

# Circulation

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The Newsletter of the British Hydrological Society

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**Copy deadline for Circulation No. 149 28th April 2021**

**Very sad to hear of the death of Jim Shuttleworth in December. Jim led the Evaporation Physics team at the Institute of Hydrology (UKCEH) and the research to develop one the first integrated eddy correlation devices. The design of the Hydra, was unique in that it measured the temperature, humidity and windspeed fluctuations all in the same path. It was also battery-powered and could work in remote locations. In 1983 it was used in the Ducke Reserve near Manaus providing the first direct measurements ever of evaporation from Amazonian rainforest.**

**When Jim moved to the University of Arizona he started to study the impact of heterogeneity on evaporation and wrote the influential chapter on evaporation in the Handbook of Hydrology, bridging the gap between engineering hydrology solutions to estimate evaporation and more process-based ones.**

**A detailed history of Jim's contribution to hydrology can be found in http://www.history-of-hydrology.net/mediawiki/index.php?title=Shuttleworth,_W_J_(Jim)**


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# President's Perspective

The last four months have seen significant innovation in the UK water sector, new opportunities for British hydrologists to share their creative ideas and loud calls for more ambitious approaches and targets.

**Innovation needs**

In November, the National Audit Office praised the Environment Agency for delivering 728 new flood defence schemes since 2015, providing better protection for over 242,000 homes. It called for details of progress in reducing flood risk for non-residential buildings, agricultural land and other infrastructure. It also welcomed the capital funding plans for better protecting 336,000 properties and reducing national flood risk by up to 11% over the next six years. It did however, call for monitoring of progress to this target up to 2027, and measurable outcomes for all plans (National Audit Office 2020).

HM Treasury published the National Infrastructure Strategy on 25 November outlining how it wished to see faster delivery of critical infrastructure for water resource and flood risk management, while enhancing the natural environment and decarbonising our grey infrastructure and systems. The strategy calls for innovation in the way we develop our infrastructure, including the use of the latest digital technologies (HM Treasury 2020).

A central element of enhancing the natural environment and decarbonising our water infrastructure is making greater use of Nature based Solutions (NbS). The UK's Water Industry Forum published a guiding document on 'Natural capital principles for the water industry' (Water Industry Forum 2020), highlighting the importance of natural capital in tackling the impacts of climate change on water resources and flood risk, reversing biodiversity loss and our move to a 'Net Zero' future.

The value of natural capital to all aspects of the UK economy, including the water sector, was further emphasised by the publication of the 'Dasgupta Review' for HM Treasury (Dasgupta 2021) and the National Infrastructure Commission 'National capital and environmental gain discussion paper' (National Infrastructure Commission, 2021). The NIC emphasised that infrastructure developments should aim to leave the environment in a measurably better condition. The Dasgupta Review was even stronger, calling for urgent and transformative change in how we think, act and measure economic success. It insists that '…humanity must ensure its demands on nature do not exceed its sustainable supply and must increase the global supply of natural assets relative to their current level…' by for example, increasing investment in NbS.



Two House of Commons committees have also recently sited the importance of natural assets. The House of Commons Environmental Audit Committee argues that nature recovery must be integral to the Government's infrastructure plans and factored in from the start (House of Commons Environmental Audit Committee 2021).

The House of Commons Environment, Food and Rural Affairs Select Committee (EFRA) called for the scaling up of Natural Flood Management (an NbS solution specific to reducing flood peaks) stating that it needs to be 'appropriately targeted' at the 'right sites that work for that catchment'. This is something that ongoing academic research is demonstrating (e.g. Hankin *et al.* 2018; Page et al 2020). The EFRA Committee report also emphasised the importance of fully compensating farmers for the introduction of NFM interventions at these target locations and of engaging farmers, and those with flood-affected homes, in the development of flood mitigation plans from the outset (EFRA 2021). The National Farmers Union also called for the farming community to be involved in planning flood mitigation and water resources in their new report on 'Integrated water management' (NFU 2021).


House of Commons
Environment, Food and Rural Affairs Committee

Flooding

Fourth Report of Session 2019–21

*Report, together with formal minutes relating to the report*

Ordered by the House of Commons to be printed 2 February 2021

**Innovation opportunities**

Over the same period, there have been significant opportunities for UK hydrologists to contribute innovative ideas to meet these new challenges. Practitioners working for Lead Local Flood Authorities (LLFAs) in England have been encouraged to submit bids (initially Expressions of Interest) for funding to support innovative research on flood resilience in their regions. Up to £200 million is allocated to the programme (Environment Agency 2020). Paralleling this initiative, water companies in England and Wales have been encouraged to enter the Ofwat 'Innovation in water challenge' to help tackle some of the biggest issues facing their industry (Ofwat 2021). *Research organisations*, including the university and consultancy sectors, are participating in both initiatives, and have been leading in the UKRI Natural Environmental Research Council (NERC) project to identify innovations needed to monitor better flood and drought processes in the UK (UKCEH 2020). BHS members have been making significant contributions to this project, led by the UK Centre for Ecology & Hydrology, beginning with the first engagement workshop on 14 January 2021. With findings from this project, NERC intends to submit a business case for significant investment in innovative monitoring for the UK hydrological research community.

**Innovation delivery**

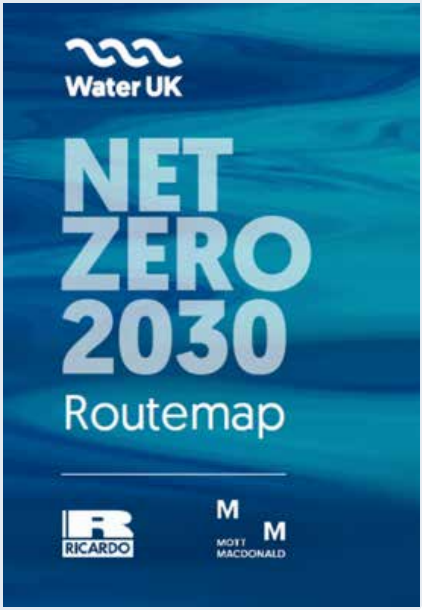
On top of these funding initiatives, the UK government and Members of Parliament have recently delivered the first iteration of a Sustainable Farming Roadmap, providing an innovative mechanism to deliver greater flood mitigation and water resources gain from the 70% of England that is farmed (Defra 2020). As more underpinning hydrological evidence finds its way into Defra's pioneering approach to the 'Environmental Land Management scheme' (ELMs), I hope that greater emphasis on targeting of NbS in the right places will come.

Of equal importance are investigations in to the causes and solutions for mitigating water quality problems in our streams and rivers to help reverse the decline of our ecology (an issue highlighted previously in Circulation 147). On 8 December, the House of Commons Environmental Audit Committee launched a new inquiry into water quality in English rivers. The focus for this inquiry is the water industry and urban diffuse pollution (House of Commons Environmental Audit Committee 2020), as the previous inquiry addressed agricultural nitrates. Highways England is also investigating water quality. On 30 December, they launched a monitoring study into the levels of micro-plastics entering natural watercourses from highways (building on a desk study: Highways England 2020a), and the degree to which NbS and sustainable urban drainage may mitigate the problem (Highways England 2020b).

The Government has joined forces with the water sector to form a 'Storm Overflows Taskforce' with the long-term goal of eliminating the ecological harm arising from storm overflows. Working with this Taskforce, our water companies have already committed to significantly increasing the number of monitoring devices at storm overflows by 2023, as a first step to tacking the issue (Defra 2021).

Engagement with this Taskforce is only one aspect our water companies' plans for innovative delivery announced over the last four months. In November, Water UK launched perhaps the world's first sector-wide plan to deliver net zero carbon emissions from the water sector by 2030 - the 'Net Zero 2030 Routemap' (Water UK 2020). Ricardo and Mott MacDonald had undertaken the pioneering research for Water UK that aims to deliver net zero emissions through greater use of solar and wind energy sources, restoration of peatlands and grasslands, biomethane capture from sewage and other actions.

Of equal importance has been the embracing of NbS by water companies, with Severn Trent Water,



South West Water and Anglian Water announcing detailed proposals for investments in a 'green recovery' in their areas.

Water companies and agencies have also delivered on planned improvements to the provision of our water supplies in recent months, with the opening of the new Mayflower water treatment works in Plymouth, completion of the first phase of the £1 billion Haweswater aqueduct renewal, and tendering for innovative satellite monitoring of leakage from supply pipes in Northern Ireland.

A new organisation, Water Resources West formed last October bringing together United Utilities, Severn Trent, South Staffs Water, Dŵr Cymru Welsh Water and the Environment Agency. Their objective is to provide strategic oversight and co-ordination of water resources matters across the river catchments of the West of England and the cross-border river systems with Wales. Their first initiative, launched at the end of last year, is an innovative digital platform for collaboration (Water Resources West 2020).

**Forthcoming Society activities in water innovation**

In response to these encouraging innovations and the calls for urgent and transformative change, BHS have been developing a range of activities to both inform you and engage you in this 'blue-green revolution'. Those supporting the membership are acutely aware that many of us are missing the all-important professional and social interactions that come with in-person meetings. While online meetings have given us some new and valuable opportunities for engagement, we do wish to see a return to some in-person meetings as soon as permitted and without the financial risks and disruption of last minute cancellations for our members. Financial commitments to in-person activities this summer do however remain difficult given the current uncertainties over our emergence from the pandemic and the economic situation. As a direct consequence, the BHS National Symposium at Lancaster University and the Lake District, planned for this summer, is moving to 6-8 September 2022 ('BHS2022'). This gives us the ability to retain 3-days of in-person activities with you.

BHS2022

We will also be offering some parallel opportunities for online engagement over the 3 days of the BHS2022 symposium.

While we may not be able to meet in-person this summer, we do wish to offer an opportunity for members to share their latest findings and ideas on the fast-developing landscape of hydrological innovation. This will take the form of an online-only BHS One-day National Symposium on Tuesday 7 September. There will be five talks on key aspects of innovation in the UK water sector covering the broad interests of our membership. These will include: dealing with

climate change projections in water resources, fundamental research on hydrological processes, the vital role of hydrologists in the assessment of emerging contaminants and effectiveness of NbS in peatlands, and how effective delivery of catchment solutions requires interactions between the public, farmers and practitioners. Critically, the event includes an opportunity for you to share a poster (or posters) on your ongoing work and have other members ask you questions. The meeting will also include a discussion on future research needs in UK hydrology, and the 2021 Annual General Meeting. This **BHS One-day National Symposium on 7 Sep 2021** will be open only to BHS members (at no cost) to give you greater opportunities to interact with presenters and other members. We encourage non-members to join the Society to participate. We will share full details of the event with you over the next weeks and months.

Our early career members, including those in full-time education or recently beginning work in the water sector are the Society's future. The organising committee for the next Peter Wolf Symposium for our early career members similarly believe in the importance of meetings involving in-person interactions. Accordingly, the next 2-day in-person Peter Wolf Symposium moves to 22-23 March 2022 retaining the venue of the University of Strathclyde. The organising committee have also kindly agreed to host a Peter Wolf Virtual Event on 8 Sep 2021, the day after the One-day National Symposium, and will share details of both of their events with you over the next few months.

I am indebted to our Honorary Secretary Lucy Barker and other members of Committee such as Michael Pollock who is now leading on our social media activities, for developing and delivering such a rewarding online BHS webinar programme over the last few months, with great membership engagement. Lucy is working on another exciting programme for 2021 that begins with Wouter Buytaert (1pm 24 Feb) telling us about his international research that benefits from an army of local volunteers, who also gain from direct engagement with experienced hydrologists. We then hear from Rob Lamb, Hannah Cloke, Sean Longfield and Nick Reynard (1pm 24 Mar) on innovations in flood hydrology captured by the emerging UK Flood Hydrology Roadmap. This will be followed by Will Rust of Atkins (1pm 28 Apr), who will remind us that the UK's excellent long-term hydrological records exhibit a range of inter-annual cycles and trends that we need to capture in our assessment of water resources and flooding. I am looking forwards to hearing these new insights; I hope that you are too.

**Nick Chappell**
**BHS President**
*February 2021*


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Water Resources West 2020. https://waterresourceswest.co.uk/
Water UK 2020. Net zero 2030 routemap. https://www.water.org.uk/routemap2030/wp-content/uploads/2020/11/Water-UK-Net-Zero-2030-Routemap.pdf

More BHS webinars and virtual events are being organised for 2021, including one from the Future Hydrology Working Group and one on the topic of machine learning in hydrology – watch out for more information, and as always remember to catch up on any webinars you've missed on the BHS YouTube channel (https://www.youtube.com/channel/UCQ3xxpdbW_AhS4Ht6bLbbDQ).

# BHS 2021 Webinars

## Watch out for registration links which will be circulated via the BHS mailing list shortly!

*Wednesday 24th February 2021 1-2pm*

## "The role of citizen science in hydrology"

**Professor Wouter Buytaert (Imperial College London)** All over the world, hydrological systems face unprecedented pressures from overexploitation, degradation, and changing climate conditions. This poses a major challenge to managing them in a sustainable way, which is often complicated further by the scarcity of scientific evidence to support adequate decision-making. Despite the advent of remotely sensed data sources, understanding and quantifying the nature and scale of hydrological processes still relies strongly on in-situ observations, which are often time- and labour- intensive to collect. As statutory monitoring activities are suffering from budget cuts and other challenges, it is opportune to explore new arrangements to support and expand hydrological data collection and evidence generation. Citizen science, which refers to the participation of the general public in the scientific discovery process, is receiving increased attention in this context.

This webinar will draw upon experiences from South America, Africa, and South Asia to discuss some of the challenges and potential solutions of implementing citizen science and other types of participatory monitoring activities in a water resources management context. It will also synthesise these findings by outlining an analytic framework that may help in the design and implementation of citizen science for environmental management.

*Wednesday 24th March 1–2pm*

## "A Flood Hydrology Roadmap for the UK - Delivery Plan for the First 7-Years"

**Professor Rob Lamb, Professor Hannah Cloke, Dr Sean Longfield and Nick Reynard** This webinar will be presented by Professor Rob Lamb, Professor Hannah Cloke, Dr Sean Longfield and Nick Reynard who are helping to steer the development of a flood hydrology roadmap for the UK. The roadmap will set out a vision for flood hydrology for the next 25-years and will be accompanied by a delivery plan which details specific actions to be delivered by the flood hydrology community in the first 7-years of the roadmap. The presenters will discuss the drivers for the roadmap, the community focused development of the roadmap, potential funding routes and the aspirations and intended outcomes of the delivery plan to improve flood hydrology in the UK.

*Wednesday 28th April 1-2pm*

## "Unearthing a hidden cycle in UK water resources"

**Will Rust (Atkins)** Predicting the next major flood or drought event is of paramount interest to water managers. In particular, understanding the behaviour of streamflow and groundwater resources is critical in estimating the risk associated with these hydrological extremes. Here, we will discuss new evidence for a multi-year cycle exhibited by the majority of UK water resources that, until recently, was hidden. This cycle can account for up to 30% of river flow behaviour and up to 40% groundwater level behaviour, with impacts on the recurrence of flooding and droughts. In this webinar we will review the nature and implications of this cycle in the UK and discuss its origin.

## Extreme flood research

The Environment Agency has started a new project to improve Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) estimation for reservoir safety, the vital calculations when assessing potential risk from dam or spillway failure which could endanger downstream communities.

The suitability of existing methods for estimating PMP and PMF originally developed in the '70s by the Flood Studies team at IH Wallingford, will be assessed and newer methods and guidelines developed to ensure that there are still adequate risk analyses for high risk reservoirs from extreme flood events.

The project has two phases. This first phase will create a catalogue of extreme historical rainfall and flood events, then review options for alternative approaches to PMP and PMF estimation and the options for updating current estimation methods from which to commend a way forward for development and implementation in Phase 2.

Phase 1 started in November 2020 and will take around 12 months to deliver. Many data sources are being mined to identify historical extreme events, such as published accounts and digital libraries and databases*. Anyone with knowledge of extreme rainfall or river flow events in the UK that were truly exceptional, no matter how localised, please get in touch with the Project Team. More details of the project and the list of Board, Project Advisory Group and Team Member (led by JBA) are given here.

* Our BHS Chronology of British Hydrological Events (www.hydrology.uk.org/Chronology_of_British_Hydrological_Events.php) will no doubt come into its own here –*Ed.*

British Hydrological Society

University of Strathclyde Engineering
Centre for Water, Environment, Sustainability & Public Health

# Peter Wolf Early Career Virtual Event 2021 & Symposium 2022: save the dates!

**The University of Strathclyde is pleased to announce that it will host the next British Hydrological Society's Peter Wolf Early Career Hydrologist's Symposium. This event is an opportunity for early career hydrologists to share their recent work with like-minded hydrolgists . Due to the COVID-19 restrictions, the in-person symposium won't be held until Spring 2022. Before then, however, the University of Strathclyde will also be hosting a Peter Wolf Virtual Event as part of the National Symposium in Autumn 2021.**

**Dates for your diary:**

- **The Peter Wolf Virtual Event (half-day, as part of the virtual BHS National Symposium): 8 September 2021**
- **The Peter Wolf Symposium at the University of Strathclyde: 22–23 March 2022**

## New members

Charlie Bleasdale.....Atkins, Cardiff
Hannah Dixon.....Mott Macdonald,Cambridge
Connor Gamble.....Environment Agency, Peterborough
Ruth Hallat.....Environment Agency, Tewkesbury
Edward Hodgson.....Birmingham
Rosanna Lane.....UKCEH, Wallingford
Gerald Morgan.....Everose Partners Ltd,, Bristol
Louise O'Regan.....Arup, Leeds
Lamprini Papadimitriou.....Mott Macdonald, Cambridge
Timothy Pickering.....Carnforth
Jamie Rae.....Perth
Martyn Roberts.....University of Aberdeen
I. Rohmueller.....JBA Consulting, Harrogate
Keith Shotton.....University of Newcastle
Claire Storer.....WSP, Bristol
Phillip Wadley.....University of Lancaster
D. White.....Rushden
Ellen Yardley.....Hyro-Logic Services Ltd., Wallingford

# An 'R' package (UKFE) to implement the methods of the Flood Estimation Handbook

I have recently developed and uploaded an 'R' package) to CRAN (the comprehensive R statistical programming language archive network). Called 'UK Flood Estimation', this package provides functions to undertake flood frequency analysis according to the methods of the Flood Estimation Handbook (FEH) and associated updates. The purpose in creating this package is to introduce the usefulness of FEH methods to a wider audience. Being based in 'R' the UKFE package offers a free and very flexible environment to implement the FEH methods. Furthermore, the functions are designed so that they are straight-forward to use even for those with limited or no 'R' experience. The package should prove useful/interesting to the general practitioner & enthusiast, but I'm hoping the flexibility of the package will be very attractive to the academic community for experimental analysis on the current methods or adaptations to them. As well as the statistical method for regional flood frequency analysis there is a revitalised flood hydrograph model (ReFH) function, as described in the FEH supplementary report (2007). There are numerous other functions such as: peaks over threshold data extraction, design hydrograph derivation, trend test, and many more. There are 67 functions in total and the key ones for the FEH are outlined in the following table.

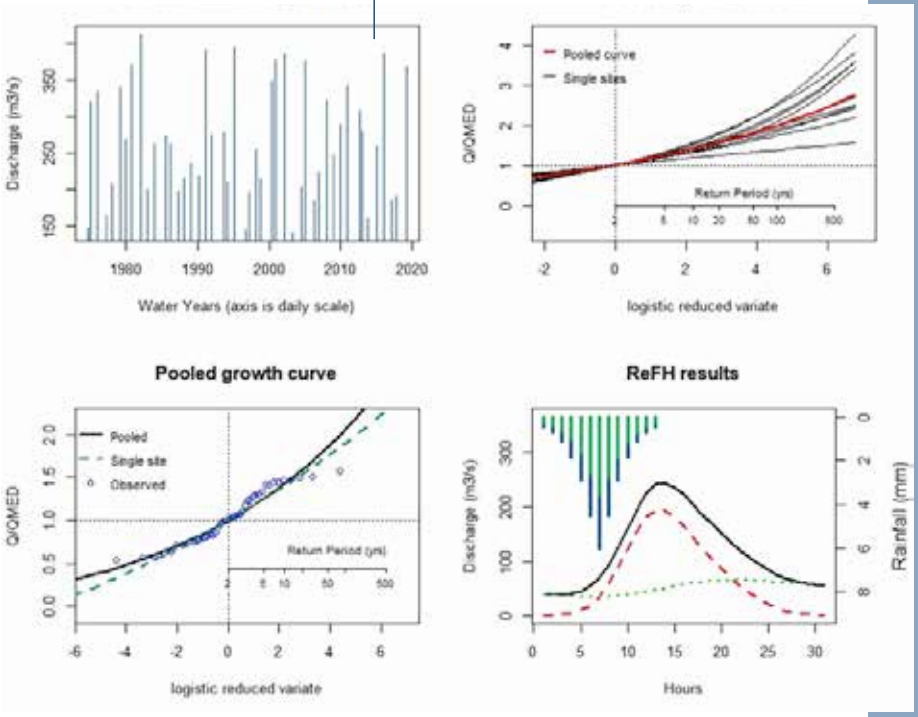
The final three each have four associated function. A growth curve function, a function applied directly to the data to estimate flow as a function of return period or vice versa, a parameter estimation function (L-moments or maximum

**Table 1.** ***Key UKFE functions for implementing the FEH methods***

| *Function* | *What it does* |
|---|---|
| GetCDs/ImportCDs | Get catchment descriptors from the sites suitable for QMED and or pooling, or import them from CD3 files |
| GetAM/ImportAM | Get annual maximum data from sites suitable for pooling or from .AM files |
| QuickResults | Provides default pooling results (gauged, ungauged or pretend ungauged), directly from catchment descriptors |
| QMED | Estimates QMED from catchment descriptors with the option of zero, one, or two donors |
| DonAdj | Provides list of donor candidates based on proximity to study catchment |
| Pool | Creates a pooling group with the option of excluding one or more sites |
| H2 | The heterogeneity measure for pooling groups |
| DiagPlots | Provides a number of plots to compare the sites in a pooling group |
| Zdist | The Zdist statistic to determine the distribution with the best fit to the pooling group |
| PoolEst | Flood estimates from the pooling group |
| Uncertainty | Quantifies uncertainty for gauged and ungauged pooling groups |
| ReFH | Implements the ReFH model |
| GenLog | Four functions for the generalised logistic distribution |
| GEV | Four functions for the generalised extreme value distribution |
| GenPareto | Four functions for the generalised Pareto distribution |

likelihood estimation) and a function to estimate flow as a function of return period or vice versa from user input parameters.

For a quick guide to using the basic FEH functions in the package, follow the URL https://www.floodhydrostats.com/ukfe-package-feh-quick-guide. For further information about the above functions and the remainder of the 67, the UKFE 'R' package comes with documentation that can be viewed in the 'R' environment or via this URL (or Google UKFE R package): https://cran.rstudio.com/web/packages/UKFE/UKFE.pdf. As a very quick guide, all you need to do to start using the package is open 'R' and input the following into the console: 'install.packages ("UKFE")' –– you only need this command the first time you use it. As well as raw results the package provides many plots with which FEH practitioners will be familiar.




Example of some plots from the UKFE package

**About me**: Utilising 15 years of experience in flood risk management, I work for JBA Risk Management as Senior Hydrologist, mostly working in R&D developing stochastically generated flood simulations on a national to global scale. During my previous role with the Environment Agency, I grew a love of flood hydrology, flood frequency analysis and statistics in general. I have a well weathered copy of the Flood Estimation Handbook and have a desire to play a part in improving the

methods. One way to improve a science is to make it more accessible to a wider audience. I am hoping this package will assist the facilitation of that aim for UK flood hydrology. I am a budding academic in my spare time (having been published as first author only once) and I'm currently working on my next paper which is about the uncertainty in the FEH methods.

Lastly, use of the package may wheedle out some errors which I have not spotted. Please let me know if you spot any so that I can correct them or supply necessary warning messages in the next update.

**Anthony Hammond**
*Senior Hydrologist at*
*JBA Risk Management*

As a courtesy to Wallingford HydroSolutions, I passed Anthony's article to Wallingford HydroSolutions who commented as follows: *Ed.*

"The revitalised flood hydrograph model (ReFH) function implemented, as described in the FEH supplementary report (2007), is now widely referred to as ReFH1. There have been numerous improvements to the ReFH model since 2007. The latest Environment Agency Flood Estimation Guidelines (2020) detail the differences between ReFH1 and ReFH2.3, the latest version of ReFH. "The ReFH2 method was first released in 2015. It was updated in 2016 to use the latest rainfall frequency statistics for the UK, FEH 2013 and improved in 2019 when a closure of the water balance was introduced, along with other changes." The Flood Estimation Guidelines state "In most situations, apply the current version of ReFH2 in preference to ReFH1." ReFH1 is limited to the FEH99 rainfall statistics, for which the Guidelines advice that practitioners should "use the FEH 2013 rainfall statistics in preference to FEH99 for all applications unless you have evidence that FEH99 should be preferred in a particular location".

Anthony then replied: "The ReFH1 model is, however, a suitable option for deriving design hydrographs in ungauged catchments, by scaling to estimated design flows from FEH statistical analysis. This functionality is available within the UKFE package's ReFH function. For gauged sites the DesHydro function can be used for the purposes of developing a design hydrograph."

***WINFAP5 is to be released shortly, see***
www.hydrosolutions.co.uk/knowledge-base/winfap-updates.



# Recent PhD theses

| *Author* | *Title* | *University* |
|---|---|---|
| Kawala, Jackson | On the impacts of climate change on water resources : lessons from the River Nith Catchment and Shire River Basin uk.bl.ethos.820959 | Strathclyde |
| Tamrakar, Rijan | Implications of forest structure on C02 fluxes uk.bl.ethos. 809516 | Bangor |
| Coughlan, Neil, | Prevention, control and eradiation of aquatic invasic=ve species uk.bl.ethos.808516 | Queen's. Belfast |
| Ferguson, Charles | The effects upstream NFM on urban surface drainage performance uk.bl.ethos818212 | Cambridge |
| Peralta-Maraver, Ignacio | Links between hydrology, community ecology and ecosystems services in the hyporheic zones of streams and rivers uk.bl.ethods. 772779 | Roehampton |
| Seaton, Fiona | Monitoring and analyss of structure, function and diversity of soils (Wales) uk.bl.ethos.809696 | Bangor |
| Meijia Estrada, Iskra | Hydrometeorological characterists of urban flash floods uk.bl.ethods. 805634 | Bristol |
| Wingfield, Thea | Crossing the disciplinary divides to support NFM delivery uk.bl.ethods. 815620 | Liverpool |
| Miles, Eleanore | Catchment-level effects on river habitats: a spatial data-science study of rivers in England and Wales uk.bl.ethos. 8153638 | Kings College London |

# UK Hydrological Bulletin: November 2020 – January 2021

**Overall, a notably wet three-month period with a cluster of named storms contributing to the 7th wettest December–January for England & Wales since 1915. From early December near-saturated soil conditions, high baseflows and, in January particularly, snowmelt contributing to exceptional runoff across much of the UK. Correspondingly, flooding was widespread and persistent particularly across England & Wales — culminating over the Christmas period, and again in late January, when community impacts were severe. Evacuations were needed in a number of, mostly urban, centres and transport disruption was extensive. Mitigation was provided by skilled weather forecasting and the natural and controlled spillage onto floodplains; the use of temporary flood barriers also played a valuable role. A beneficial aspect of the exceptional rainfall was the abundant replenishment of groundwater resources**

Regional rainfall totals for **November** were moderately below average across most of the UK with the exception of western Scotland and, generally, the normal west-to-east rainfall gradient was enhanced; eastern Britain registering only marginally above half of the average monthly rainfall. However, the passage of Storm Aiden at the beginning of the month brought sustained heavy rainfall to many areas; in north Wales, Capel Curig recorded 113 mm over the first two days. With many catchments close to saturation, Flood Warnings were extensive particularly across the northern half of the country. Notably high runoff characterised river draining Snowdonia and the Pennines (the Yorkshire Ouse causing modest flooding in York). Following widespread frontal rainfall on the 15th with localised surface flooding (e.g. in London), river flows generally declined markedly across almost all of the country and were substantially below average at month-end. However, catchment runoff totals were mostly well within the normal range –

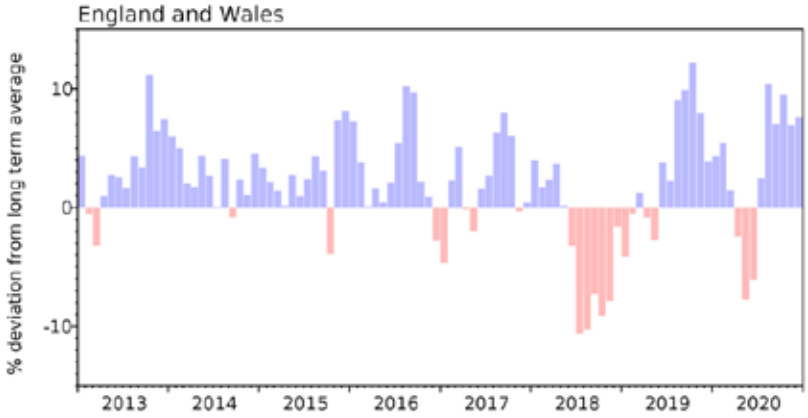



**Fig 1.** A guide to overall month-end reservoir stocks for England & Wales

exceptions included notably high runoff from the Mourne (Northern Ireland), Conwy (north Wales) and Itchen (Hampshire) catchments; the latter benefitting from the remarkably high groundwater recharge in October. Whilst groundwater levels at month-end remained depressed in some deep Chalk wells (e.g. at Therfield, Herts), most were considerably above average. This was true of the majority of reservoir stocks also (see Fig. 1), an exception being the small Ardingly reservoir (Sussex) which, despite a 20% increase over the month, remained less than half full entering December.

A dominant westerly airflow during **December** ensured substantially above average monthly precipitation in almost all regions and, with saturated soil conditions, flood episodes were damaging and repetitive. Sustained frontal precipitation on the 4th – with rainfall totals exceeding 40 mm in a number of areas – resulted in widespread moderate flooding across southern England whilst urban flooding afflicted parts of Scotland (e.g. in Edinburgh and Aberdeen). A fortnight later, a 24-hour rainfall total of 64 mm was recorded at Libanus (Powys) and around 40 Flood Warnings were in operation across England & Wales, many in the South-West where several landslides caused the closure of the Eden Project in Cornwall. After a lull, sustained rainfall during the fourth week triggered over 100 Flood Warnings mostly across the southern half of the country. In East Anglia exceptional flows in the Ouse and Nene necessitated evacuations in Bedford (over 1000 homes at risk) and at Billing Holiday Park. The arrival of storm Bella in northern Scotland on the 26th brought further abundant rainfall – Achnagart (Wester Ross) registered 82.6 mm in 24 hrs. Flood warnings were again very extensive and wind damage contributed to major transport disruption across the country. The rivers Waveney (Norfolk) and Warleggan (Cornwall) were among a substantial number registering new maximum December runoff totals.

Notwithstanding an exceptional spring drought (see Fig.2) the UK registered its 6th highest annual rainfall total in the

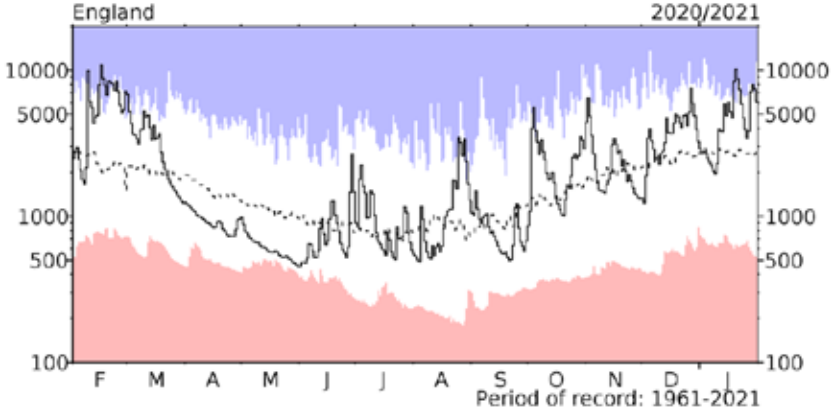



**Fig. 2** Daily outflows from England m3sec-1(black trace); the blue and pink envelopes are the pre-2021 daily max. and min. outflows and the grey trace is the long-term daily average

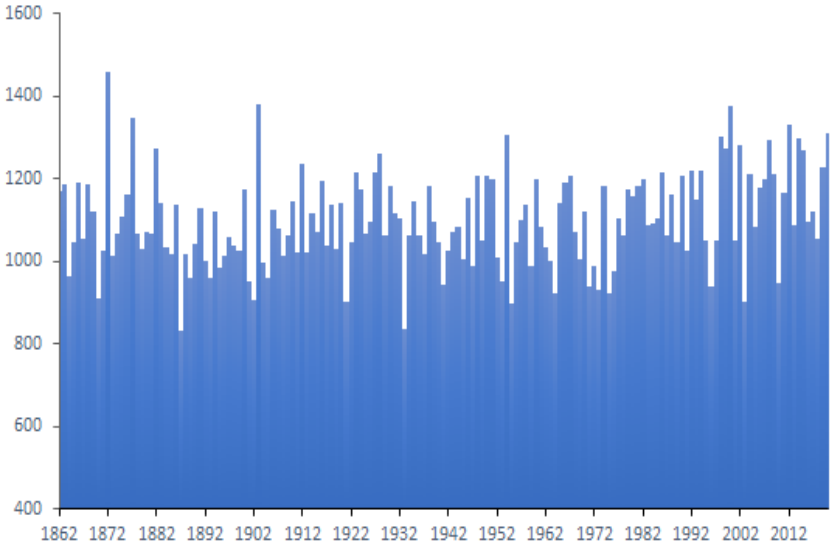



**Fig. 3** Annual rainfall totals (mm) for the UK Data source: Met Office

Met Office series beginning in 1862; substantially lower than in 1872 but, more notably, 9 out of the 16 wettest years in the series cluster in the post-1997 period (Fig. 3). A number of rivers including the Mourne, Lune and Cynon established new annual runoff maxima in 2020 and outflows from England & Wales were the third highest in a 60-year series.

Despite below average precipitation across much of the Scottish Highlands, **January** was the second wettest since 2008 and the second coldest for the UK since 1997. Soils were close to saturation and snowfall was common across many upland areas. Correspondingly, snowmelt added to the risk of flooding which, in some areas, was also aggravated by rapidly rising groundwater levels in late-2020 – see Fig. 4. Fortunately, early January was largely dry but spate conditions were widespread on the 12–14th and the arrival of Storm Christoph on the 19th heralded a further exceptionally wet episode. A 48-hr rainfall accumulation of 168 mm was record at Capel Curig with over 150 mm recorded in parts of the Brecon Beacons.

By the 21st, a remarkable 7 Severe Flood Warnings, 240 Flood Warnings and 280 Alerts were in operation embracing most areas of England & Wales and aggregated outflows from England were exceptional during the first week (see Fig. 2) . Provisional daily flow data indicate that floods on the Severn, Yorkshire Ouse and Don had return periods in the 8–12 year range with more extreme floods reported from England....or some rivers draining west from the southern Pennines where snowmelt made a significant contribution. Evacuations – some precautionary – were required in many areas including Warrington, Manchester, Northwich, Ruthin, Bangor-on-Dee and Neath, and both road and rail transport was heavily impacted. The Mersey and Don were among a substantial number of rivers registering

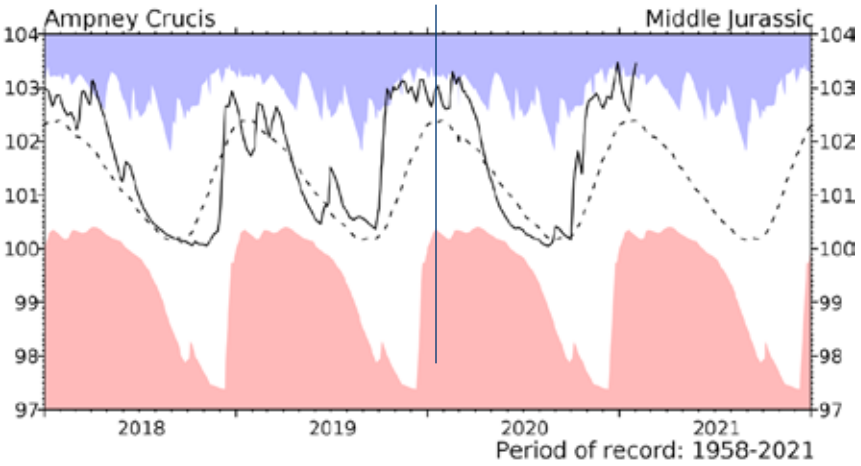



**Fig. 4.** Groundwater levels for the Ampney Crucis borehole in the Cotswolds; the blue and pink envelopes are the long-term max. and min. levels and the broken trace is the long-term average

new maximum January runoff totals and thus reservoir stocks in all index reservoirs were at, or approaching, capacity and month-end. In addition, a significant minority of index wells and boreholes (e.g. in the Jurassic Limestone outcrop – Fig. 4) recorded new maximum January groundwater levels. Correspondingly, some local groundwater flooding was reported (e.g. in central southern England); sewage contamination was an aggravating factor in a few areas.

***Note**: Due to a cyber-attack on the SEPA website over the Christmas period, very limited hydrological data for Scotland was available to inform the December and January commentaries. Covid-19 restrictions also impacted on data acquisition in some other areas.*

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