m digital terrain model (DTM)
    - artificial drainage and engineering are not represented: features such as field drains, ditches, culverts, embankments and flood defences are not explicitly included in flow routing
- Pollutant transport to rivers via subsurface (groundwater) pathways is not considered
- Hydrological connectivity between source areas and rivers is assumed to be static in time and does not vary with antecedent wetness, flow conditions or season

1.3.1.3 Receptors

- Estimated concentrations of sediment, sediment-bound phosphorus and nitrogen in rivers assume that all pollutants lost from the landscape are delivered to the river network with no attenuation, storage or in-stream processing
- Runoff is estimated using a simple soil moisture accounting model (see Section 5); this provides an indicative representation of runoff generation rather than event-scale dynamics

1.3.2 Limitations

- The tool is designed for screening and exploratory assessment, rather than for predicting detailed, site-specific decision making
- Uncertainty in input datasets and empirical coefficients is not explicitly quantified
- Model outputs do not represent observed or measured pollutant loads or concentrations and should not be interpreted as such
- Results represent relative spatial patterns and potential risk, rather than absolute quantities or compliance with environmental standards
- Temporal dynamics, including seasonal variation, storm events and management timing, are not represented
- The assumption of full delivery of pollutants to rivers means that absolute river impacts are likely overestimated in many settings
- Subsurface pathways, including groundwater transport and artificial drainage, are not explicitly represented
- Flow pathways derived from topography may misrepresent real hydrological connectivity, particularly in low-relief, engineered or urban landscapes
- Uncertainty associated with empirical methods, parameter values and input datasets is not quantified or communicated spatially
- Differences between locations may reflect data availability or model assumptions rather than true differences in pollution pressure
- The tool does not assess the effectiveness, feasibility or cost of mitigation measures
- Outputs should not be used for regulatory enforcement, site-specific design or attribution of responsibility

1.4 INPUT DATA

The input data used in the development of Source To Steam sediment, sediment-bound phosphorus, nitrogen, road runoff pollution and river water concentration datasets is tabulated in each of the related sections.

2 Sediment loss across the landscape

Quantifying soil erosion and associated sediment loss at the catchment scale is an essential component of understanding diffuse pollution pressures on rivers and downstream environments. A range of empirical and process-based models have been developed to estimate soil erosion, varying in complexity, data requirements and spatial applicability. For regional to national-scale assessments, models that balance conceptual robustness with practical implementation considerations are commonly favoured, particularly where long-term average conditions rather than individual erosion events are of primary interest.

Sediment loss rates in the Source to Stream tool have been estimated using the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), a well-established empirical modelling framework that has been widely applied in both research and operational contexts. RUSLE has been extensively used across Europe to provide spatially distributed assessments of soil erosion driven by rainfall and land management, including continental-scale applications such as that of Panagos et al. (2015a), which produces harmonised estimates of soil loss across Europe. Its widespread adoption reflects both the physical interpretability of its component factors and its suitability for application using nationally available climatic, land-cover and soil datasets. These characteristics make RUSLE an appropriate and proportionate tool for estimating long-term average sediment loss across UK catchments.

The methodology underpinning RUSLE is described in Section 2.1 and a summary of the estimated rates across the upper River Thames catchment, UK, is provided in Section 2.2. The datasets used in its application within Source to Stream are listed in Table 1.

Table 1 Data used in the calculation of sediment loss.

Dataset	Source and licence type
Land surface elevation: Environment Agency LIDAR Composite DTM 10 m 2022	https://environment.data.gov.uk/dataset/ce8fe7e7-bed0-4889-8825-19b042e128d2 (Open Government Licence)
Land-cover type: WorldCover 2021 Map v200 (10 m)	https://esa-worldcover.org/en/data-access (CC BY 4.0 licence)
Soil types: BGS Soil Parent Material Model	https://www.bgs.ac.uk/datasets/soil-parent-material-model/ (BGS licence)
Rainfall data: Environment Agency 15-minute rainfall	https://environment.data.gov.uk/flood-monitoring/doc/rainfall (Open Government Licence)

2.1 REVISED UNIVERSAL SOIL LOSS EQUATION

Developed by the United States Department for Agriculture (Renard et al., 1997), the Revised Universal Soil Loss Equation (RUSLE) is an empirical model designed to estimate long-term average annual soil loss caused by rainfall-induced erosion. It does not predict individual erosion events but provides estimated of long-term, mean erosion rates that are representative of prevailing climate and land management.

RUSLE represents an update to the original Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), incorporating advances in process understanding, improved datasets and expanded applicability across a wider range of climatic, land-use and management conditions. Despite its simplicity, RUSLE has become one of the most widely applied tools in soil conservation, land-use planning and environmental assessment.

RUSLE builds on the central hypothesis of USLE: that average soil loss can be estimated as the multiplicative combination of independent factors representing rainfall erosivity, soil erodibility, topography, land cover and management, and conservation practices. The model is expressed as:

$$A = R \times K \times LS \times C \times P \qquad \text{Equation 1}$$

Where:

- A is the predicted average annual soil loss per unit area, typically expressed in tonnes per hectare per year
- R is the rainfall-runoff erosivity factor
- K is the soil erodibility factor
- LS is the slope length and degree factor
- C is the land-cover management factor
- P is the conservation practice factor

Each factor is dimensionless or scaled such that the product yields a soil-loss estimate consistent with measured erosion under standard plot conditions.

2.1.1 *R* factor

The rainfall-runoff erosivity factor (*R*) describes how rainfall patterns influence the erosion of soil by water. It expresses the potential of precipitation and the resulting overland flow to cause erosion, based on the combined effects of rainfall energy and intensity, and their ability to mobilise and move soil material. Because it reflects underlying climatic conditions, especially how often intense storms occur and how severe they are, *R* varies across space. Within soil erosion modelling, the *R* factor represents the climatic control on erosion processes and relates average, long-term soil loss to prevailing rainfall regimes rather than to individual rainfall events.

Panagos et al. (2015b) describes the calculation of the *R* factor, on which the following summary is based. It is calculated by multiplying the kinetic energy and the maximum rainfall intensity during a period of 30 minutes of each rainfall event. It accumulates the rainfall erosivity of individual rainstorm events and averages this value over multiple years.

$$R = \frac{1}{n} \sum_{j-1}^{n} \sum_{k-1}^{mj} (EI_{30})_k \qquad \text{Equation 2}$$

Where:

- R is the average annual rainfall erosivity (MJ mm ha^{-1} hr^{-1} yr^{-1})
- n is the number of years
- m_j is the number of erosive rainfall events for each year
- EI_{30} is the rainfall erosivity index of a single event k

The rainfall erosivity index EI_{30} (MJ mm ha^{-1} hr^{-1}) is calculated as:

$$EI_{30} = \left(\sum_{r=1}^{0} e_r \, v_r \right) I_{30} \qquad \text{Equation 3}$$

Where:

- e_r is the unit rainfall energy (MJ ha^{-1} mm^{-1}) during a time period r
- v_r is the rainfall (mm) during a time period r
- I_{30} is the maximum rainfall intensity during a 30-minute period of a rainfall event (mm hr^{-1})

The unit rainfall energy, e_r, for each time interval is given by:

$$e_r = 0.29[1 - 0.72\ \exp(-0.05\, i_r)]$$

Where:

- i_r is the rainfall intensity (mm hr^{-1}) during the time interval

The *R* factor calculation requires identification of erosive rainfall events m_j for each rain gauge record within an area.

There are three criteria that identify an erosive event, which are specified by Renard et al. (1997) as:

- the cumulative rainfall of an event is greater than 12.7 mm
- the event has at least one peak that is greater than 6.35 mm during a period of 15 minutes or 12.7 mm during a period of 30 minutes
- a rainfall accumulation of less than 1.27 mm during a period of six hours splits a longer storm period into two storms

2.1.1.1 RAINFALL DATA

Fifteen-minute rainfall data for 41 rain gauges within and around the upper Thames catchment were obtained through the API provided by the Environment Agency (2025) and used to calculate the *R* factor at the gauge locations. These *R* factor values were then interpolated across the upper Thames catchment using ordinary kriging. The *R* factor values across the catchment vary between 220 and 470 MJ mm ha^{-1} hr^{-1} yr^{-1}, which are consistent with those of Panagos et al. (2015b), which calculates *R* values on a 1 km grid across Europe. This European study, which used about 30 rainfall records across Britain, calculated *R* values between 210 and 510 MJ mm ha^{-1} hr^{-1} yr^{-1} across the upper Thames catchment.

2.1.2 *K* factor

The *K* factor expresses the potential of a soil to erode and is related to soil properties such as organic matter content, soil texture, soil structure and permeability. Panagos et al. (2014) presents a soil erodibility map for Europe at a 500 m resolution and, based on the work of Wischmeier and Smith (1978) and Renard et al. (1997), defines the calculation of *K* as:

$$K = \left[\left(2.1 \times 10^{-4} M^{1.14}(12 - OM) + 3.25(s - 2) + 2.5(p - 3)\right) / 100\right] \times 0.1317 \qquad \text{Equation 4}$$

Where:

- M is the textural factor: $M = \left(m_{silt} + m_{vfs}\right) \times (100 - m_c)$
- m_c [%] is the clay fraction content (less than 0.002 mm)
- m_{silt} [%] is the silt fraction content (0.002 to 0.05 mm)
- m_{vfs} [%] is the very fine sand fraction (0.05 to 0.1 mm)
- OM [%] the organic matter content
- s the soil structure class (Table 2)
- p the permeability class (Table 3)

The values of the parameters m_c, m_{silt}, m_{vfs}, OM, s and p in Equation 4 were derived using information on soils from the BGS Soil Parent Material Model (SPMM) (Lawley, 2021), which details the distribution of physiochemical properties of the weathered and unweathered soil parent materials of Great Britain. It provides information on:

- material texture
- colour
- structure
- mineralogy
- lithology
- carbonate content
- genetic origin

Textural classes for each soil parent material were obtained from the SPMM (Table 1). As the texture classes defined within the SPMM do not map directly onto the standard UK soil texture triangle, percentage contents of sand, silt and clay were assigned to each SPMM class using best-estimate relationships between the two classification schemes. Once representative particle-size distributions had been defined, they were used to calculate the texture-related terms in the *K* factor equation (m_c; m_{silt}; m_{vfs}). RUSLE requires the proportion of very fine sand (typically 0.05 to 0.1 mm), which is not routinely reported in soil datasets. Following Panagos et al. (2014), the very fine sand fraction was therefore assumed to represent 20 per cent of the total sand content.

The soil structure was taken from the European Soil Database (King et al., 1994), following the approach adopted by Panagos et al. (2014). This parameter reflects the degree of soil aggregation and structural stability, which influences porosity, infiltration capacity and susceptibility to erosion. Due to the limited availability of the spatially resolved data required to distinguish between structural classes at the catchment scale, a uniform value of $s = 2$ was applied across the study area. This corresponds to a fine, granular soil structure with aggregate diameters of approximately 2 to 5 mm, classified as 'normal' within the European Soil Database. This assignment is consistent with the pedotransfer functions developed by Van Ranst et al. (1995). In addition, soil organic matter content was represented using a constant average value of 3.05 pr cent in the *K* factor calculation.

Soil permeability was assigned on the basis of texture class (Table 3), again following the methodology of Panagos et al. (2014). Where particle-size percentages were available, bulk density was estimated using standard empirical relationships linking soil texture and density, as documented in published soil property datasets.

Table 2 Soil structure classes. After Panagos et al. (2014).

Structure class (s)	Particle size (mm)
1 Very fine granular	1–2
2 Fine granular	2–5
3 Medium or coarse granular	5–10
4 Blocky, platy or massive	>10

Table 3 Permeability structure classes. After Panagos et al. (2014).

Permeability class (p)	Texture
1 Fast and very fast	Sand
2 Moderate fast	Loamy sand; sandy loam
3 Moderate	Loam; silty loam
4 Moderate slow	Sandy clay loam; clay loam
5 Slow	Silty clay loam; sand clay
6 Very slow	Silty clay; clay

2.1.3 *LS* factor

The *LS* factor represents the effect of topography on soil erosion by combining slope length (*L*) and slope steepness (*S*) into a single term. It quantifies how erosion potential increases with longer flow paths and steeper slopes, reflecting the greater runoff volume and velocity that enhance detachment and transport of soil.

$$LS = (L/22.13)^m \, (0.065 + 0.045\, S + 0.0065\, S^2) \qquad \text{Equation 5}$$

Where:

- L is the slope length in metres
- S is the slope steepness (%)
- m is an exponent (see Table 4)

The exponent m reflects the relative importance of rill versus interrill erosion and increases with slope steepness. In spatial applications, *L* is not measured as a single uniform hillslope. Instead, it is estimated from a gridded DTM using the number of upslope cells that drain into it, n, and the grid cell size Δx:

$$L = n \cdot \Delta x \qquad \text{Equation 6}$$

This allows the *L* factor to vary continuously across the landscape and adapt to complex topography.

The DTM used is the Environment Agency LiDAR Composite DTM 10 m 2022 (Table 1).

Table 4 Values of the exponent m in the calculation of *LS*. After Wischmeier and Smith (1978).

m	Slope (%)
0.5	>5
0.4	3–5
0.3	1–3
0.2	<1

2.1.4 *C* factor

The cover management factor (*C*) represents the effect of vegetation cover, crop type and land-management practices on soil erosion by water. It is defined as the ratio of soil loss from land under a specific cover and management regime to soil loss from continuously bare soil under otherwise identical conditions. The *C* factor captures the protective role of plant canopy, surface residues and soil-surface conditions in reducing rainfall energy and runoff erosivity and is sensitive to land use and seasonal vegetation dynamics.

C is commonly assigned using land-cover-specific values or derived from vegetation indices, and typically varies over several orders of magnitude between well-protected surfaces, such as forest or permanent grassland, and poorly protected, bare or intensively cultivated soils (Wischmeier and Smith, 1978; Renard et al., 1997). Land-cover classes are assigned a *C* value based on the classification of Panagos et al. (2015c), which estimates country-specific *C* values across Europe. Those for the UK are listed in Table 5.

The definition of land cover is based on the WorldCover 10 m 2021 v200 global land-cover dataset (Zanaga et al., 2022) produced by the European Space Agency. This provides a consistent, high-resolution (10 m) classification of the Earth's land surface for the year 2021. Table 6 shows the *C* values assigned to the 11 WorldCover classes.

Table 5 *C* values for the UK. After Panagos et al. (2015c).

Land cover type	*C* factor
Pastures	0.0867
Complex cultivation	0.1201
Agriculture and natural areas	0.1068
Forests	0.0011
Grasslands	0.0319
Transitional woodland and shrub	0.0183
Sparse vegetation	0.0183

Table 6 ESA WorldCover classes and associated *C* values.

Land cover class	C factor
Tree cover	0.0011
Shrubland	0.0183
Grassland	0.0867
Cropland	0.1068
Built-up	0
Bare/sparse vegetation	0.1825
Snow and ice	0
Permanent water bodies	0
Herbaceous wetland	0
Mangroves	Not applicable
Moss and lichen	Not applicable

2.1.5 *P* factor

The support practice factor (*P*) represents the effect of soil conservation practices that reduce the erosive power of runoff by modifying its flow direction, velocity or hydraulic connectivity. It is defined as the ratio of soil loss from land managed with a specific support practice to soil loss from land cultivated along the slope under otherwise identical conditions. The *P* factor captures the influence of practices such as contour farming, strip cropping, terracing and bunding, which act primarily by reducing runoff length and slope gradient or by interrupting flow paths.

P values used in the calculation of Equation 4 are based on those of Wischmeier and Smith (1978) as summarised by Sampath and Radhakrishnan (2023) (Table 7).

Table 7 *P* factor values.

Type of land	Slope(%)	*P* factor
Agricultural	0–5	0.1
	5–10	0.12
	10–20	0.14
	20–30	0.19
	30–50	0.25
	50–100	0.33
Non-agricultural	All	1.00

2.2 SUMMARY OF SEDIMENT LOSS ESTIMATES

The distribution of sediment loss rates calculated for all of the 10 m pixels across the upper Thames area is plotted in Figure 1.

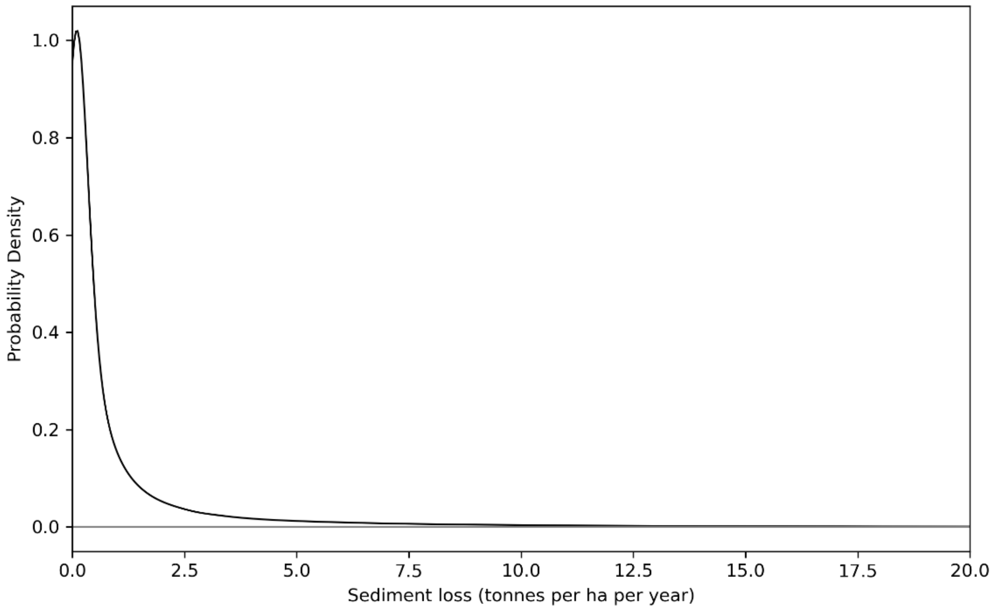

Figure 1 Distribution of estimated sediment loss across the upper River Thames catchment. This is the catchment above the Day’s Weir gauging station near Dorchester on Thames. BGS © UKRI 2026.

3 Sediment-bound phosphorus loss across the landscape

The datasets used in the estimation of sediment-bound phosphorus loss across the landscape are listed in Table 8.

Table 8 Data used in the calculation of sediment-bound phosphorus loss.

Dataset	Source and licence type
Source to Stream sediment loss	https://sourcetostream.bgs.ac.uk
Topsoil phosphorus: UK topsoil geochemistry dataset phosphorus P_2O_5	https://www.ukso.org/static-maps/uk-topsoil-geochemistry.html (Open Government Licence)

The sediment-bound phosphorus dataset provides an estimate of the phosphorus embedded in the soils eroded from the landscape. This was calculated by combining data on phosphorus concentrations in soil from the rural and urban topsoil geochemical atlas (Everett et al., 2023) with the estimates of sediment loss described in Section 2.

The geochemical atlas data is combined with other datasets to form the UK topsoil geochemistry dataset, which can be accessed via the UK Soil Observatory viewer[2].

The phosphorus data in the geochemical atlas is provided as concentrations of phosphorus pentoxide (P_2O_5) with units in w% (10^4 mg kg^{-1}). The loss of phosphorus in sediment within each 10 × 10 m pixel of the resulting raster dataset is calculated as:

$$P_{sediment} = \frac{0.4364 \times 10^4}{100\,n} P_2O_5 \cdot S \qquad \text{Equation 7}$$

Where:

- $P_{sediment}$ is the sediment-bound phosphorus loss for each 10 m pixel of the raster dataset (g day^{-1})
- P_2O_5 is the soil concentration (w%, equivalent to 10^4 mg kg^{-1})
- S is the sediment loss (tonnes ha^{-1} year^{-1})
- n is the number of days in a year
- 0.4364 converts the mass of P_2O_5 to the mass of phosphorus

The distribution of sediment-bound phosphorus loss calculated for all of the 10 m pixels across the upper Thames area is plotted in Figure 2.

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[2] https://mapapps2.bgs.ac.uk/ukso/home.html

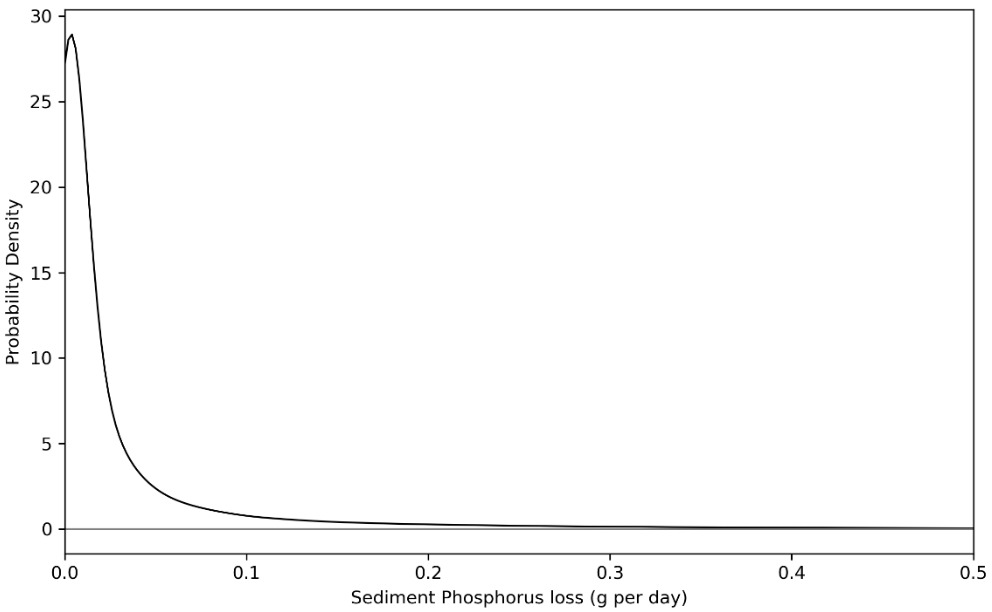


Figure 2 Distribution of estimated sediment-bound phosphorus loss across the upper River Thames catchment. This is the catchment above the Day's Weir gauging station near Dorchester on Thames. BGS © UKRI 2026.

4 Nitrogen loss across the landscape

As described in Section 1, Source to Stream provides estimates of the loss of nitrogen derived from two sources:

- the deposition of atmospheric nitrogen
- the application of inorganic fertiliser

Losses from other sources of nitrogen were not considered. Specifically, nitrogen inputs from livestock manure were not calculated. This is because manure-derived nitrogen typically undergoes gradual mineralisation and release over extended timescales, resulting in a comparatively diffuse and lower-intensity contribution to short-term losses in runoff. In addition, the spatial and temporal variability in manure application practices, combined with the absence of consistent livestock data, would introduce substantial uncertainty into the model.

Given the study's focus on landscape-scale patterns driven by constrained inputs, this simplification was considered appropriate. Consequently, the total input of nitrogen, N_{input}, is defined as:

$$N_{input} = N_{atmospheric} + N_{inorganic}$$

Where:

- $N_{atmospheric}$ is the input from atmospheric deposition
- $N_{inorganic}$ is the input for fertiliser application

The datasets used to estimate nitrogen inputs across the landscape are listed in Table 9.

Table 9 Data used in the calculation of nitrogen inputs.

Dataset	Source
Sulphur and nitrogen atmospheric Concentration Based Estimated Deposition (CBED) data for the UK, 2020–22	https://catalogue.ceh.ac.uk/documents/d356bddc-fd06-466a-a206-639711bba7f2 (Open Government Licence)
Crop cover: crop map of England (CROME) 2020	https://www.data.gov.uk/dataset/be5d88c9-acfb-4052-bf6b-ee9a416cfe60/crop-map-of-england-crome-2020 (Open Government Licence)
British survey of fertiliser practice dataset	https://www.data.gov.uk/dataset/ca60d8f9-a9ed-4010-92ac-39d2d7c72cd8/british_survey_of_fertiliser_practice (Open Government Licence)

4.1.1 Atmospheric deposition of nitrogen

Total atmospheric nitrogen deposition was calculated as the sum of oxidised (NO_y) and reduced (NH_x) nitrogen components. In the CBED dataset (Levy et al., 2024), oxidised nitrogen comprises species such as:

- nitrogen dioxide (NO_2)
- nitric acid (HNO_3)
- nitrate (NO_3^-)

Reduced nitrogen includes:

- ammonia (NH_3)
- ammonium (NH_4^+)

These components are estimated separately for both wet deposition (derived from precipitation chemistry and rainfall data) and dry deposition (calculated using measured or modelled air concentrations combined with deposition velocities). The resulting deposition fields are spatially resolved at 1 × 1 km grid resolution and expressed in units of nitrogen flux (for example, kg N ha^{-1} yr^{-1}). Summing the oxidised and reduced fractions therefore provides the estimate of total atmospheric nitrogen deposition to the land surface.

4.1.2 Application of nitrogen as inorganic fertiliser

To estimate of the amount of nitrogen applied to arable land, information was combined from two sources:

- Crop map of England (CROME) 2020: a high-resolution, nationwide, spatial dataset produced by the Rural Payments Agency that classifies land cover and crop types across England for the 2020 growing season
  - represents England as approximately 32 million hexagonal cells, identifying over 15 main crop types alongside grassland and non-agricultural land covers such as woodland, water and fallow land
  - crop classifications were generated using supervised Random Forest models applied to combined Sentinel-1 radar and Sentinel-2 optical satellite imagery acquired between January and September 2020, with quality assurance conducted through field inspection data and visual validation
- British Survey of Fertiliser Practice (BSFP) dataset: this provides nationally representative annual estimates of inorganic fertiliser application rates in Great Britain, reported primarily for nitrogen (N), phosphate (P_2O_5) and potash (K_2O)
  - application rates are reported by crop type and land use, based on field-level data collected from a stratified sample of farms each year (Figure 3)

The most recent fertiliser data (2024) was used to represent inorganic nitrogen inputs for the principal crops (winter wheat; spring barley; winter barley; maincrop potatoes; oilseed rape; sugar beet) while an average application rate was applied to all other crop types.

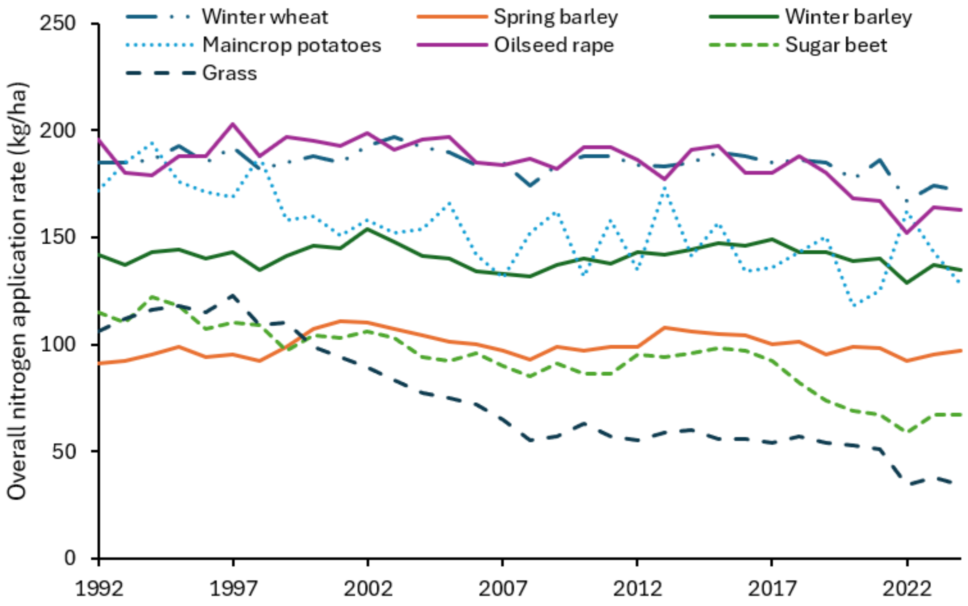


Figure 3 Overall application rate (kg/ha) on major crops, Great Britain 1992 to 2024. Data from BSFP dataset. BGS © UKRI 2026.

4.1.3 Loss of nitrogen in runoff

We estimated the loss of nitrogen across the landscape within surface runoff (the component of runoff that does not travel through the groundwater system to form river baseflow). Losses of nitrogen to groundwater and transport via the subsurface were not considered. We assumed that nitrogen losses are derived primarily from nitrate, the most mobile form of nitrogen in soils, as it remains largely in solution and does not readily bind to soil particles, making it more susceptible to transport via runoff.

Empirical evidence on nitrogen losses via surface runoff expressed as a proportion of applied nitrogen is relatively limited, with many studies instead reporting concentrations in runoff. Available studies indicate a wide range of loss fractions depending on soil type, land management, rainfall intensity and experimental conditions. Controlled rainfall simulation studies report losses ranging from less than 1 per cent of applied nitrogen (Dunigan et al., 1976) to approximately 5 per cent (Gascho et al., 1998). Field and review studies suggest somewhat higher ranges under certain conditions, with Sharpley et al. (1987) reporting losses of approximately 3 to 9 per cent of applied nitrogen and Garwood and Ryden (1986) reporting values of 2 to 10 per cent in managed grassland systems. These higher-end estimates are often associated with intensive management and conditions conducive to runoff generation.

Importantly, the literature consistently shows that nitrogen losses increase with application rates and hydrological connectivity. Given this variability and recognising that the upper Thames study area comprises a mixed agricultural landscape under typical UK management rather than extreme conditions, a value of 2 per cent was selected as a conservative and representative estimate.

Figure 4 shows a histogram of estimated nitrogen loss values for all of the 10 m pixels across the upper Thames area, assuming that 2 per cent of the nitrogen input is lost in surface runoff. The discontinuous nature of the plot results from the classification of the crops across the area into seven types shown in Figure 3.

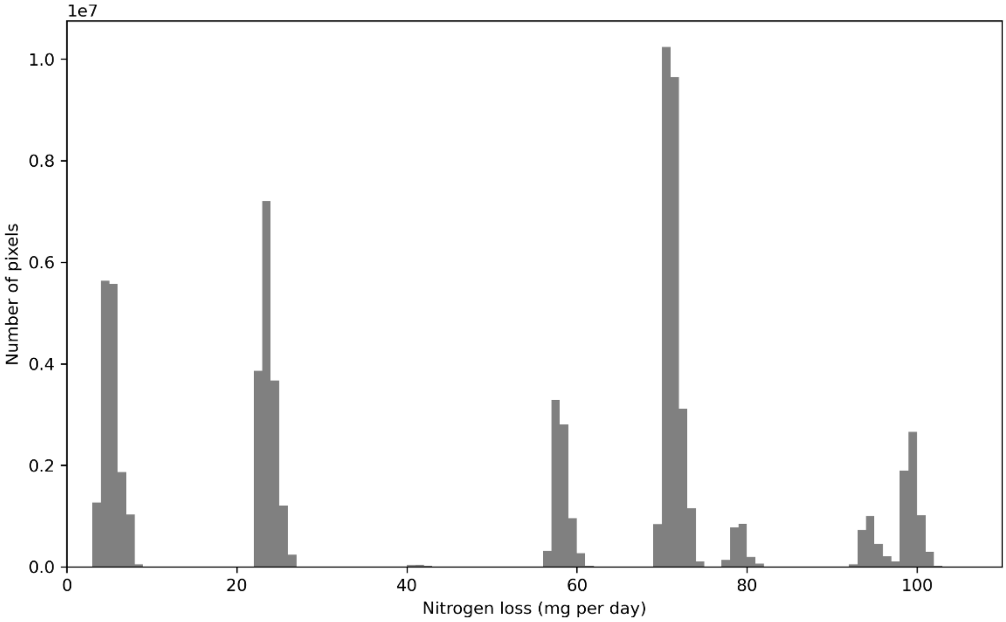
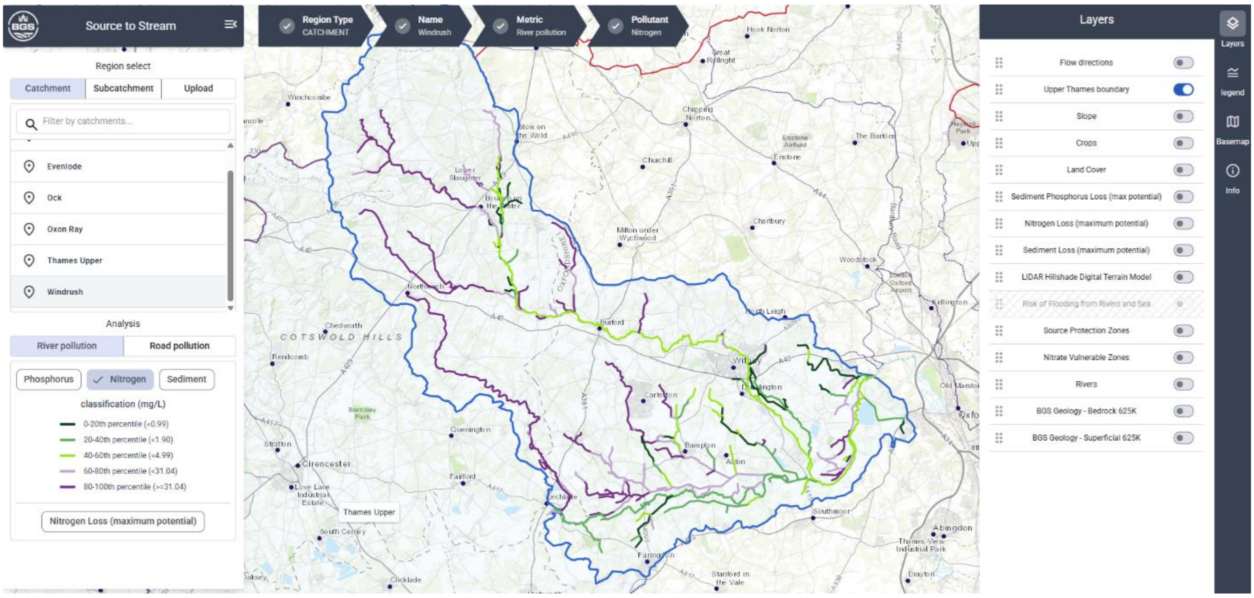


Figure 4 Histogram of estimated nitrogen loss across the upper River Thames catchment. This is the catchment above the Day’s Weir gauging station near Dorchester on Thames. BGS © UKRI 2026.

5 River-water pollutant concentrations

The Source to Stream tool visualises a concentration of the three pollutants (sediment; sediment-bound phosphorus; nitrogen) in river water. These values are calculated assuming that all pollution generated across the landscape arrives to rivers. This is a major assumption, which in reality will not be the case, so the visualised concentrations must be considered as an (uncertain) proxy for the maximum quantity of the pollutants in river water. Furthermore, pathways from pollutant source areas (pixels) to river reaches are derived from the DTM, which is also a simple representation of the transport of surface runoff to rivers. Pollutants are assumed to be transported to rivers along the direction of maximum downhill slope. The DTM used is the Environment Agency LIDAR Composite DTM 10 m 2022 (Table 1).

To calculate river-water concentration, mean runoff across the area is routed to rivers over the DTM. Transport of pollutants to rivers via groundwater (that is, arriving in the baseflow component of river flow) is not considered. We use the model of Mansour et al. (2018), subsequently updated by Bianchi et al. (2024), to obtain mean surface runoff rates across the upper Thames catchment. As for the pollutants, surface runoff is routed to rivers along the direction of maximum downhill slope. For each pixel along the river, the accumulated pollutant load is divided by the accumulated runoff to derive a concentration in the river. Average concentrations along sections of the rivers, up to around 1 km, are visualised in the application as shown in Figure 5.



Region Type: CATCHMENT
Name: Windrush
Metric: River pollution
Pollutant: Nitrogen

Figure 5 Example visualisation of the concentration of nitrogen in river water under the assumptions described in Section 5. Contains OS data © Crown copyright [2026]. BGS © UKRI 2026.

6 Integrated road runoff pollution classification

The potential contribution of roads to river pollution is represented in the Source to Stream tool using an integrated pollution classification (IPC), adapted from the BGS Road Pollution Solutions tool[3]. This approach provides a simple, intuitive way to identify and compare sections along major roads (motorways, A and B roads) according to their relative pollution risk, while still being grounded in underlying estimates of pollutant generation and transport.

The classification is derived from modelled concentrations of multiple pollutants associated with road runoff. These pollutants include particulate matter (total suspended solids) and a range of contaminants linked to vehicle activity, such as metals and hydrocarbons (for example, zinc; copper; cadmium; polycyclic aromatic hydrocarbons). Concentrations are estimated based on a combination of traffic volume and composition, pollutant emission rates, rainfall and contributing road surface area, which together determine the mass of pollutants deposited on road surfaces and mobilised during runoff events (Visanji, 2023).

For each pollutant, modelled concentrations are compared across all road sections and ranked from highest to lowest. These individual rankings are then combined into a single, integrated score that reflects the overall pollution potential of each road segment. This process ensures that the classification captures multiple dimensions of road runoff pollution, rather than focusing on any single contaminant.

The resulting scores are grouped into four priority classes, representing relative levels of pollution risk within the mapped road network:

- high (approx. top 5 per cent): road sections with the greatest potential contribution to pollution
- moderate (approx. 6 to 15 per cent)
- lower (approx. 16 to 40 per cent)
- lowest (remaining roads)

The approach is intentionally comparative; it highlights where pollution risks are likely to be greatest relative to other roads in the study area, rather than providing absolute measures of environmental impact.

It is important to note that, consistent with the wider Source to Stream framework, the IPC is based on modelled estimates of pollutant generation at the road surface, rather than direct measurements or fully coupled hydrological water quality simulations. The classification therefore represents pollution potential at source and does not explicitly account for dilution, attenuation or transformations that may occur during transport through drainage networks and receiving waters.

Despite these limitations, the IPC provides a robust and accessible means of incorporating road runoff into catchment-scale assessments. By combining multiple pollutants into a single, interpretable metric, it supports screening, prioritisation and communication of road-related pollution risks, and can help guide further investigation and the targeting of mitigation measures within the wider Source to Stream framework.

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[3] https://mapapps.bgs.ac.uk/road-pollution-solutions/

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