Institution: University of Bristol		
Unit of Assessment: 14) Geography and Environmental Studies		
Title of case study: Pioneering computer models have transformed global flood risk management		
Period when the underpinning research was undertaken: 2008-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Professor Paul Bates CBE Dr Jeff Neal	Professor of Hydrology Senior Lecturer	1995-present 2007-present
Period when the claimed impact occurred: 1 August 2013-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

The numerical algorithms, datasets and outputs of the LISFLOOD-FP flood inundation model developed by the University of Bristol's Hydrology Research Group have been adopted by >1600 non-governmental organisations, multinational companies, governments, (re)insurers, specialist risk modelling firms and non-commercial users serving the world's flood risk management sector to protect assets worth >USD1.35 trillion and the infrastructure used by billions of people.

The impact has been realised directly and through the team's start-up company Fathom (12 staff in 2020, with turnover >USD2 million) which has created the first high-resolution simulations of continental and global flood dynamics, hazards and risks.

The work has improved flood risk management and decision making globally, resulting in avoided losses, reduced risk to populations, better asset management and the creation of numerous jobs in the hazard risk analysis sector since August 2013.

2. Underpinning research

Since 2008, there has been a concerted effort to develop a first generation of national-to-global scale flood inundation models. Prior to this, flood risk analyses were typically conducted over relatively small areas (river reaches a few 10s of km long) using detailed models and local data, such as hydrometry and ground survey, collected specifically for the purpose. Flood inundation modelling for larger domains or for regions outside the handful of developed countries with good local data was effectively prevented by: (i) the computational cost of running highly detailed flood simulations globally; (ii) the low suitability of global terrain data sets for flood modelling; (iii) the lack of suitable data detailing global river widths; (iv) the absence of methods to calculate extreme flood magnitudes for all global rivers; and (v) the need to automate the model building process. However, many problems in flood science and management explicitly demand large scale, national and even global views of hazard and risk. These include insurance and reinsurance pricing, corporate supply chain and risk management, environmental rating and risk analysis of global investment portfolios, financial authority stress testing, humanitarian response to disasters, climate change analysis and decisions on national flood defence spending levels.

Ground-breaking research, conducted by the Hydrology Research Group at the University of Bristol (UoB) between 2008 and 2020, has addressed and provided solutions to each of these previously intractable problems and has led to the development of the first ever high resolution (3 arcsecond, approximately 100m) simulations of global flood dynamics that have predictive skill down to these scales **[1].**

The developments pioneered by this group that contributed to these high-resolution global flood simulations were:

- In 2010, the researchers published a set of highly efficient numerical solutions derived from shallow water theory that could be used by flood inundation models **[1]**. This numerical solution was between 100 and 1000x faster than the code it replaced and has subsequently been developed for implementation on high performance computing within the LISFLOOD-FP model to achieve a further 10x speed-up.
- The team developed code to automatically create and conduct wide area, high-resolution simulations using only globally available datasets **[2, 3]**.
- Working with a team from Japan (University of Tokyo, Tokyo Institute of Technology, Japan Aerospace Exploration Agency), they developed bespoke and open source variants of NASA's Shuttle Radar Topography Mission (SRTM) global terrain dataset expressly designed for flood inundation modelling using tests and diagnostics developed by the UoB team **[4]**. SRTM is the current global benchmark terrain dataset, but prior to this work contained significant artefacts, errors and noise which rendered it unsuitable for inundation prediction.
- The development of new methods to predict the probability distribution of extreme river flow anywhere on the global river network to provide the boundary conditions for global inundation simulations **[5]**.
- The production of global, open source databases for river width and hydrography – key parameters in hydrodynamic river simulations – which could then be applied to continental and global scale river modelling. This was done with collaborators from University of Tokyo and University of North Carolina, with UoB researchers involved in all aspects of the work **[6]**.
- The above components were combined within an automated model build and execution framework that allowed regional to global scale hazard simulation by the hydrodynamic model LISFLOOD-FP **[1]**.

3. References to the research

[1] **Bates PD,** Horritt MS and **Fewtrell TJ** (2010). A simple inertial formulation of the shallow water equations for efficient two dimensional flood inundation modelling, *Journal of Hydrology*, **387**, pp.33-45, https://doi.org/10.1016/j.jhydrol.2010.03.027

[2] **Sampson CC, Smith AM, Bates PD, Neal JC,** Alfieri L and **Freer JE** (2015). A high resolution global flood hazard model, *Water Resources Research*, **51(9)**, pp.7358-7381 https://doi.org/10.1002/2015WR016954

[3] **Neal J, Schumann GJ-P** and **Bates PD** (2012). A subgrid channel model for simulating river hydraulics and floodplain inundation over large and data sparse areas, *Water Resources Research*, **48**, Paper no. W11506, https://doi.org/10.1029/2012WR012514

[4] Yamazaki D, Ikeshima D, Tawatari R, Yamaguchi T, O'Loughlin F, **Neal JC, Sampson CC**, Kanae S and **Bates PD** (2017). A high accuracy map of global terrain elevations, *Geophysical Research Letters*, **44(11)**, pp.5844-5853, https://doi.org/10.1002/2017GL072874

[5] **Smith A**, **Sampson C** and **Bates PD** (2015). Regional flood frequency analysis at the global scale, *Water Resources Research*, **51**, pp.539-553, https://doi.org/10.1002/2014WR015814

[6] Yamazaki D, Ikeshima D, **Sosa J**, **Bates P,** Allen G and Pavelsky T (2019). MERIT Hydro: A high-resolution global hydrography map based on latest topography dataset, *Water Resources Research*, **55(6)**, pp.5053-5073, https://doi.org/10.1029/2019WR024873

Grant evidence

- **Bates PD** (Co-I), *Consortium on Risk in the Environment: Diagnostics, Integration, Benchmarking, Learning and Elicitation (CREDIBLE)*, NERC NE/J017450/1, 2013-2017, Bristol share GBP300,000 (out of GBP1.9 million)
- **Bates PD** (Co-I), *Susceptibility of catchments to INTense Rainfall and flooding (Project SINATRA),* NERC NE/K00882X/1, 2013-2017, Bristol share GBP350,000 (out of GBP2.6 million)
- **Bates PD** (PI), **Neal JC** (Co-I), *Open access global flood hazard layers*, NERC NE/M007766/1, 2014-2016, GBP140,000
- **Bates PD** (PI), *Development of the next generation of global flood inundation models*, Leverhulme RF-2017-171, 2016-2017, GBP50,000
- **Neal JC** (PI), *An Interdisciplinary Approach to Understanding Past, Present and Future Flood Risk in Vietnam*, NERC NE/S003061/1, 2018-2021, Bristol share GBP370,000

- **Neal JC** (PI), *Next Generation Flood Hazard Simulation for the African Continent*, NERC NE/S006079/1, 2018-2021, Bristol share GBP420,000

4. Details of the impact

The impact of this research is as follows:

1. **A new business was created in November 2013, co-founded by Bates and Neal, to apply the equation sets and algorithms in the underpinning research [1-6] to produce flood risk analytics for organisations around the world.**

This business, Fathom (www.fathom.global), has so far created 12 permanent jobs and will generate turnover in excess of USD2 million in 2020 **[a]**. Using these equation sets and algorithms, Fathom have developed: (i) global 90m resolution flood hazard layers (i.e. maps of water depths at this scale) for 10 different return periods, from 1 in 5 years to 1 in 1,000; (ii) a similar dataset for the US using higher resolution data at 30m resolution; (iii) a set of 100,000 years of realistic flood patterns over the US that can be used to estimate flood losses; and (iv) a US catastrophe risk model for flood by combining developments ii and iii. Fathom also works in collaboration with technology companies Simplitium (https://www.simplitium.com/) and Oasis (https://oasislmf.org/) to implant their data products within standard risk modelling platforms which enable insurers to model portfolio losses using the Oasis open loss modelling framework. This was the first implementation of flood hazard data within Oasis over large areas.

The work has been recognised by industry prizes, including "Best piece of research / evaluation / validation" at the London Catastrophe Modelling Association 2020 awards (www.catinsight.co.uk/awards) and the 2019 Allianz Climate Risk Research Award to Dr Ollie Wing, who at the time was a joint Fathom/UoB employee (www.allianz.com/en/sustainability/low-carbon-economy/climate-risk-research-award/meet-our-finalists1.html).

2. **The insurance industry, blue-chip companies, NGOs and regulators around the world have benefitted from the global flood hazard and risk datasets developed through Fathom Ltd since November 2013 and underpinned by the research conducted at the University of Bristol.** Examples include:

i. US, UK and Asian insurers, including Aon, Canopius, Chaucer, Sompo International, Hiscox and Trans Re, who use Fathom's data directly in the pricing of flood risk for millions of assets worth at least USD1.35 trillion (Hiscox: USD1.2 trillion; Sompo: USD134.5 billion; data from other companies withheld as commercial in confidence). This resulted in payable annual insurance premiums of at least USD1.5 billion (Trans Re, USD1 billion; Sompo, USD500 million; data from other companies withheld as commercial in confidence) **[a, b]**. Fathom data are also used by these insurers and re-insurers to identify new market opportunities and to better understand their risk and exposure **[b]**. Examples include risk assessment and underwriting for the US National Flood Insurance Programme (NFIP) by Hiscox Ltd. and for consistent flood risk underwriting for all types of insurance across all locations by Sompo International. The data have allowed insurers to "*improve both underwriting and portfolio management practices by providing greater certainty in the quantification of a critical catastrophe risk*" (Global Risk Analytics Director, Sompo International), make "*more informed underwriting decisions, manage downside risk and develop new products*" (Head of Digital Product, Canopius) and "*more holistically approach client's flood risk management and quantification needs*" (Head of Client Management, Aon). As a result of the data, Hiscox have been able to generate "*very strong growth year on year in our flood business*" (Group Head of Catastrophe Research). Numerous insurers state that the strong basis of Fathom's work in the peer-reviewed science conducted at UoB and the close connection between UoB and Fathom are key reasons for their adoption of these datasets **[b]**.

ii. First Street Foundation, *"a non-profit research and technology group committed to defining America's flood risk"*, who use the data to calculate the past, present, and future flood risk of every home and property in the United States and who make these data freely available to the public and researchers **[c]**. Most Americans rely on the Federal Emergency Management Agency (FEMA) for flood risk information, yet recent and repeated flooding events across the US have destroyed thousands of homes classified as low risk in the FEMA database. Seventy-five per cent of FEMA maps are outdated and fail to account for changing

environmental factors, like rising sea levels and changing precipitation patterns. As a result, millions of Americans are unaware of their true flood risk and are consequently unprepared. The First Street Foundation aims to correct this knowledge imbalance and in doing so heighten awareness of both flood risk and climate change. Data access is provided through: (1) Flood Factor (https://floodfactor.com/), the Foundation's online database and visualisation tool; (2) an Application Programming Interface (or API); and (3) by integrating the data within the web searches from leading online US real estate database companies, such as Realtor and Zillow. These data have also been used to determine the economic, fiscal, and social impacts of the US's changing flood risk in the country's first national flood risk assessment (https://firststreet.org/flood-lab/research/2020-national-flood-risk-assessment-highlights). *"Fathom are producing new and updated versions of their US hazard data for pluvial, fluvial, coastal and hurricane-induced flooding that will sit at the heart of the data sets we will deliver to the US public and decision makers. In turn these data are based on the world-leading science that your group has produced over the last decade, thereby giving us assurance that the methods have been rigorously tested and peer-reviewed"* (Executive Director, First Street Foundation) **[c]**.

iii. Risk analytics companies, such as Four Twenty Seven (a subsidiary of the ratings agency Moodys), who offer risk information and products to investors, corporations, and governments. Four Twenty Seven use Fathom's data to correctly price current and future flood risk for a variety of financial sectors and instruments through on-demand risk scoring, creation of company risk scores for investors, and analysis of sovereign risk **[d]**.

iv. The World Bank, whose Global Facility for Disaster Reduction and Recovery (GFDRR) licenses Fathom's global data to provide the default global source of flood hazard information for the entire Bank. The data are used in GFDRR's web-based 'Think Hazard' tool (http://thinkhazard.org/), which enables over 10,000 users per month in any country to consider the impacts of flood disasters on new development projects. Fathom data are also used in the Bank's City Resilience Programme, which provides information on risk and resilience conditions of urban centres in Bank client countries around the world to aid intelligent planning, and in numerous projects to assess national scale flood risk in territories including Argentina, Belize, Bangladesh, Vietnam, Georgia and Armenia. These latter studies are used by the Bank to decide on multi-billion USD investments and loans for infrastructure and disaster resilience projects that enhance the lives of millions of people. In total, based in part on Fathom data, the Bank disbursed nearly USD50 billion in funding in 2019 **[e, a]**.

v. Microsoft uses Fathom data to assess and manage risks to its global cloud infrastructure, including location decisions and risk mitigation actions, and to optimise service delivery during extreme events. In this way, Fathom data help protect network infrastructure worth over USD15 billion that stores over 30 trillion data objects and which is relied upon by over 400 million people **[f]**.

vi. The Nature Conservancy (TNC), which is one of the largest environmental non-profit organisations in the world, with annual revenues in excess of USD1 billion. TNC is based in the US and protects over 0.5million km^2 of land in 79 countries across 6 continents. UoB research and Fathom data are used by TNC in their Mississippi River Basin Floodplain Prioritization Tool (http://fptool.org/) to inform spatial decision making and floodplain management by local and regional agencies across the basin, to help guide floodplain conservation projects across the US and to develop the economic case for investment in floodplain conservation (summarised in a paper published in Nature Sustainability by TNC and UoB authors in 2020) **[g]**.

3. **Direct users of LISFLOOD-FP model outputs and science created by the University of Bristol.** Examples since August 2013 include:

i. The UK's Department of International Development (DFID), for whom the UoB researchers provided flood risk assessment that informed the planning and humanitarian response during cyclones Idai and Kenneth which affected Southern and East Africa in 2019. For this effort, the team provided rapid-response real-time forecasts of future flood inundation based on climate model ensembles created by the European Centre for Medium Range Weather Forecasting and hydrology analysis by the University of Reading. This allowed flood risk maps to be disseminated to risk managers in the region 24 hours ahead of cyclone landfall, which

were then updated daily during the crises. The analysis was used in the daily situation reports of the UN's Office for the Coordination of Humanitarian Affairs and by the Government of Mozambique to establish aid airbridges and to prioritise locations to which ground response teams should be sent **[h]**. The success of the process resulted in an identical study being performed for the recent cyclone Amphan, which struck Bangladesh, India and Burma in May 2020, and an ongoing contract to provide these services in the future via DFID's Expert Advisory Call Down service.

ii. Google, which has used the LISFLOOD-FP algorithm blueprint **[1, 3]** to develop its own flood inundation forecasting model, which has been run operationally for basins in India over the last two years. Google has already used the system to send out hundreds of flood alerts to millions of people, and is looking to expand this initiative to more basins globally and thereby improve flood risk knowledge for hundreds of millions of Google users **[i]**.

iii. The Swedish Meteorology and Hydrology Institute, which uses LISFLOOD-FP **[1, 3]** in Sweden's national flood forecasting system (SHYPE, Swedish Hydrological Predictions for the Environment). LISFLOOD-FP has been used to generate flood mapping for all catchments in Sweden larger than 50km^2 at a spatial resolution of 5m, thereby covering more than 98% of Sweden's land surface area. This will create an archive of flood extent maps relating to different flow conditions that can be drawn from to provide real-time predictions of future inundation extent and flood depth for use by first responders and risk managers (e.g. for road and rail closures, evacuation decisions and deployment of temporary flood defences) **[j]**.

iv. Since 1 August 2013, more than 1,600 non-commercial and NGO users in around 60 countries have benefitted from a shareware version of LISFLOOD-FP **[1, 3]** made available by the Bristol Hydrology Group. Users download a model executable, user manual, and training materials for LISFLOOD-FP and use the code both to solve their own flood risk problems and learn the techniques of flood risk modelling. The shareware is being used in diverse ways for a variety of studies and is currently being made fully open source.

5. Sources to corroborate the impact

[a] Fathom – Testimonial letter, *Use of LISFLOOD-FP algorithms by Fathom* (2020), Chief Technical Officer

[b] Testimonial letters from insurance industry (all 2020): AON, *Aon Impact Forecasting – Fathom/UoB partnership,* Head of Client Management; Chaucer (x2), *Use of Fathom/University of Bristol data by Canopius,* Head of Digital Product, and *Impact of University of Bristol flood risk research,* Catastrophe Research Manager*;* Sompo International, *Flood risk at Sompo International,* Global Risk Analytics Director; Hiscox, *Flood risk pricing at Hiscox Ltd,* Group Head of Catastrophe Research

[c] First Street Foundation – Testimonial letter, *Mapping America's flood risk at the First Street Foundation* (2020), Executive Director

[d] Four Twenty Seven – Testimonial letter, *Impact of University of Bristol science and Fathom data products on Four Twenty Seven Inc* (2020), Chief Development Officer

[e] The World Bank – Testimonial letter, *Use of University of Bristol science and Fathom data products at the World Bank* (2020), Global Facility for Disaster Risk Reduction

[f] Microsoft – Testimonial letter, *Fathom flood risk products at Microsoft* (2020), Senior Service Engineer

[g] The Nature Conservancy – Testimonial letter, *Impact of University of Bristol science and Fathom data products on The Nature Conservancy* (2020), Deputy Director of Agriculture, North America

[h] DFID – Testimonial letter, *Analytical input to humanitarian response on Cyclone Idai and Cyclone Kenneth* (2020), Chief Scientific Adviser

[i] Google – Testimonial letter, *Impact of University of Bristol science on flood forecasting at Google* (2020), Senior Software Engineer, Google Tel Aviv

[j] Swedish Meteorology and Hydrology Institute – Testimonial letter (2020), Head of Forecasting.