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DATA ARTICLE

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Spatially consistent physical characteristics of UK rivers: 1-km data

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Abstract

The physical river characteristics datasets described here provide spatially consistent information to support hydrological and inundation modelling at a 1 km × 1 km resolution across the United Kingdom, on the British National Grid. The datasets of physical river characteristics provide gridded datasets (outflow drainage directions, catchment areas, widths of bankfull rivers and depths of bankfull rivers) and a comma-separated table of NRFA (National River Flow Archive) gauging station locations. These datasets are derived from a range of sources: outflow drainage directions, catchment area and bankfull river widths are derived from existing higher resolution datasets, whereas bankfull river depths were harder to source and instead are derived from sparse historical measurements. The new gridded datasets provide a derived value for each UK land cell on the British National Grid (BNG). The comma-separated NRFA gauging station locations table provides the most appropriate locations of 1,499 river flow gauging stations on the 1 km resolution grids, together with the approximate error in the 1 km × 1 km gridded delineation of the upstream catchment area. This article explains how UK-wide 1-km grids of these variables were estimated, their format and how to use them. The data are available from the Environmental Information Data Centre (EIDC).

KEYWORDS

drainage directions, hydrological modelling, river depth, river width

Dataset

Identifier: https://doi.org/10.5285/8df65124-68e9-4c68-8659-1c6b82c735e9

Creator: UK Centre for Ecology and Hydrology (Davies, H.N.; Rameshwaran, P.; Bell, V.A)

Dataset correspondence: Helen N Davies (hnd@ceh.ac.uk)

Title: Gridded (1 km) physical river characteristics for the UK v2

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Resource type: Metadata document

Version: 1.0

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1 | INTRODUCTION

Hydro-JULES is a Natural Environment Research Council (NERC)-funded research programme which aims to build a three-dimensional community model of the terrestrial water cycle to underpin hydrological research in the United Kingdom. Hydro-JULES is delivered by the UK Centre for Ecology and Hydrology (UKCEH) in partnership with the British Geological Survey (BGS) and National Centre for Atmospheric Science (NCAS). Part of this programme aims to provide a consistent suite of datasets for hydrological and flood-inundation modelling of the United Kingdom at a 1 km × 1 km resolution, on the British National Grid (BNG). Gridded datasets included, and presented here, are outflow drainage directions, catchment areas, bankfull river widths and bankfull river depths. Here, 'bankfull' width and depth represent the river dimensions that correspond with the maximum discharge that a river can carry without flooding. We also provide a linked dataset of UK flow gauging station locations to enable users of the gridded data to compare flow estimates from 1-km gridded hydrological models with observations.

A range of outflow drainage direction and catchment area datasets are already freely available, for example, Hydro1k (USGS, 2002), MERIT Hydro (Yamazaki et al., 2019), HydroSHEDS (Lehner et al., 2008), the dominant river tracing (DRT) products (Wu et al., 2011, 2012) and code developed by Yan et al. (2019). These global datasets are widely used to support hydrological modelling (Budhathoki et al., 2021; Hou et al., 2022; Yamazaki et al., 2011), but they also provide information required for the derivation of river widths and depths using power-law relationships with river characteristics. Leopold and Maddock (1953) developed an approach for estimating river width, depth and velocity by assuming a dependence on a power function of discharge. This approach was used by Andreadis et al. (2013) to produce a simple global river bankfull width and depth database based on the HydroSHEDS data and hydraulic geometry equations. Other equations have been derived to estimate river widths and depths globally (Frasson et al., 2019) or for specific regions of the world, such as Bent and Waite (2013) and Johnson and Fecko (2008) who estimated river channel geometry in the Eastern United States.

The outflow drainage directions and catchment areas presented here are derived from a higher resolution hydrologically corrected UK digital terrain model. The geographical projection of these datasets is BNG rather than the latitude and longitude coordinate system typically used in global datasets. This makes the dataset presented here particularly useful for UK-based modelling as spatial flow connectivity can be lost when re-projecting outflow drainage direction data from one coordinate system to another. Here, the derived UK bankfull river width and depth datasets are based on outflow drainage direction and catchment area data coupled with power law relationships that are parametrised and assessed using UK observation-based data (river width, river depth and rainfall). All the UK datasets are provided on the same spatial extent and assume the same land sea mask (see Section 3). They also include cross-border catchments that flow into Northern Ireland (NI) from the Republic of Ireland as these will be required for any hydrological modelling in NI. Included with the spatial datasets for the UK is a comma-separated NRFA gauging station locations table, providing the most appropriate 1-km resolution location of each river flow gauging station for which model simulations and flow observations can be compared.

2 | DATA PRODUCTION METHODS

Here, outflow drainage directions, catchment area and bankfull river widths on 1 km × 1 km grids are derived from higher resolution datasets, whereas bankfull river depths are derived from sparse datasets of historical measurements. While high resolution digital data are used to estimate outflow drainage directions and catchment area, power-law relationships between catchment area and rainfall characteristics and bankfull river widths/depths are used to estimate these variables for all UK land cells. All the datasets are provided for UK land grid-cells despite some of the data (observed bankfull river widths and depths data) only being available for Great Britain (GB). To estimate bankfull river widths and depths for NI and for sub-catchments in the Republic of Ireland that flow into NI, the catchment area and rainfall power-law relationships derived for GB were assumed to apply.

2.1 | River outflow drainage directions and catchment area

Outflow drainage direction and associated catchment area datasets were considered primary datasets from which other datasets (bankfull river widths, depths and gauging station locations) could be derived. Outflow drainage directions at a 1 km scale were derived using the method of Paz et al. (2006) as applied by Davies and Bell (2009) from the hydrologically corrected 50 m IHDTM (CEH Integrated Hydrological Digital Terrain Model [IHDTM] – Catchment Management Modelling Platform, Morris & Flavin, 1990). To ensure that the derived 1-km resolution river network was as close as possible to reality, manual corrections were made to outflow drainage directions, particularly near flow gauging stations, using visual inspection to compare the 1-km resolution-derived river network with the 50-m IHDTM river network. Outflow drainage directions used the D8 approach (Jenson & Domingue, 1988), assuming eight outflow drainage directions. Two different outflow drainage direction numbering systems are provided: Esri GIS mapping software numbering system (East = 1, South East = 2, South = 4, South West = 8, West = 16, North West = 32, North = 64, North East = 128) and Unifhy (Unified Framework for Hydrology:unifhy · PyPI) numbering system (North = 1, North East = 2, East = 3, South East = 4, South = 5, South West = 6, West = 7 and North West = 8).The Esri version numbering system is used by models such as Grid-to-Grid (Bell et al., 2009), whereas the Unifhy numbering system is particularly suitable for Hydro-JULES modelling applications. Figure 1a presents a map of the outflow drainage directions for the ESRI numbering system. The catchment area dataset is derived from the drainage direction dataset using ArcGIS tools, and represents the number of upstream 1 km cells draining to each cell, including the cell itself (Figure 1b). The catchment area dataset does not allow for fractions of grid-cells to lie within different catchments, so the discretisation process will result in some 1-km resolution catchments being too large, and others too small compared to the base IHDTM. From comparisons at 1499 flow gauging stations for which a 'true' catchment area is associated, the errors between the 1-km-derived and the 'true' 50-m resolution catchment area have a median value of 1%, and generally affect smaller catchments.

2.2 | Bankfull river widths

A 1 km × 1 km bankfull river width dataset for the United Kingdom has been derived from a regression relationship that uses information from the OS MasterMap Water Network Layer (Ordnance Survey, downloaded in 2018), which provides a highly detailed mapping of all the watercourses in Great Britain (OS MasterMap Water Network Layer | Heighted Water Network | Vector Map Data [ordnancesurvey.co.uk]). This dataset contains tens of thousands of river widths for river network segments across Great Britain, and it typically provides multiple river width values in each 1-km grid-cell. Most of the water features in the OS MasterMap Water Network Layer are based on detailed topographic data and for this analysis the river widths are assumed to provide a reasonable estimate for bankfull river width. Each 1-km cell requires a single best estimate of river width from the Water Network Layer (WNL) and this is chosen by comparing the 50-m IHDTM catchment area draining to the location of each WNL river width with the area draining to the 1 km grid-cell and choosing the WNL river width for which they are closest. Sometimes there is more than one WNL river in which case the maximum width is chosen as this is more likely to represent the 1 km cell and avoids selecting tiny tributaries, particularly as we are only including 1 km cells with a catchment area > 7 km^2 in the analysis. Small catchments are excluded in the analysis to avoid confusion between multiple tributaries; however, discrepancies can still occur and sometimes a much higher or lower river width than expected results from this analysis. As a number of these anomalies exist, a GB-wide power-law relationship between OS MasterMap river widths, catchment area and mean catchment area rainfall has been used to smooth the derived 1 km × 1 km bankfull river widths through river systems, and remove any jumps and discrepancies. Specifically, a derived equation relates the OS MasterMap river widths in each 1-km grid-cell to catchment area and catchment Standard Average Annual Rainfall for the period 1961–1990 (SAAR) as follows:

$$R_W = 0.0042\, A^{0.409}\, \mathrm{SAAR}^{0.86} \tag{1}$$

where R_W is river width (m), A is catchment area (km^2) and *SAAR* is standard average annual rainfall (mm). SAAR values were derived by the Met Office and licensed to UKCEH. A comparable public version is available as part of HadUK-Grid (Met Office, 2022). The fit of this equation (1) to the bankfull width data for 38,600 sites is reasonably good, with $R^2 = 0.80$. For the Isle of Man, some coastal and small island 1-km cells SAAR is not available, and in these instances, the mean SAAR of the nearest cells is used to infill any missing data.

The scatterplot in Figure 2a compares the bankfull river widths (m) estimated from equation (1) with the observations from the OS MasterMap Layer river width data (also in m). The plot highlights the good overall fit of the regression equation (1), but with some scatter (standard error of approximately 0.5 m) thought to arise from local anthropogenic alteration of the natural river network and/or the OS MasterMap river width not being representative of the 1-km river cell. Figure 3a shows the spatial distribution of widths used in the equation. Here, equation (1) which was based on GB river width data is used to derive river widths for the whole of the UK land domain including areas, such as NI, for which observations of bankfull river width are not readily available. Figure 1c presents a map of the final derived UK-wide 1-km resolution bankfull width dataset.

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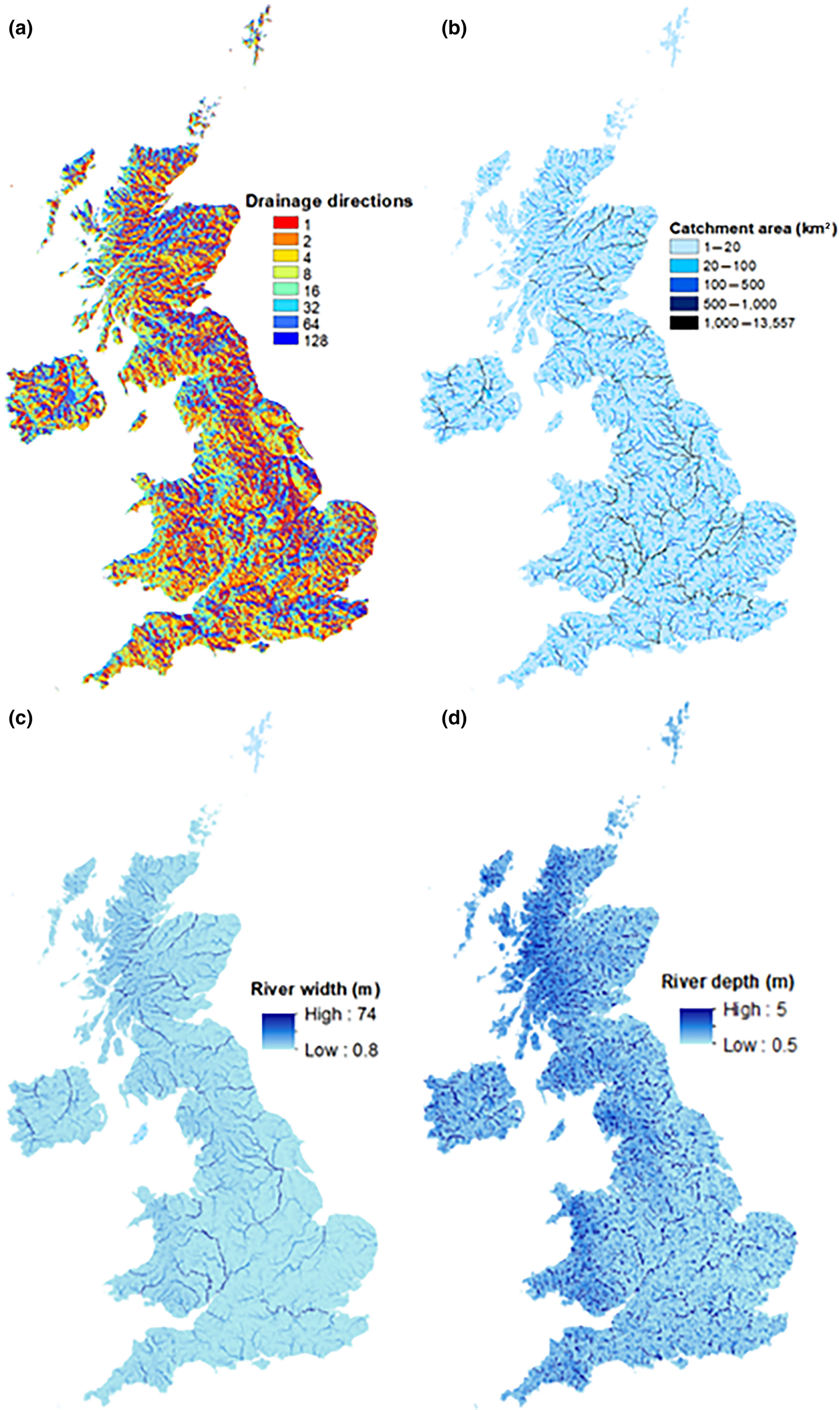

FIGURE 1 UK maps showing 1 km × 1 km derived datasets for (a) Outflow drainage directions (D8/Esri numbering); (b) Catchment areas (km^2); (c) River widths (m); (d) River depths (m).

2.3 | Bankfull river depths

UK-wide bankfull river depth estimates are derived using a similar approach to the bankfull-river widths, based on a regression relationship using historical bankfull river depth measurements. Accurate mean bankfull river depth measurements are relatively sparse and have been collated from multiple sources; Naden and McCartney (1991); Nixon (1959); NRFA and Environment Agency digitized cross-section data. A total of 90 depth measurements are used here for river locations with upstream catchments ranging from 16 to 9868 km^2, and while there are only a few in Scotland, they provide a reasonable spatial distribution across GB (Figure 3a).

From these 90 historic measurements, power-law relationships have been estimated that relate the observed

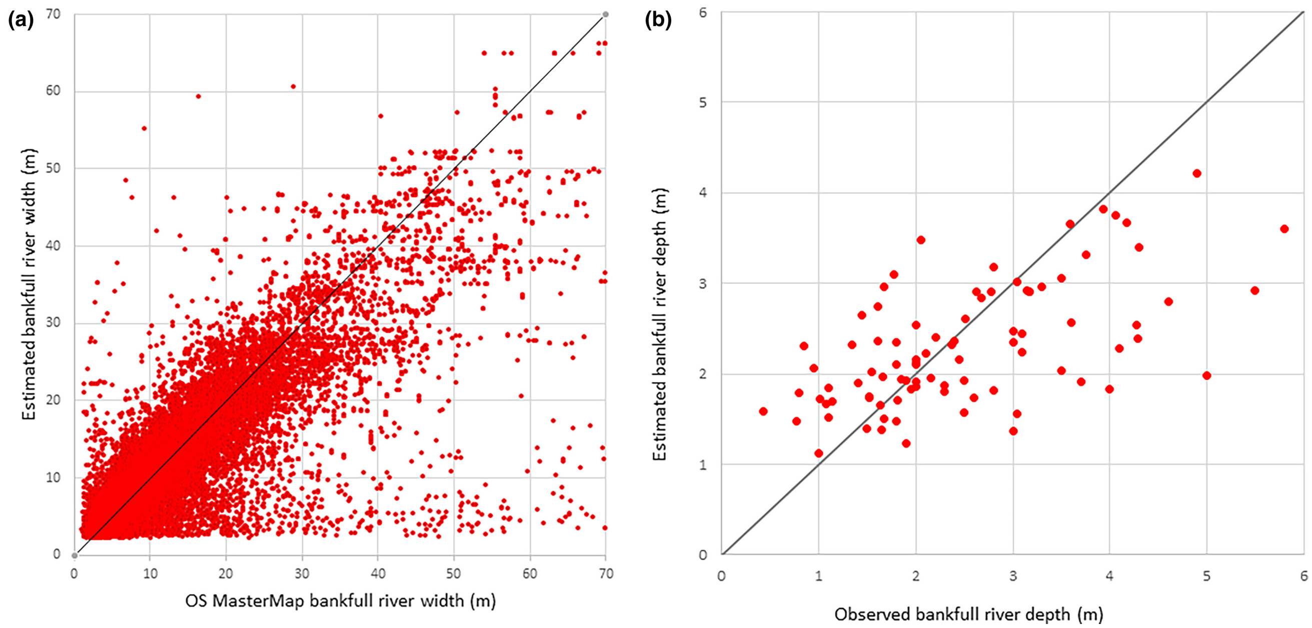

FIGURE 2 A comparison of GB values of (a) observed OS MasterMap and estimated bankfull river widths, and (b) observed and estimated bankfull river depths.

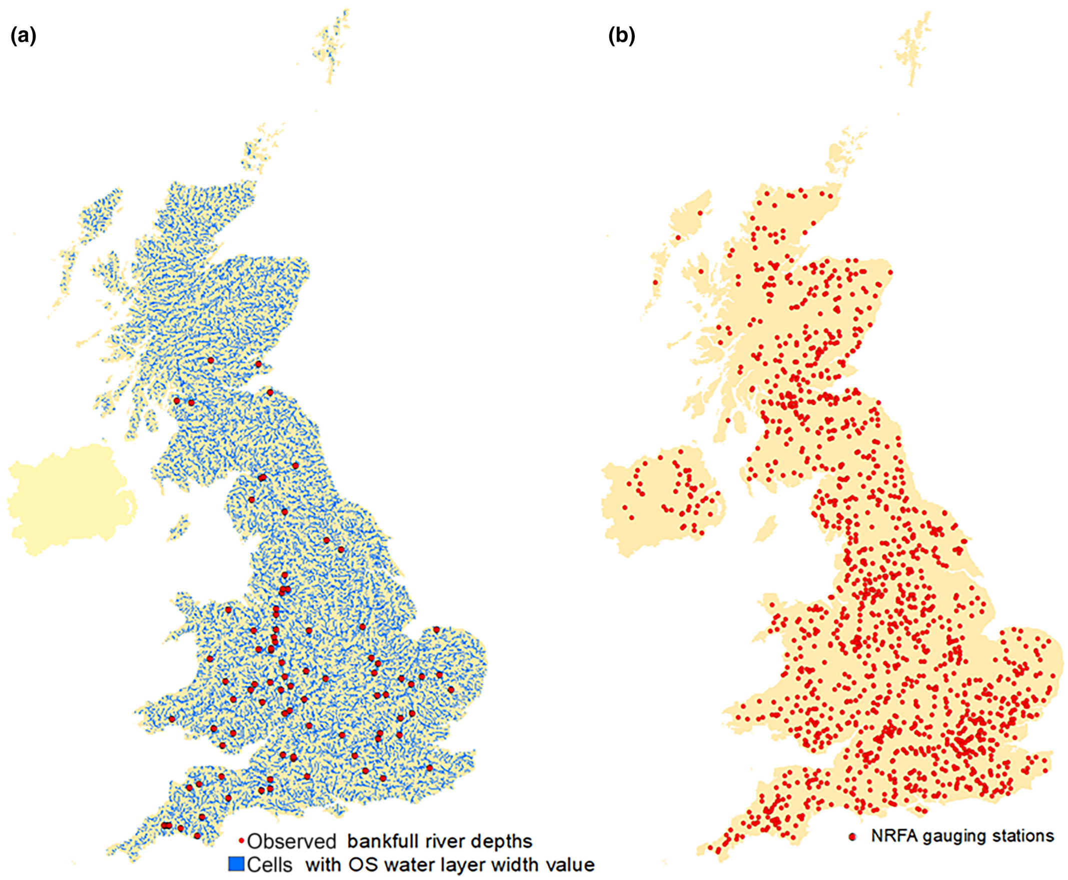

FIGURE 3 (a) River depth observations (red dot) and river width locations (blue shading) (b) NRFA gauging station locations (red dots).

river depths (m) with rainfall on a 1-km resolution across the United Kingdom. The derived equation is similar to equation (1), and using regression, it relates bankfull depth, R_D, to standard average annual rainfall (SAAR, mm) and area (A, km^2) via the following power law equation;

$$R_D = 0.02643\, A^{0.202}\, \mathrm{SAAR}^{0.482} \quad (2)$$

For the Isle of Man, some coastal 1-km cells and small islands, where SAAR is not available, the mean SAAR of the nearest cells is used to infill any missing data.

The fit of equation (2) to the observed bankfull depths for 90 results in a $R^2 = 0.57$. The scatterplot in Figure 2b shows the relationship between the 90 estimated and observed bankfull river depth values. There is considerable scatter (standard error of approximately 0.36 m) particularly at larger river depths, which can be attributed to a number of issues including the regression equation which has been applied to sparse data (2) and measurement uncertainty. UK river systems are often modified and although the measurements used here are taken to be 'natural' bankfull river depth readings, most large rivers in the United Kingdom are normally modified to some extent (Petts, 1988) and not necessarily natural. Significant variation in river depths are typically observed along a reach associated with meandering, pools and ripples, leading to challenges in identifying a representative value of bankfull depth, particularly for large rivers with uneven river beds. Another source of uncertainty in the river depth data is associated with different methods of measurement, as the method used is not always mentioned in the data. For example, river depths are assumed here to be mean bankfull depth across the river as opposed to maximum or bankside readings. Similarly, there is often a lack of information on how previous dredging might have impacted on river depth measurements, particularly in larger rivers. Figure 1d shows the final UK-wide bankfull depth dataset. The overall tendency is for the derived depths to overestimate smaller bankfull river depths and underestimate larger river depths.

2.4 | NRFA river flow gauging station locations on the 1 km × 1 km river network

The National River Flow Archive (NRFA) is the primary archive of daily and peak river flows for the United Kingdom. The archive incorporates daily, monthly and flood peak data from over 1,500 gauging stations, which are valuable both for hydrological analyses and for assessing the performance of hydrological models. However, the 1 km × 1 km grid-cells in which these gauging stations are geographically located may not be appropriate, because the simplification of the true river network to 1-km resolution can lead to discretisation and network delineation errors.

To assist hydrological applications that use the 1-km resolution river information provided here, an accompanying table links the 1-km-derived river network with the most suitable locations of 1,499 NRFA river gauging stations (https://nrfa.ceh.ac.uk/), Figure 3b shows these gauging station locations. Gauging stations with small catchments and those where a suitable location on the 1 km × 1 km derived river network was harder to locate are not included in the table. The 1-km gauging station locations in the table have been identified through a process that compares the upstream catchment area of the NRFA gauging station and the nearest derived river network location, and incrementally adjusts the location on the 1-km grid until the upstream areas are as close as possible. Where an appropriate upstream area could not be found within 2-km upstream or downstream, the gauging station locations were manually checked and an optimal location was identified where possible. The gauging station location file also provides values for the errors in the upstream areas (the IHDTM catchment area compared to the 1 km × 1 km resolution catchment area). An additional quality check indicates the discrepancy (%) in the spatial overlap between the 50 m and 1 km resolution upstream catchments, where 0% catchment overlap would indicate a perfect match, and 100% indicates that the upstream catchments do not overlap at all. For gauging stations where the spatial % discrepancy was large, manual checks were performed and the gauging station was moved to a more appropriate neighbouring 1-km cell, if possible. Across the United Kingdom, the percentage spatial discrepancies typically ranged from 0.8% to 44% with a median error of 7%.

In summary, the gauging station location file provides the following information:

- BNG grid reference (m),
- column and row number,
- 1-km catchment area (km^2),
- IHDTM (50 m resolution) catchment area (km^2),
- percentage error in catchment area (%),
- overlap area between 1 km and IHDTM catchments (km^2) and
- upstream catchment spatial discrepancy (%).

The table includes information on gauging stations in Northern Ireland, however, due to the re-projection of the IHDTM from the Irish National Grid to the BNG, the catchment overlap statistics are not available for these stations.

3 | DATASET FORMAT

The data are available from the Environmental Information Data Centre (EIDC) (https://doi.org/10.5285/8df65124-68e9-4c68-8659-1c6b82c735e9). The gridded 1 km × 1 km resolution datasets are stored in separate NetCDF files and the NRFA gauging station information is in a comma-separated table (csv). The names of the files are as follows;

- Drainage directions (D8/Esri format): UK_outflow_drainage_directions_1km_ESRI.nc
- Drainage directions (D8/Unifhy format): UK_outflow_drainage_directions_1km_Unifhy.nc
- Catchment areas (km^2): UK_catchment_areas_1km.nc
- Bankfull river widths (m): UK_bankfull_river_widths.nc
- Bankfull river depths (m): UK_bankfull_river_depths.nc
- NRFA gauging station locations: NRFA_gauging_station_locations_1km.csv

The gauging station table includes the Easting and Northing grid reference of the 1-km location, the column and row number of the gauge location (West to East, North to South), together with the approximate percentage error in catchment overlap between the 1 km × 1 km gridded delineation of the upstream catchment area and the IHDTM catchment area.

The gridded data are provided for a 656 km × 1,220 km spatial domain on the British National Grid from lower left corner (0,0) to top right (656,000, 1,220,000) (in metres). Values for each 1 km × 1 km grid box refer to the river which best represents the 1-km cell.

The data covers the CHESS land mask (https://catalogue.ceh.ac.uk/documents/7de9790e-66a2-44b5-988e-283d764ef52f) for GB but with added land cells for the Shetland Islands and some mainland inland missing data cells, while for Northern Ireland, the Ordnance Survey land mask is used (opendatani.gov.uk/dataset/osni-open-data-50m-dtm) with the inclusion of extra cells that flow into Northern Ireland from the Republic of Ireland.

4 | DATASET USE

These datasets are expected to be useful for configuring the hydrological components of gridded land surface and hydrological models and have been derived in support of Hydro-JULES (https://hydro-jules.org/). All four gridded datasets provide values for all UK 1-km land grid-cells and the user can set their own mask to delineate rivers, which could be based on catchment area (e.g. grid-cells with a catchment area > 20 km^2 could be considered 'rivers') or other observation-based datasets. All the spatial datasets have been extended into tidal regions to provide full coverage across the UK land mass, but the river depth and river width estimates in these area should not be considered representative of the actual tidal river and will greatly underestimate their true values in estuaries. Coastal grid-cells with flow directions that go directly from land to sea can be used to identify coastal outflows when used with hydrological models.

The spatial datasets can be read directly into ArcGIS or QGIS to generate 1-km resolution UK river networks for analysis or display.

AUTHOR CONTRIBUTIONS

Helen N. Davies: Data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); validation (equal); visualization (equal); writing – original draft (equal). **Ponnambalam Rameshwaran:** Supervision (equal); validation (equal); writing – review and editing (equal). **Victoria A. Bell:** Supervision (equal); writing – review and editing (equal). **Simon Dadson:** Supervision (supporting); validation (supporting); writing – review and editing (supporting).

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OPEN RESEARCH BADGES

This article has been awarded Open Data Badge for making publicly available the digitally-shareable data necessary to reproduce the reported results. Data is available at Open Science Framework

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