National Infrastructure Resilience Demonstrator (NIRD)

Stress-testing road networks against extreme floods

Presenter: Dr. Raghav Pant, Environmental Change Institute, University of Oxford

Collaborators: **Yue Li**, Tom Russell, Fred Thomas, Jim W. Hall, Philip Oldham, Rob Lamb, Paul Young

DAFNI seminar
September 24, 2025, Online

Outline

- Background and Motivation
- NIRD aims and methodology
- Demonstration
- Project outcomes
- Ongoing and future work

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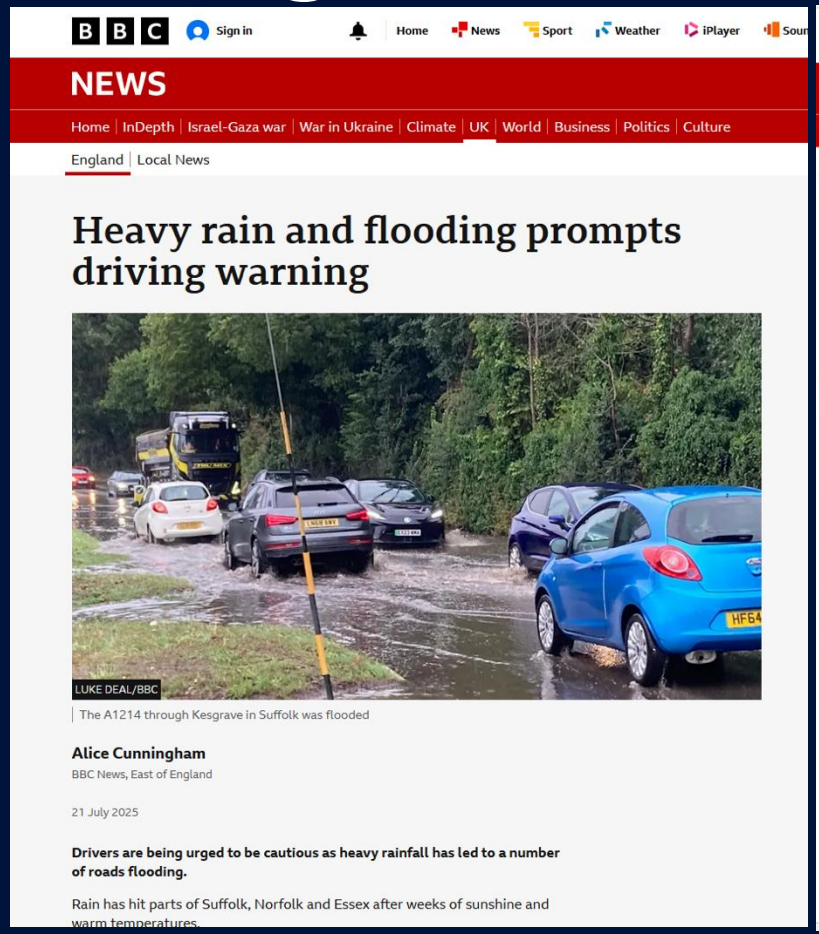
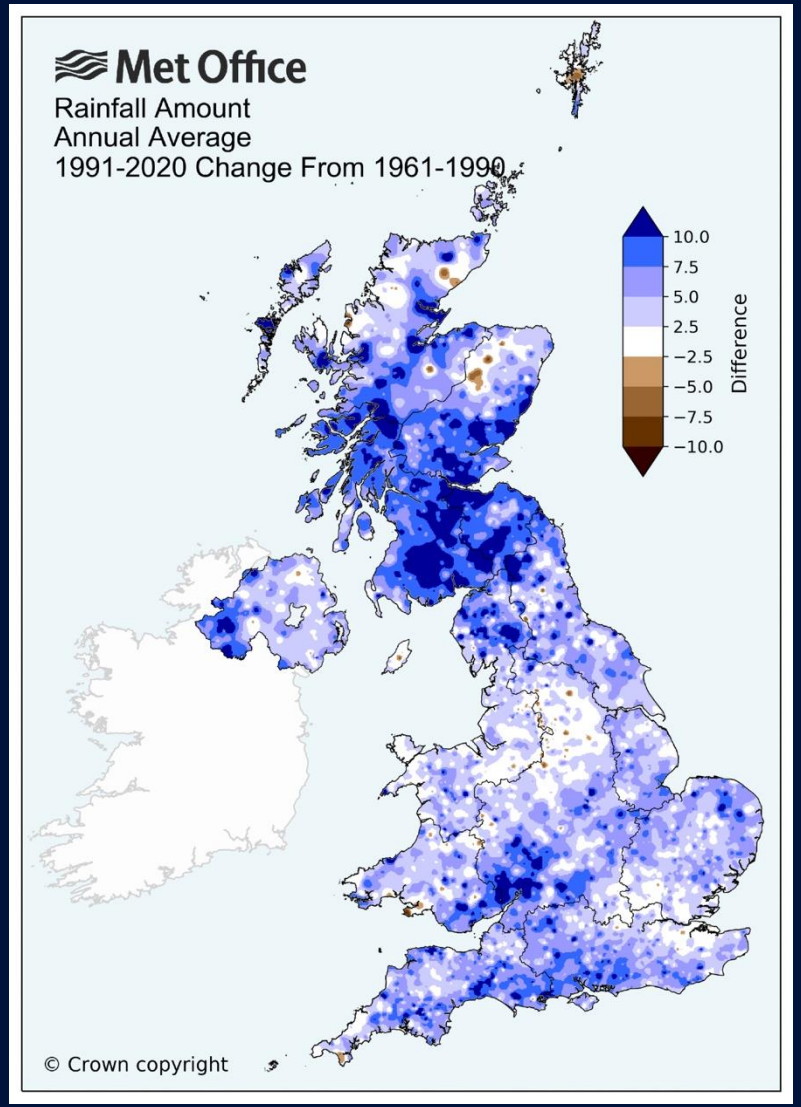
Background – *Increased flooding*





The UK spent **£125 and £287 million,** respectively, to cope with floods **on road networks** in 2007 and 2015-16.

- Office of Budget Responsibility

https://www.metoffice.gov.uk/about-us/news-and-media/media-centre/weather-and-climate-news/2021/climate-change-continues-to-be-evident-across-uk

Background – *Gap in systemic impact assessment*

- There is a lot of **uncertainty** in the assessment of **road damages and losses** for large flood events
- Current **government methodology does not consider indirect losses in a sufficient way**
- **Lack of a tool to measure flood impacts** at national scale

Box 8: Best estimate of costs incurred by road damages and delays

Best estimate of road damages (£220 million) = local authority estimate of cost of repairs to local road networks

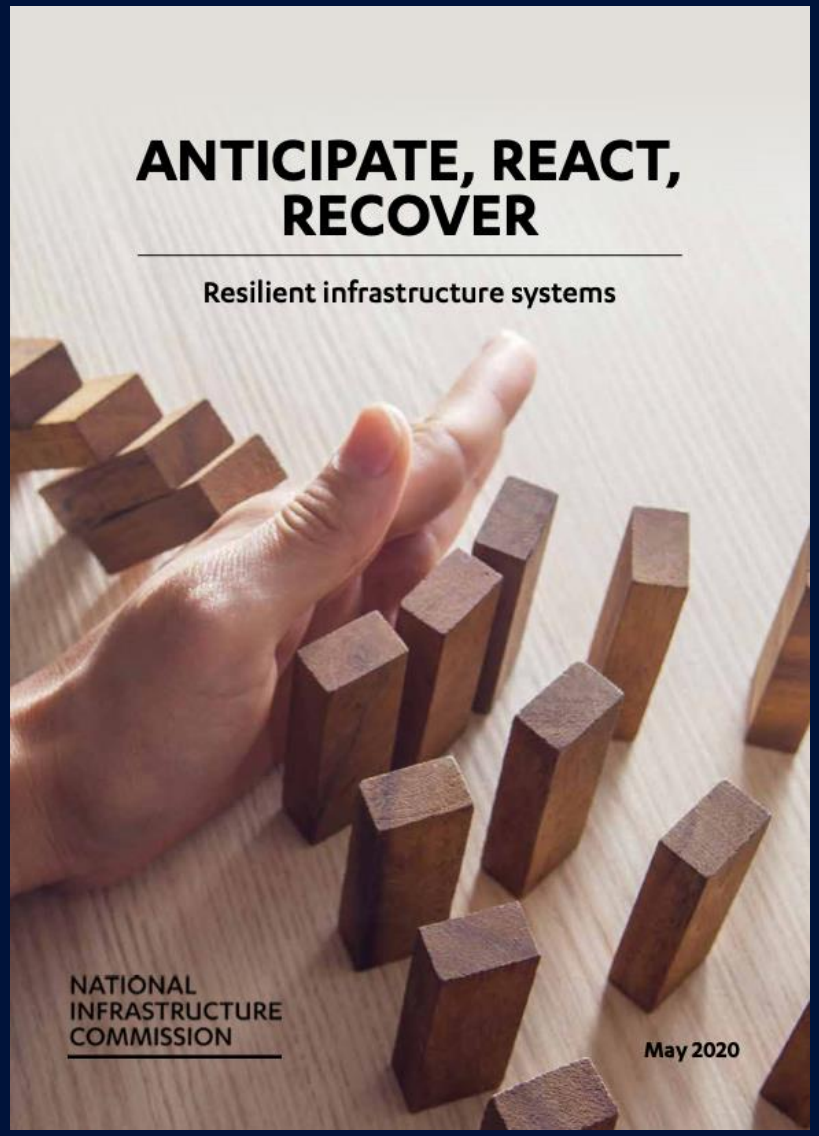
where:

- 50% is assumed to be for economic damages for the local and strategic road networks
- 50% is assumed to be for welfare damages (delay and disruption) for the local and strategic road networks

Key uncertainties

- The assumptions on welfare damages

Motivation – *Stress-testing infrastructures*



Recommendation

- Regulators should require a **system of regular stress testing by 2024 for infrastructure** operators, to ensure resilience standards for infrastructure services

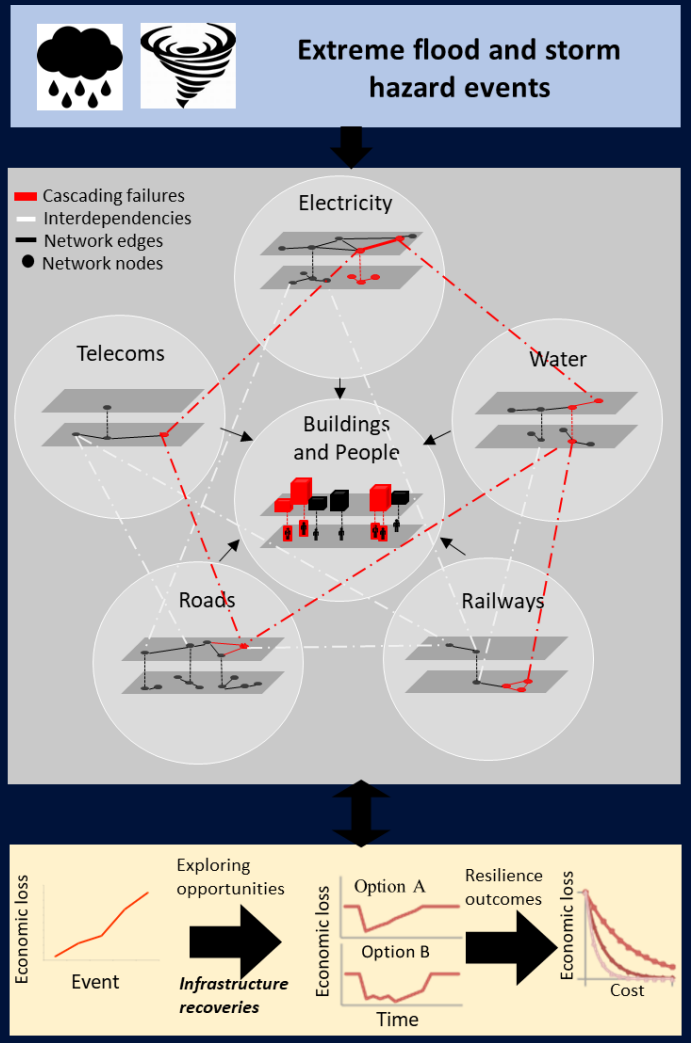
Gaps

- **Lack of understanding of systemic failures** remains a major challenge for operators in estimating and tackling climate risks

- **Lack of coherent data for modelling infrastructure interactions** and **inconsistent risk measures** that makes it difficult to compare resilience outcomes across different sectors

NIRD

National Infrastructure Resilience Demonstrator



Objectives

(1) Provide a capability to build **process-based network usage models** at large-scale analysis

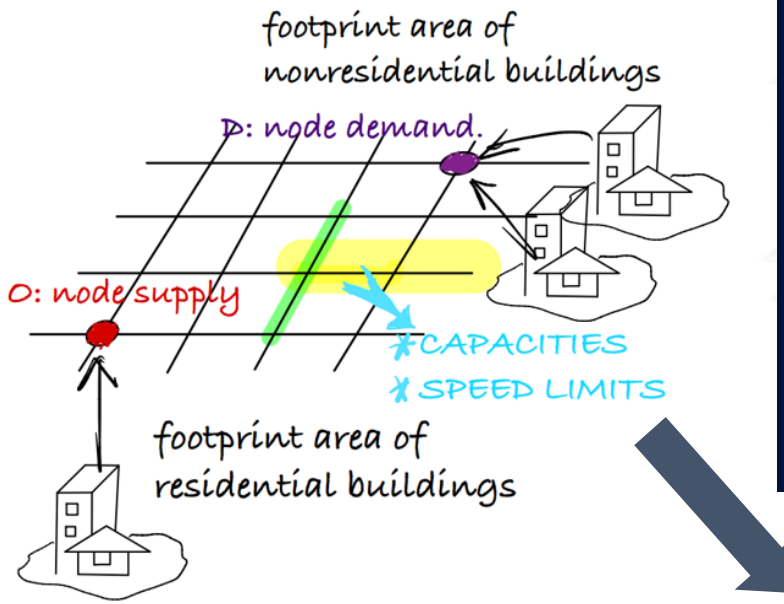
(2) Stress-test networks with **extreme hazards** events

(3) Model **systemic failures** to quantify indirect network losses

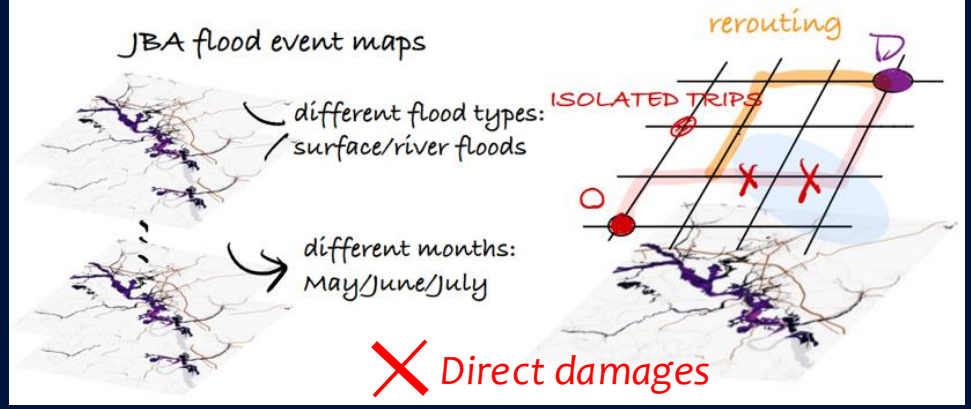
Project outcome

Deliver accessible **national-scale modelling capability and software tools** for quantifying UK infrastructure **risk and resilience to extreme hazard events**, supported by the **DAFNI platform**

NIRD – *Framework for national-roads*



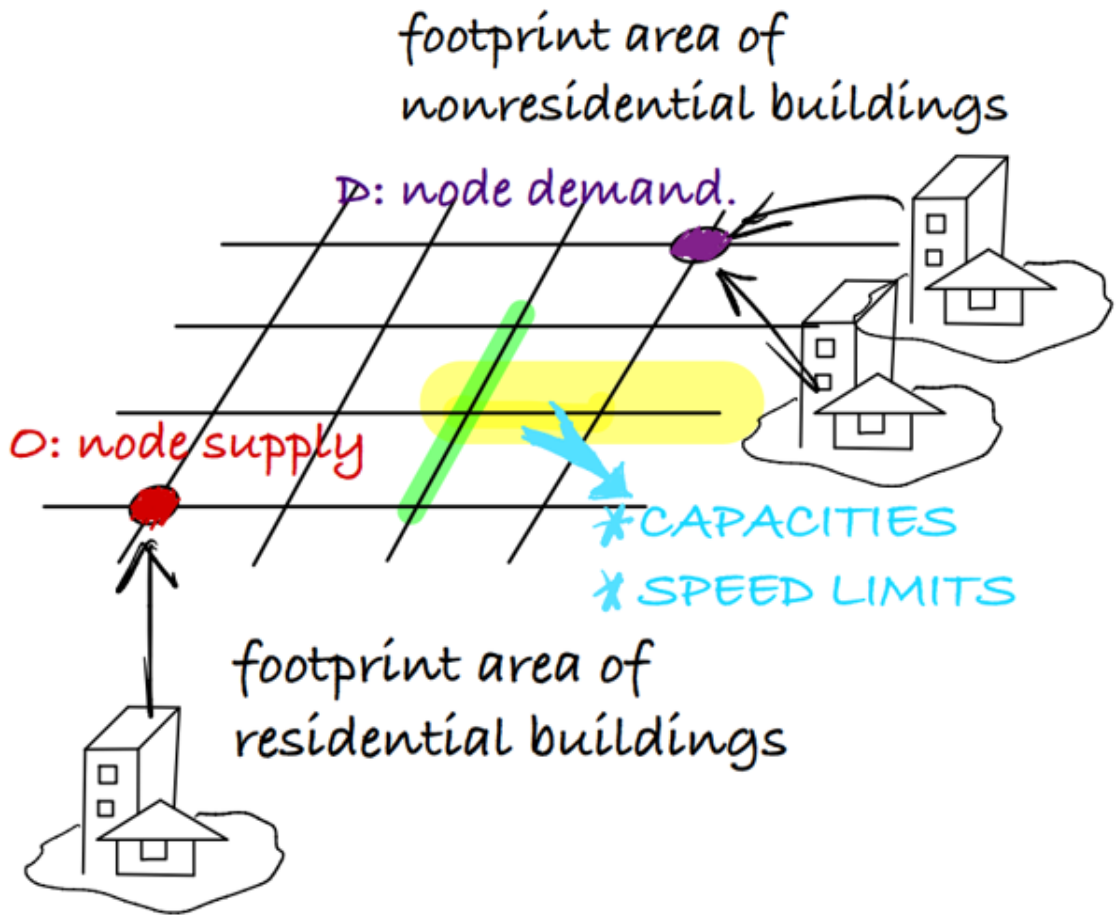
Road Disruption and Rerouting Analysis



spatial flow changes

spatial trip isolation heatmap

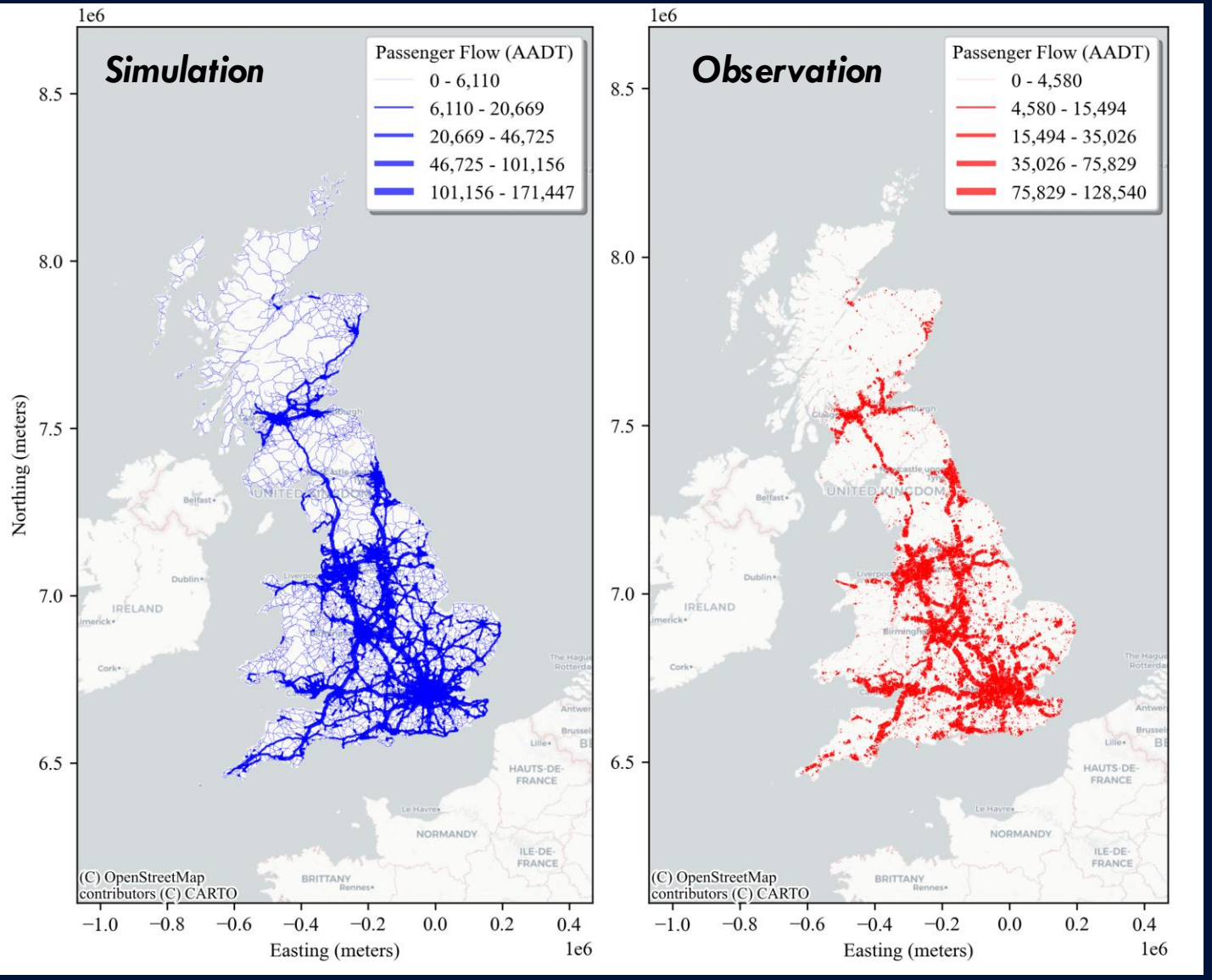
Demonstration – *GB scale trip allocation*

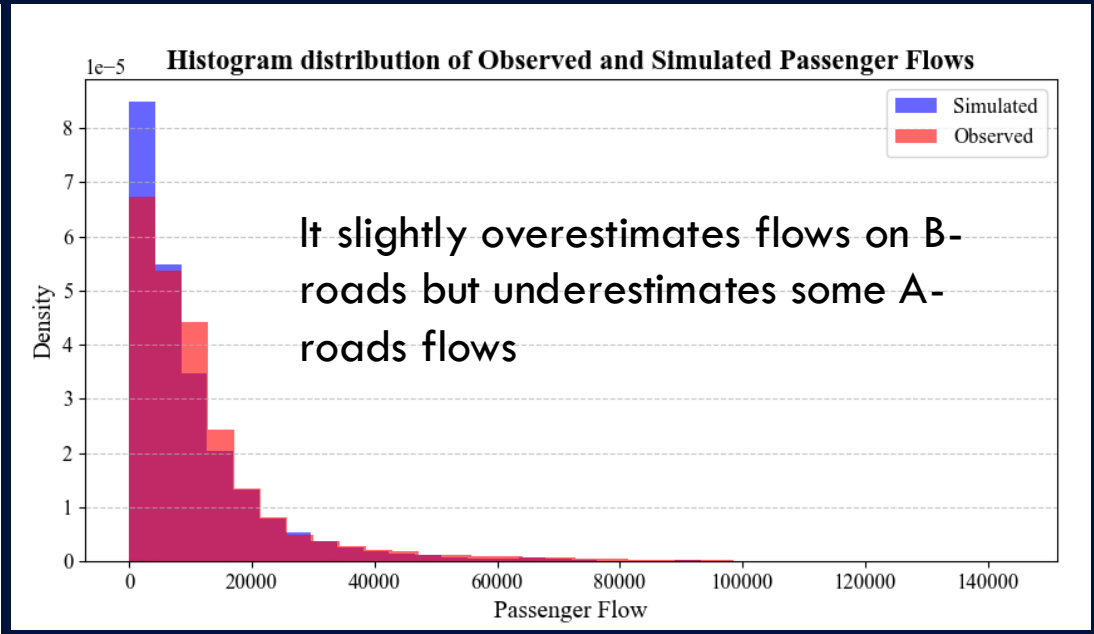


Journey-to-work trip allocation

- Current analysis uses the **2021 journey-to-work statistics at ~ 235,000 Output Areas (OA) level harmonised for Great Britain**, but model is generic
- **~12 million journey-to-work trips** across Great Britain's **~82,000 kms motorways, A-road and B-roads**
- **Speed and capacity consideration** along roads to account for **congestion as trips get allocated**

Demonstration – *GB scale trip allocation*



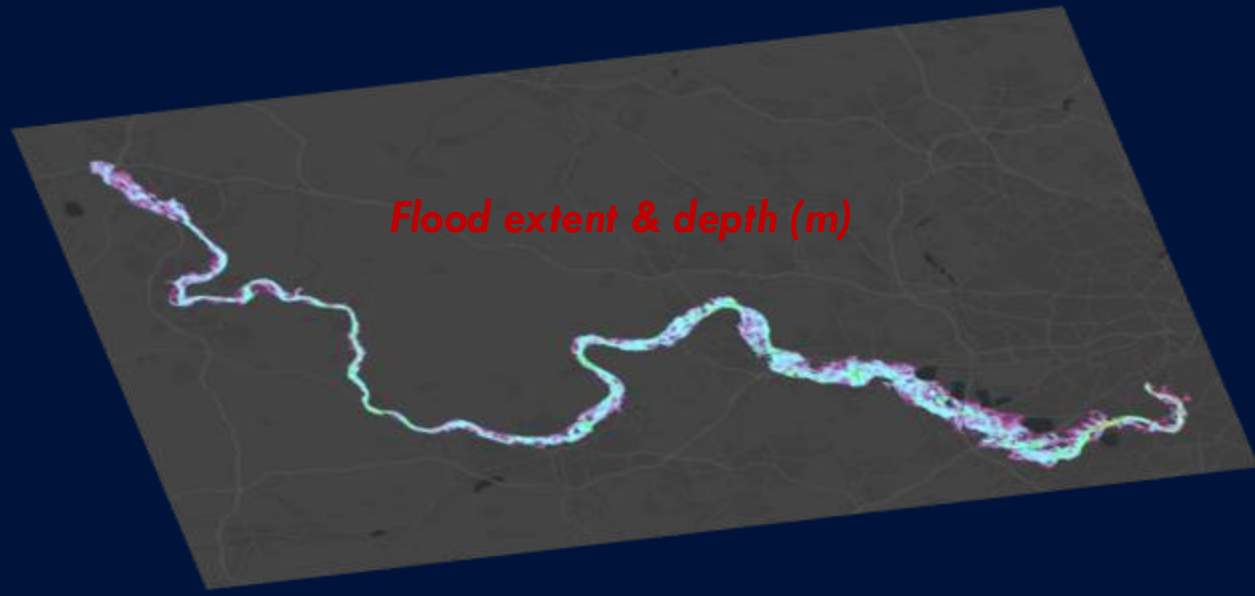


Gaps addressed

- ❑ No **national-scale model for trip allocation** at such detailed scale
- ❑ Builds **national scale picture from local scale**

Introducing flood events

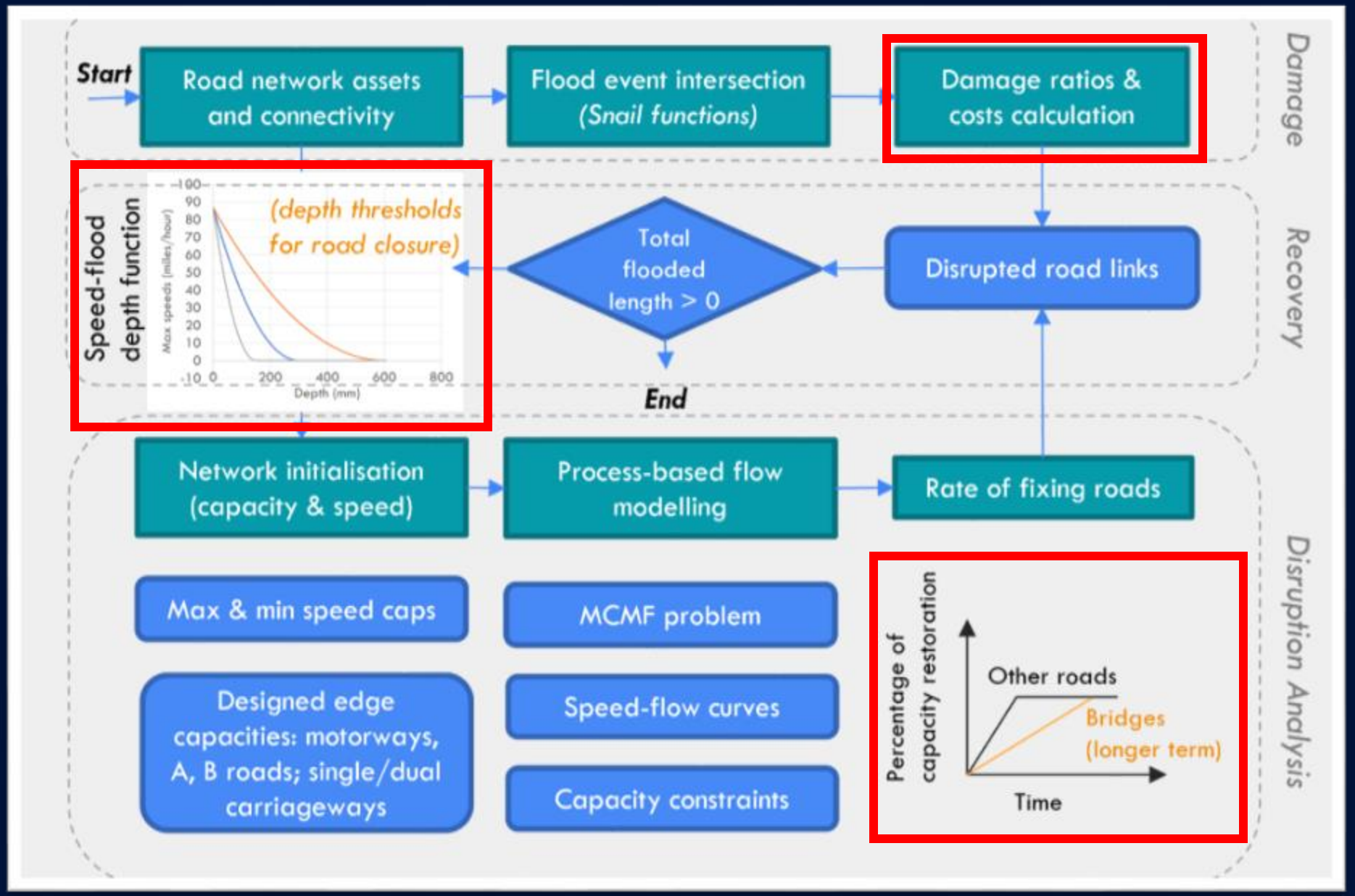
Year	Events
1953	1953 UK
1998	1998 Easter_UK Floods
2007	2007 Summer_UK Floods/May
2007	2007 Summer_UK Floods/June
2007	2007 Summer_UK Floods/July
2013	2013 December_UK Storm Xaver
2014	2014 February_UK Southern England
2015	2015 December_UK Storm Desmond
2015	2015 December_UK Storm Eva
2015	2015 December_UK Storm Frank
2016	2016 January_UK Scotland
2018	2018 May_UK Midlands
2019	2019 November_UK Floods
2020	2020 February_UK Storm Ciara
2020	2020 February_UK Storm Dennis
2023	2023 October_UK ROI Storm Babet
2024	2024 January_UK Storm Henk_U



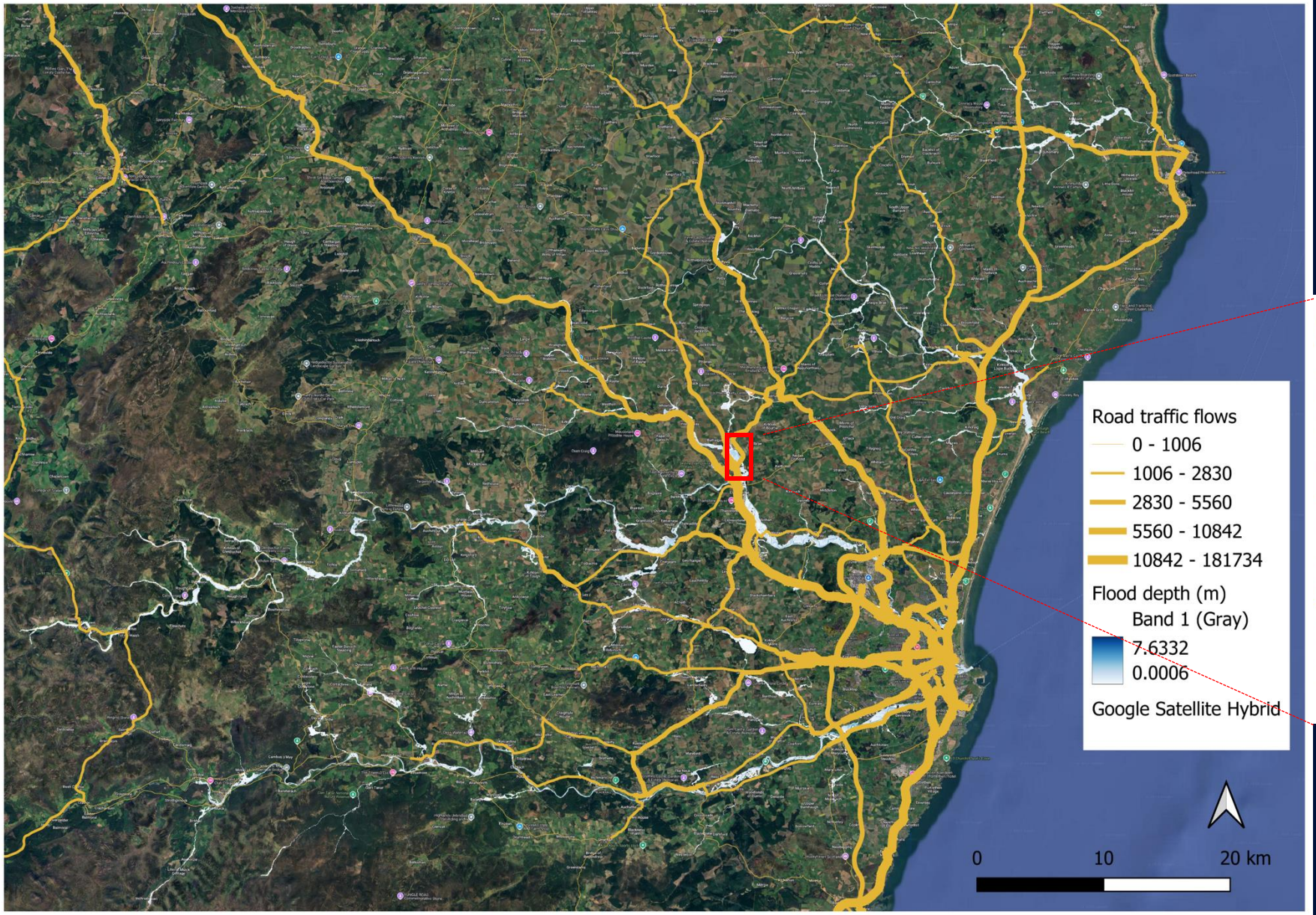
- Using **known extreme flood events** to do a **counterfactual stress-testing of road networks with 2021 flow conditions**
- Flood events here show **maximum flood depths over number of days**

JBA risk management

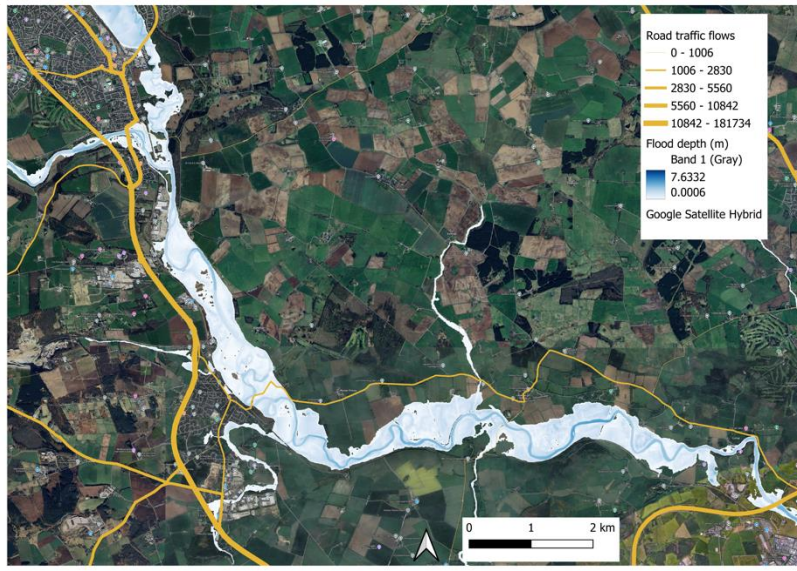
Damage and disruption assessment



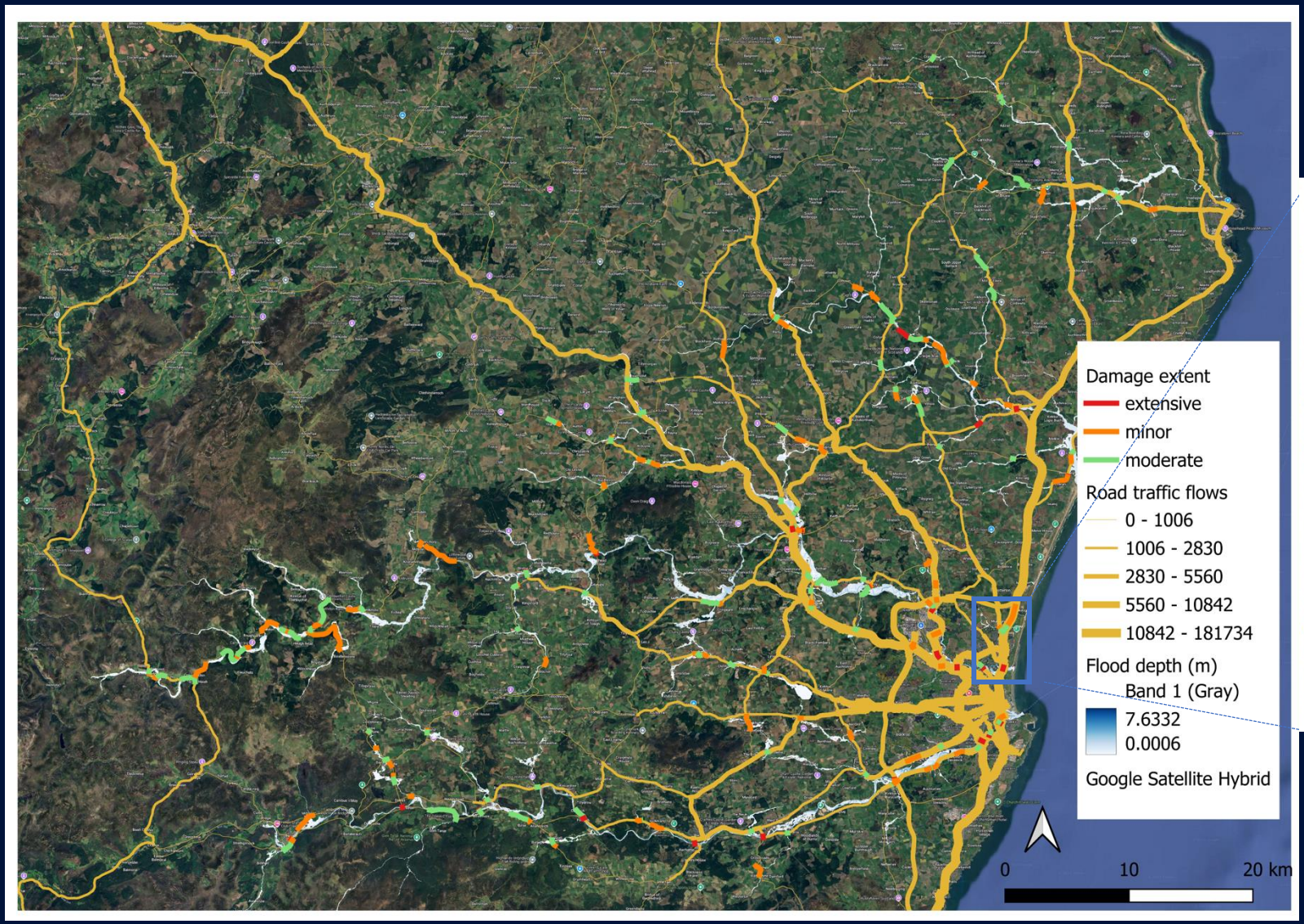
Demonstration – *Example flood event*



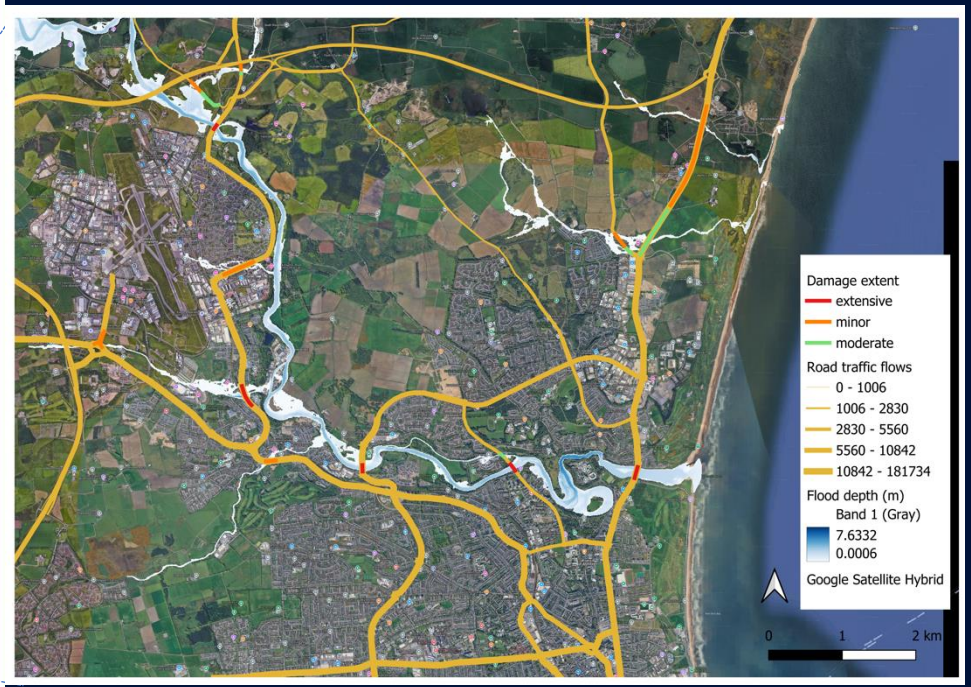
2016
Floods in Scotland



Demonstration – *Flood damages*

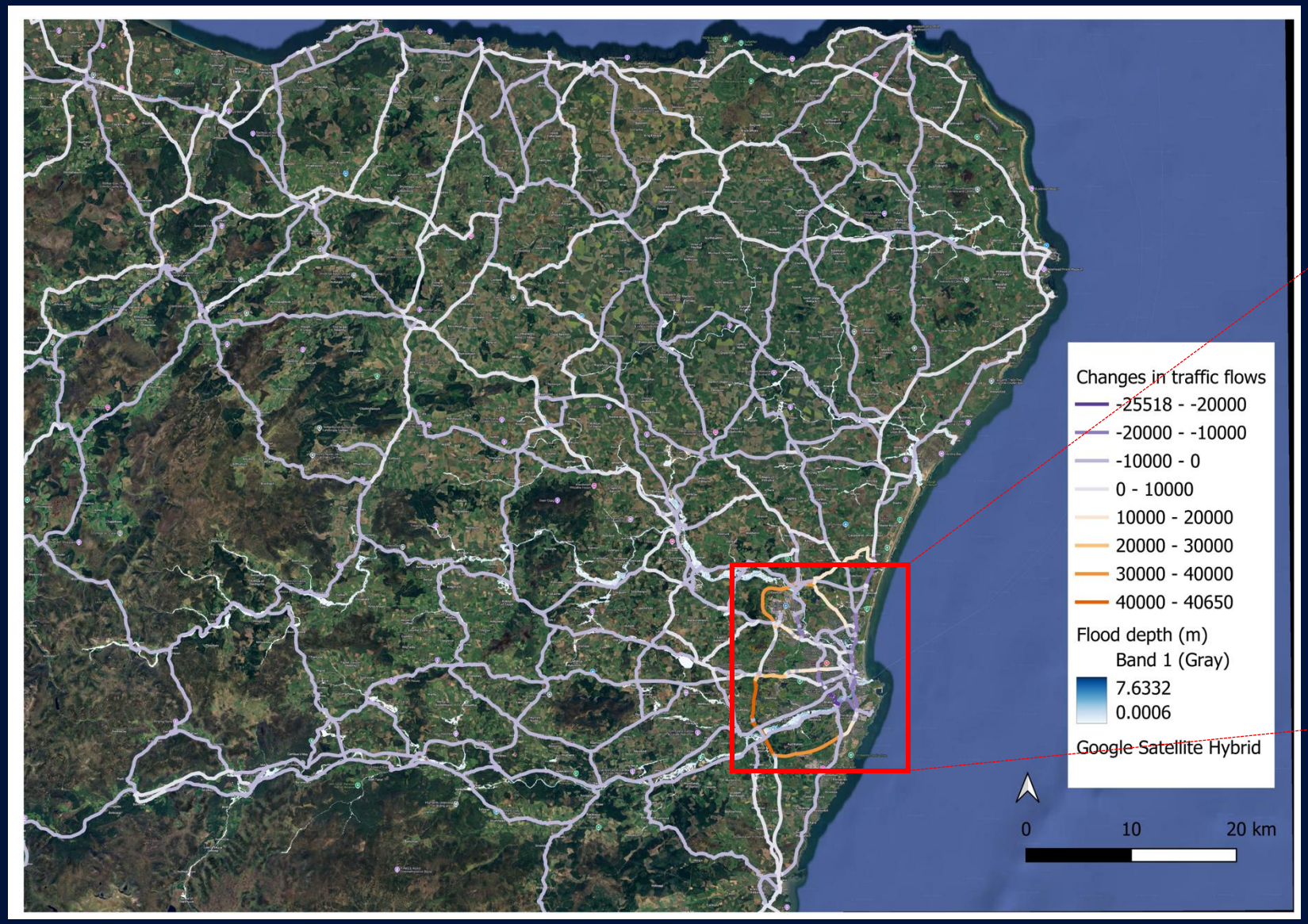


2016
Floods in Scotland

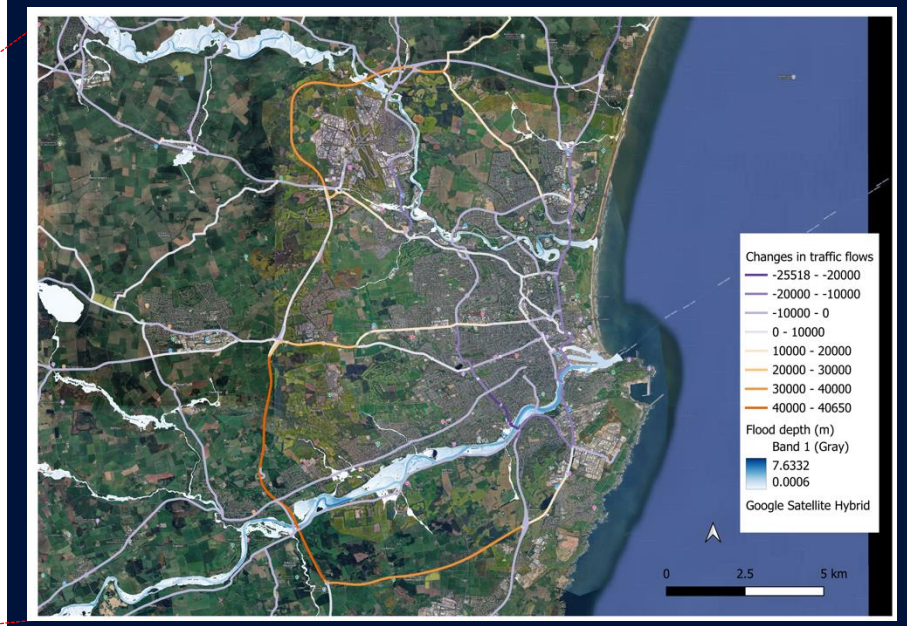


Estimated direct damages
£12.3 – 17.7 million

Demonstration – *Flood disruption*

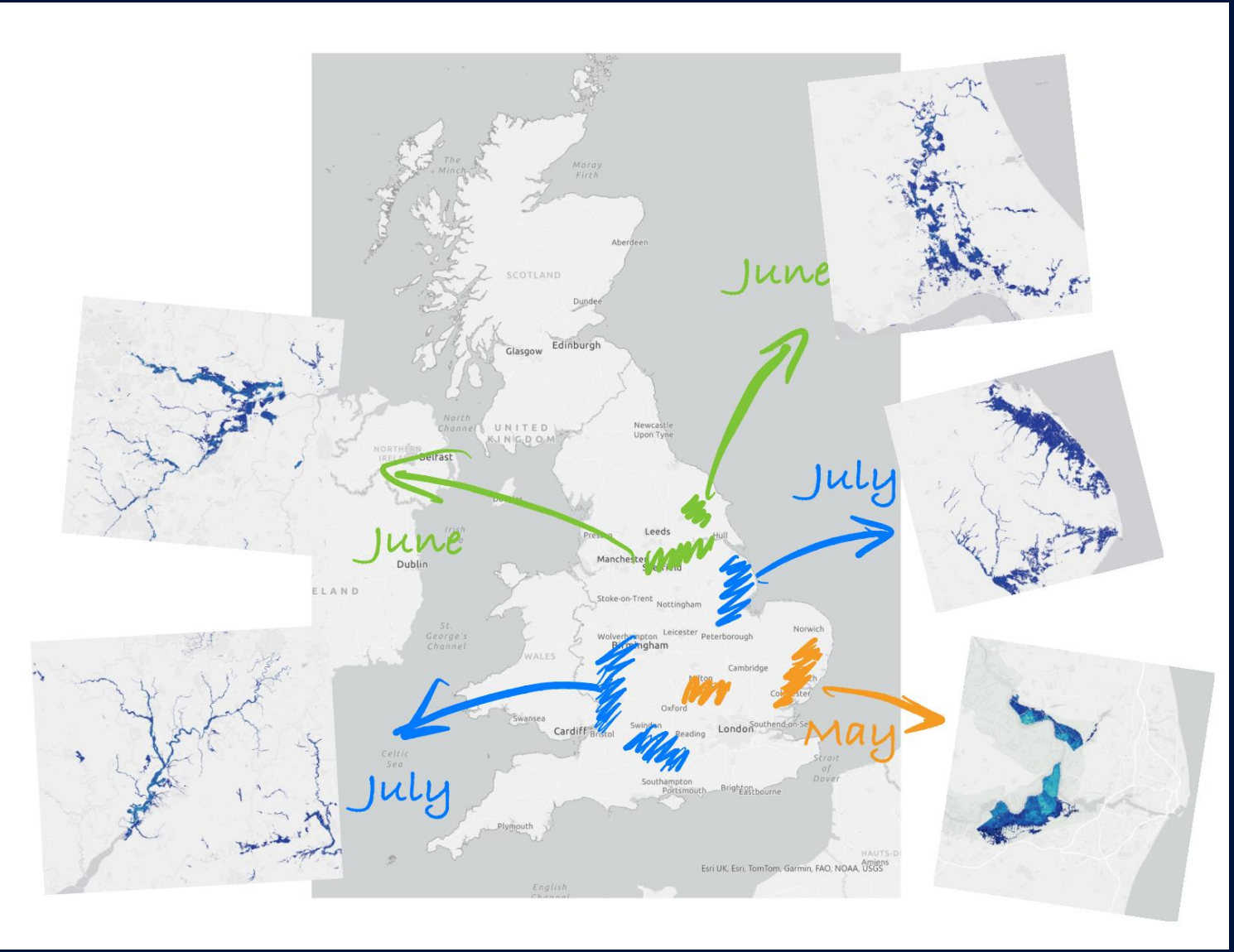


2016
Floods in Scotland



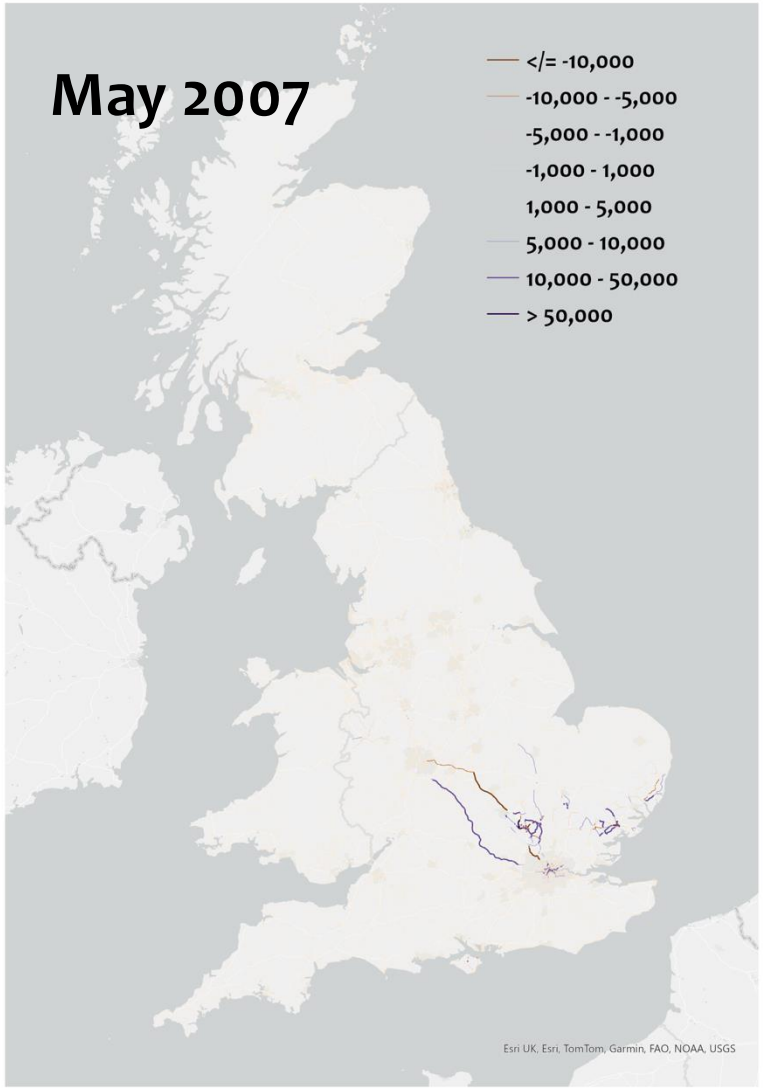
Estimated disruptive impacts
£90 – £150 million

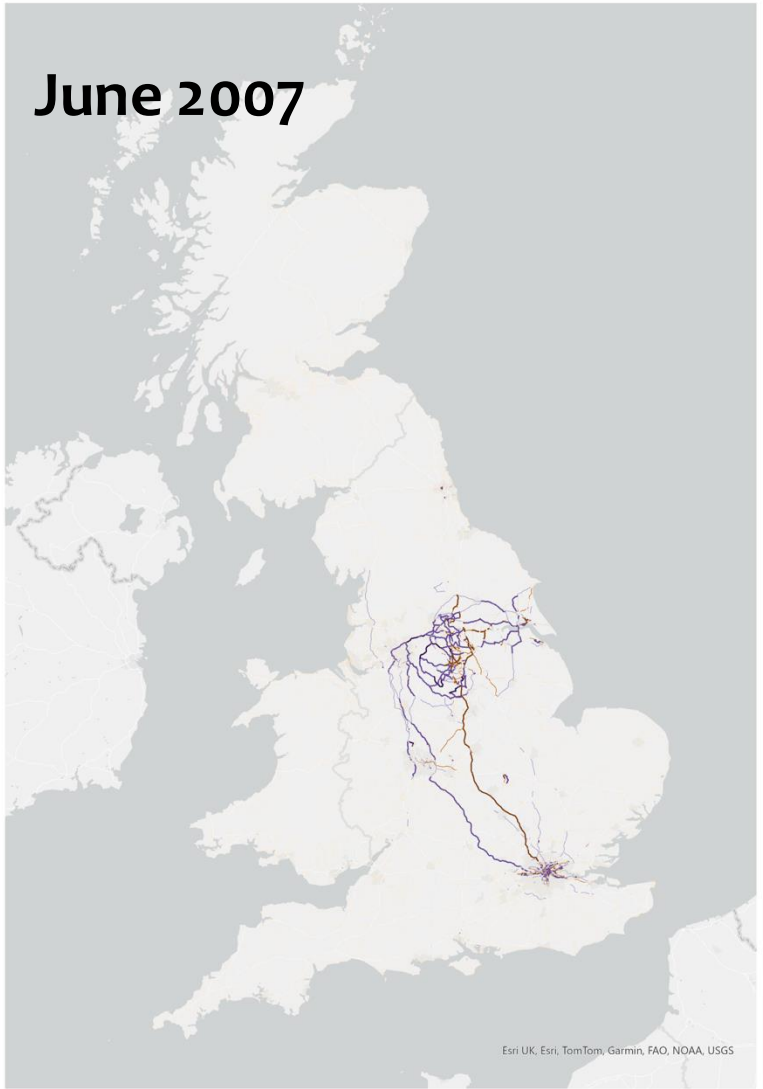
Demonstration – *2007 UK Summer Floods*

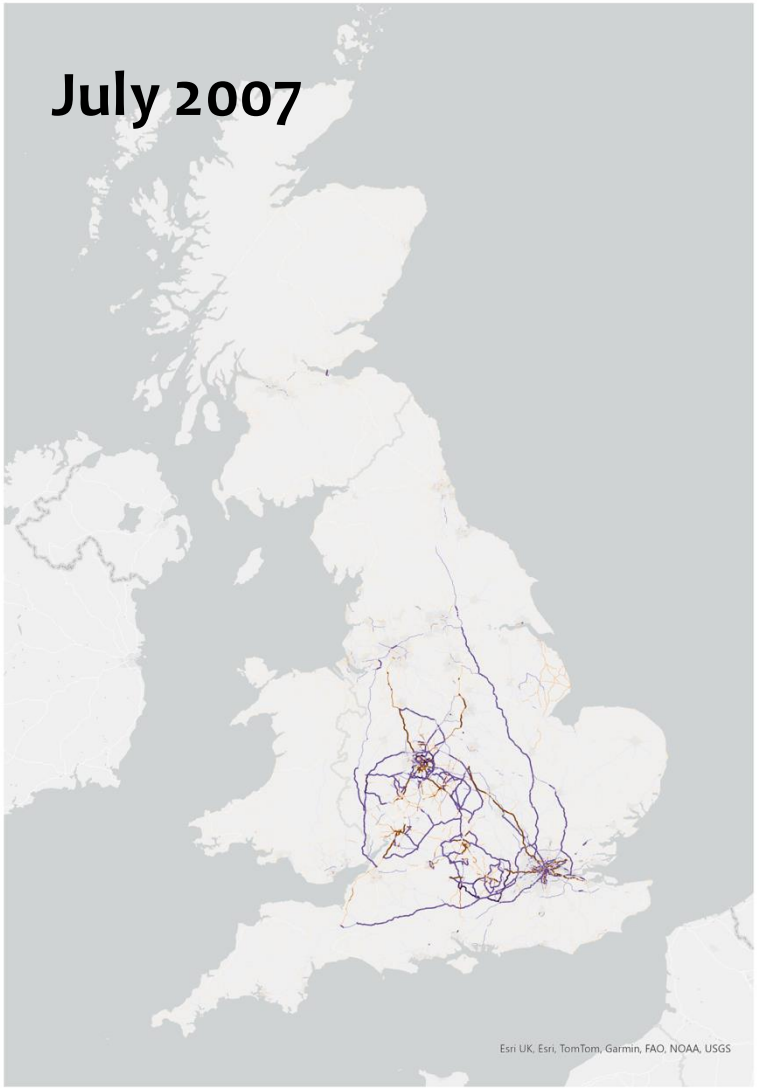


- Flood extent/coverage for **May (orange), June (green) and July (blue)**
- The flood data include both **surface (FLSW) and river (FLRF) flood event maps** across three months

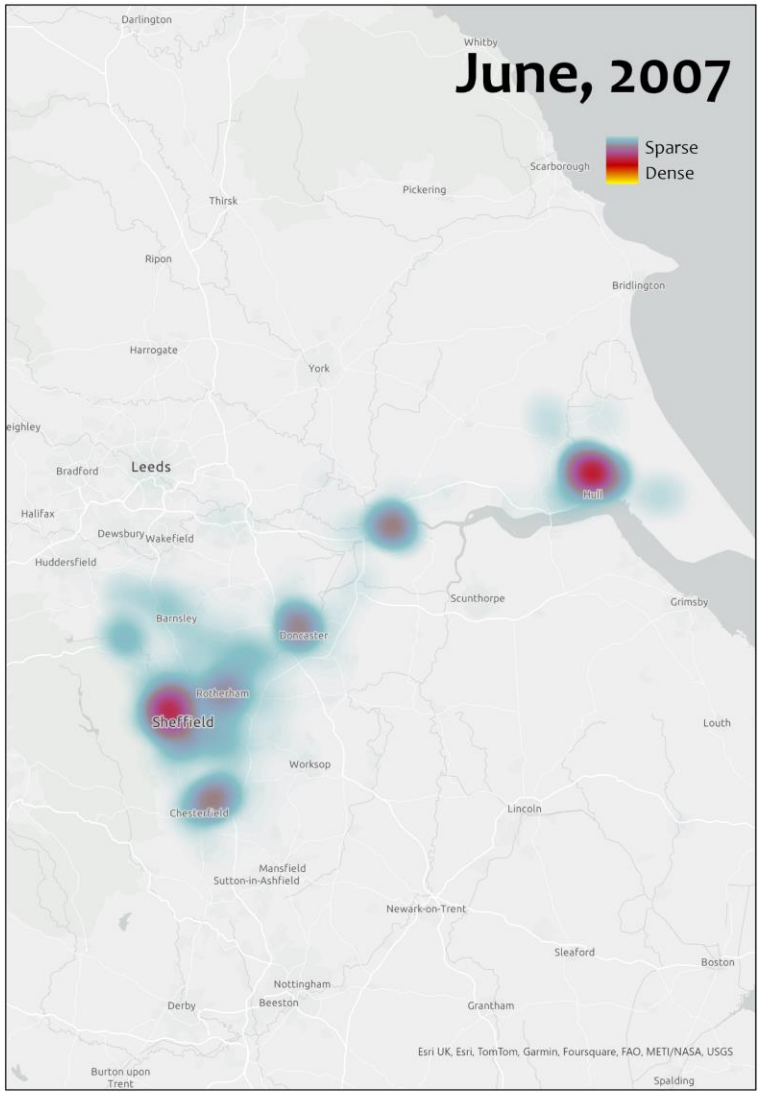
Demonstration – *Flow Changes under UK Summer Floods*

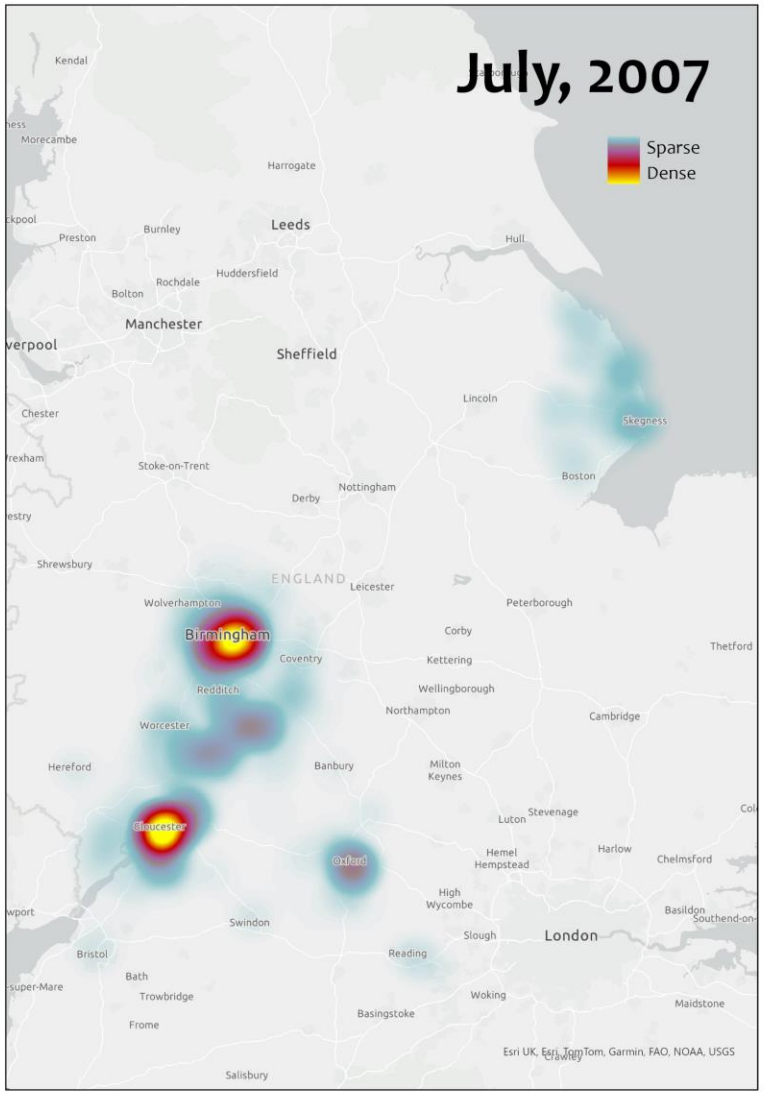






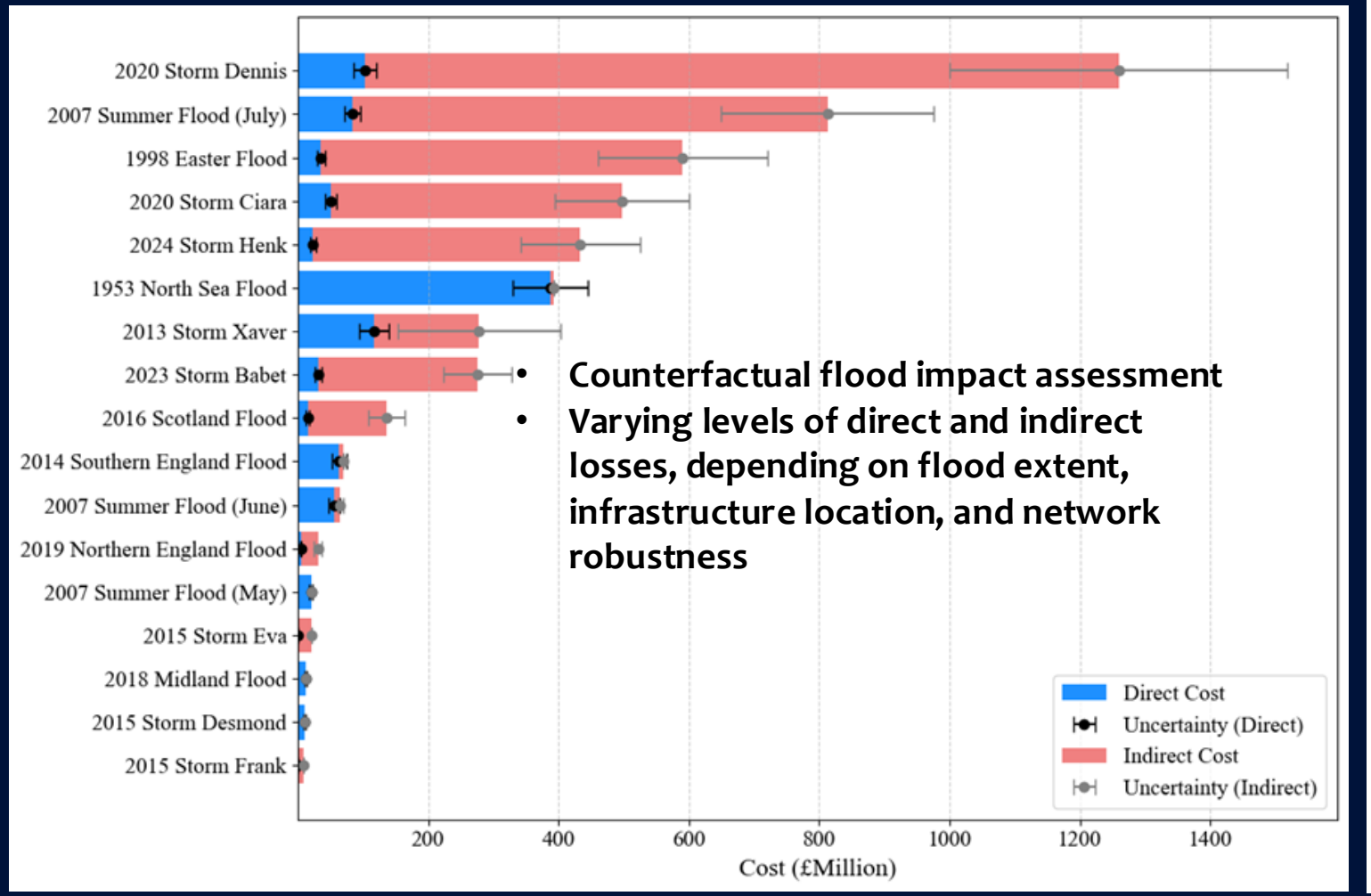
Demonstration - *Isolated Passenger Flow Heatmap*



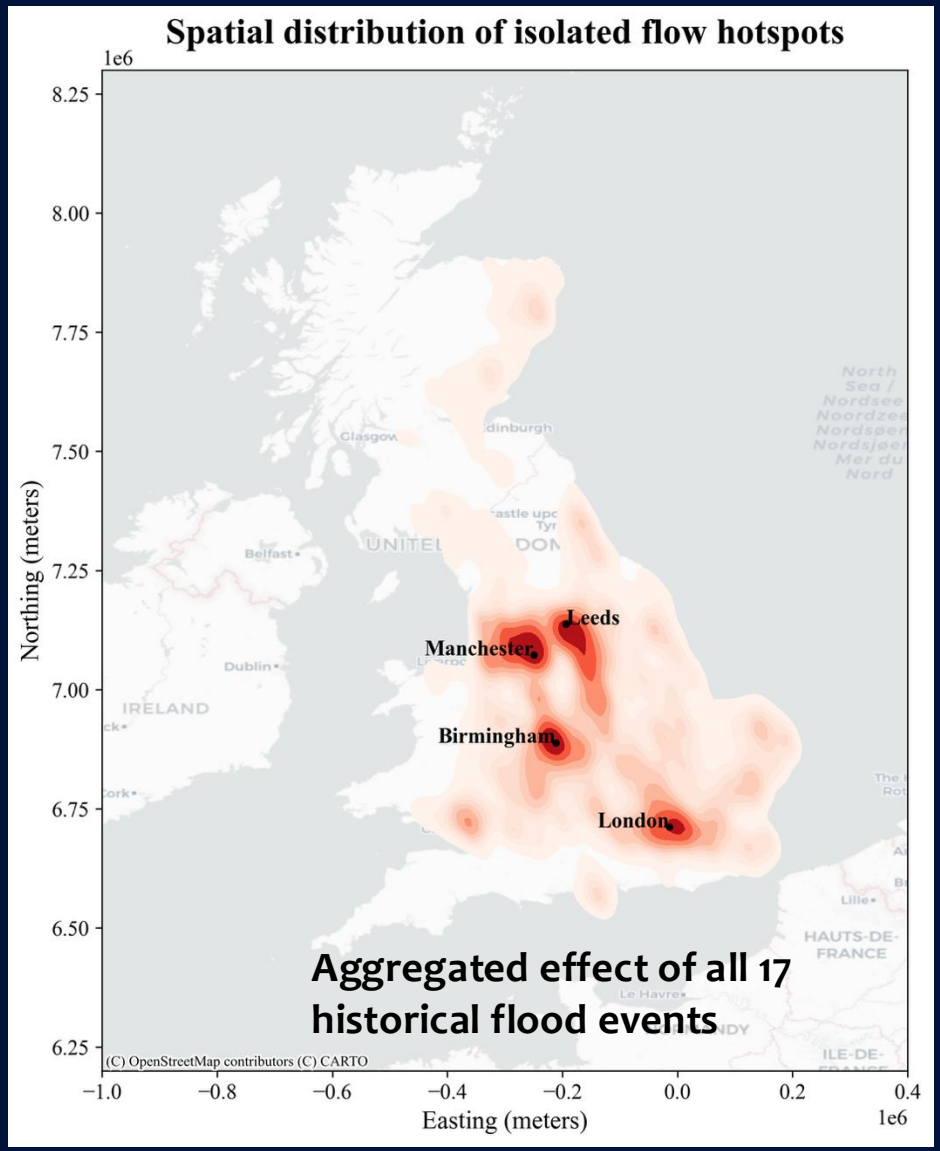


Demonstration – *National scale*

Direct vs indirect damages



- Counterfactual flood impact assessment
- Varying levels of direct and indirect losses, depending on flood extent, infrastructure location, and network robustness

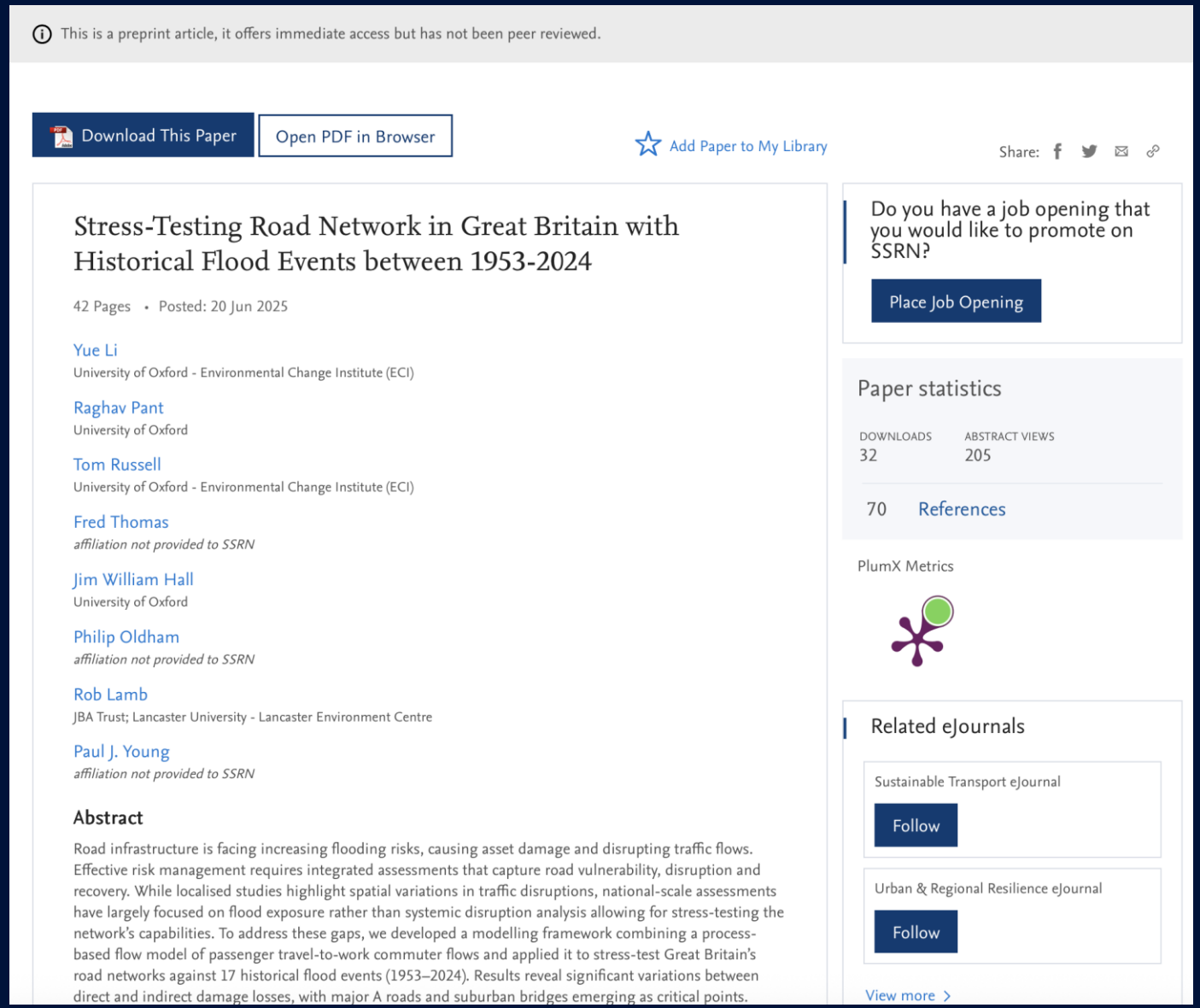


Aggregated effect of all 17 historical flood events

Economic losses validation – *Average losses*

Flood events	Average direct damage costs (£ million)	Average indirect damage costs (£ million)	Estimated total damage costs (£ million)	Estimated total damage costs (by group)	Reported total losses
1953 UK	387	6	393	total: £ 393 million direct: £ 387 million (98%) indirect: £6 million (2%)	multi-sector total direct: £1.3 billion **transport: ~£433 million**
2007 Summer_UK Floods/July	83	729	812	total: £897 million direct: £159 million (18%) indirect: £738 million (82%)	direct: £127 million indirect with uncertainties: £22~174 million
2007 Summer_UK Floods/June	55	9	64		
2007 Summer_UK Floods/May	21	0.02	21		
2013 December_UK Storm Xaver	117	161	278	total: £348 million direct: £180 million (52%) indirect: £ 168 million (48%)	total: £225 million direct: £112.5 million (50%) indirect: £112.5 million (50%)
2014 February_UK Southern England	63	6	70		
2015 December_UK Storm Desmond	10	0.00	10	total: £278 billion direct: £ 129 million (43%) indirect: £149 billion (57%)	total: £258 million direct: £129 million (50%) indirect: £129 million (50%)
2015 December_UK Storm Eva	78	21	99		
2015 December_UK Storm Frank	26	8	34		
2016 January_UK Scotland	15	120	135		

Project outcomes – *Journal Paper under review*



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Stress-Testing Road Network in Great Britain with Historical Flood Events between 1953-2024

42 Pages • Posted: 20 Jun 2025

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Abstract

Road infrastructure is facing increasing flooding risks, causing asset damage and disrupting traffic flows. Effective risk management requires integrated assessments that capture road vulnerability, disruption and recovery. While localised studies highlight spatial variations in traffic disruptions, national-scale assessments have largely focused on flood exposure rather than systemic disruption analysis allowing for stress-testing the network's capabilities. To address these gaps, we developed a modelling framework combining a process-based flow model of passenger travel-to-work commuter flows and applied it to stress-test Great Britain's road networks against 17 historical flood events (1953–2024). Results reveal significant variations between direct and indirect damage losses, with major A roads and suburban bridges emerging as critical points.

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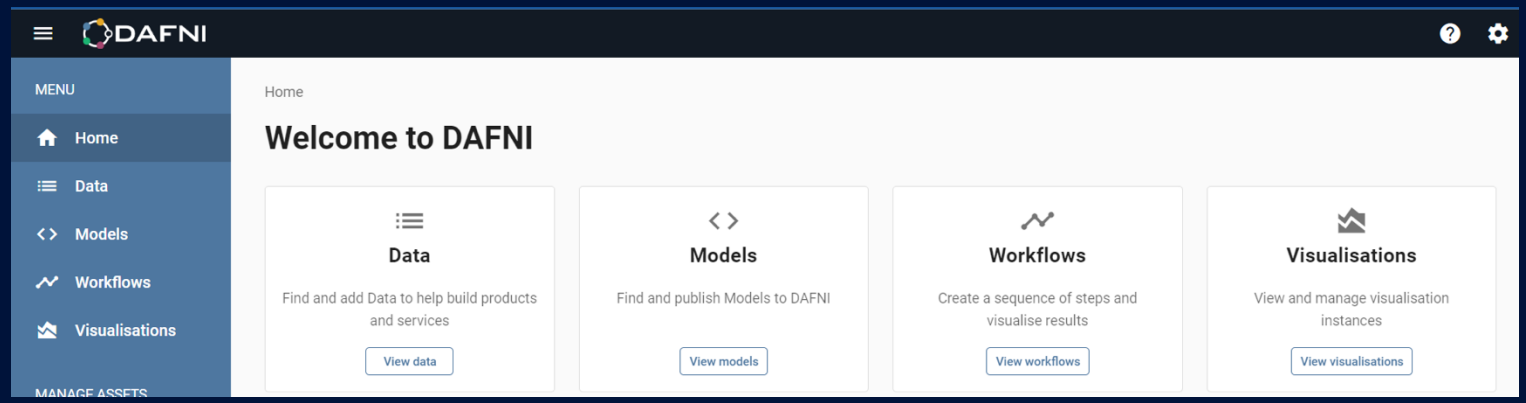
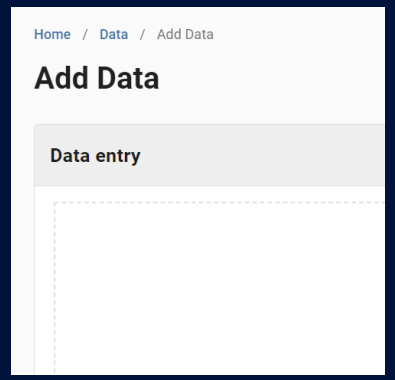
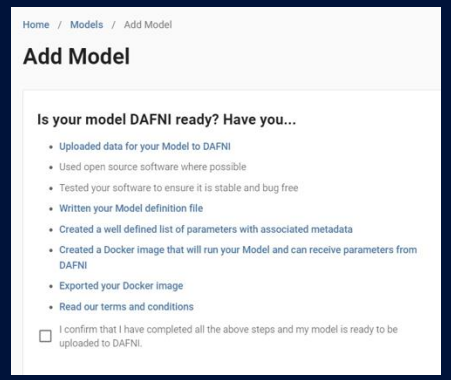
Project outcomes – *Implementation on DAFNI Platform*



Data Packaging and Uploading

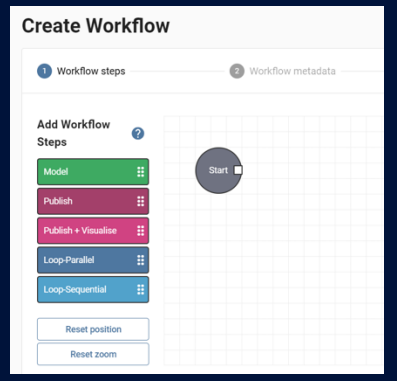


Use Docker to Manage Model Scripts

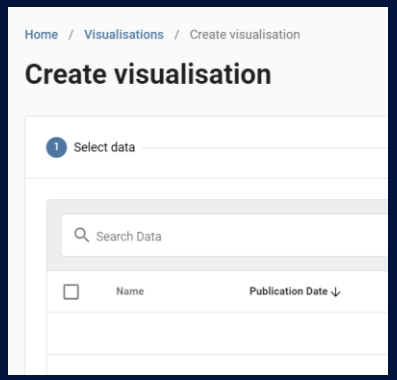


Create a Docker file → Building a Docker image → Run a Docker container

Define the Connection between Models

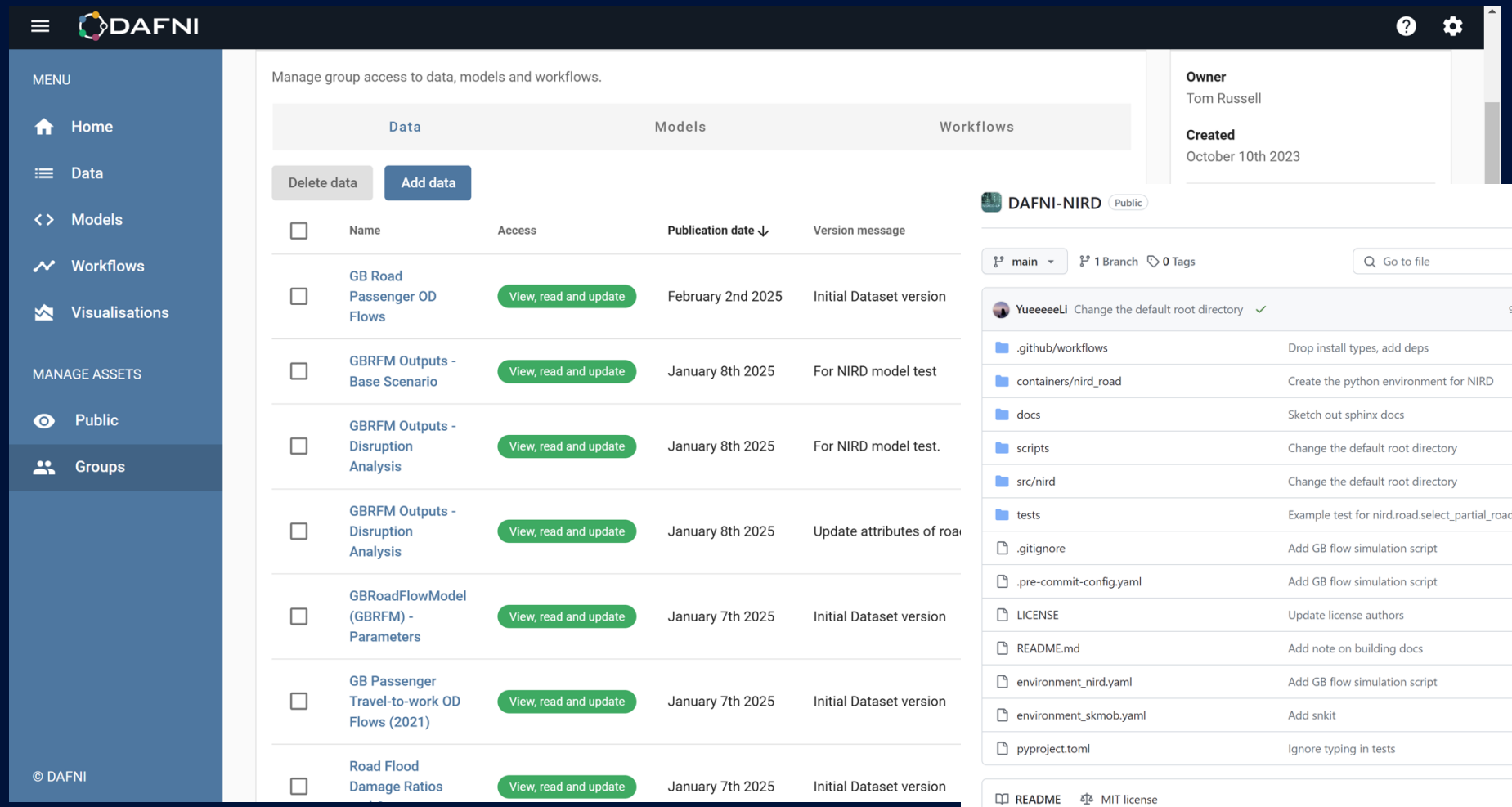


Create Instance for Visualisation



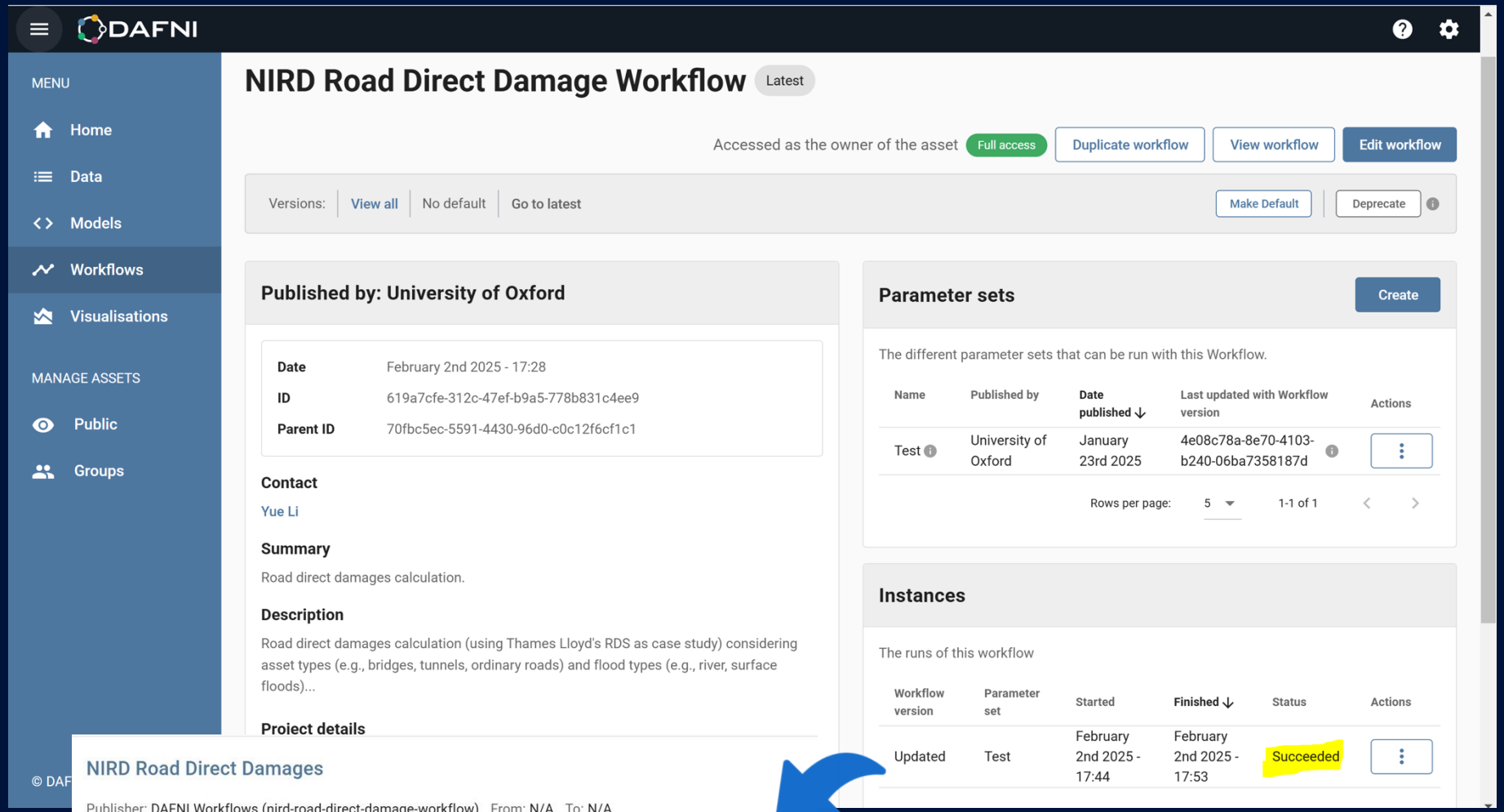
Create an Instance to run the workflow and generate outputs

Project Outcomes – *Open-access data and code*



https://github.com/nismod/DAFNI-NIRD

Project Outcomes – *Outputs on DAFNI platform*

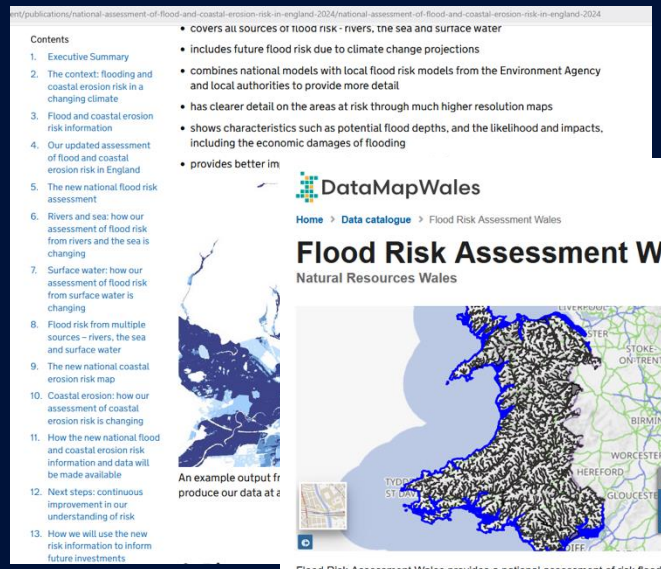


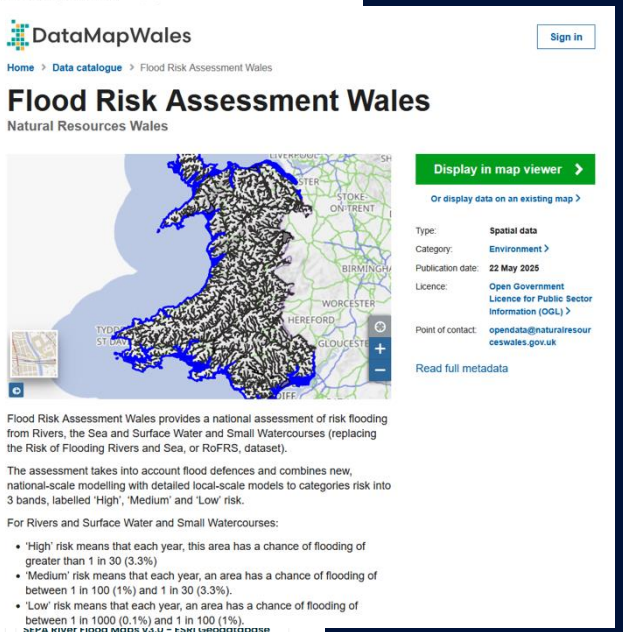
Outputs (automatically saved to the Data catalogue)

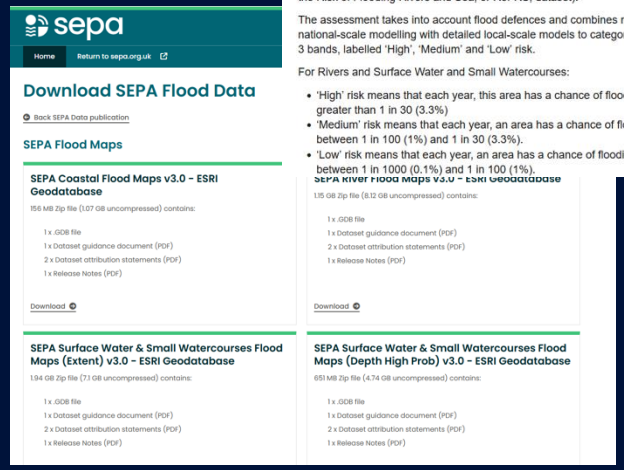
Ongoing and future work

NIRD + OpenCLIM

UK SSPs: future population grids







- How will **road flows change in the future** under new population scenarios?
- How will **flood vulnerability outcomes change in the future**?

OpenCLIM population scenarios

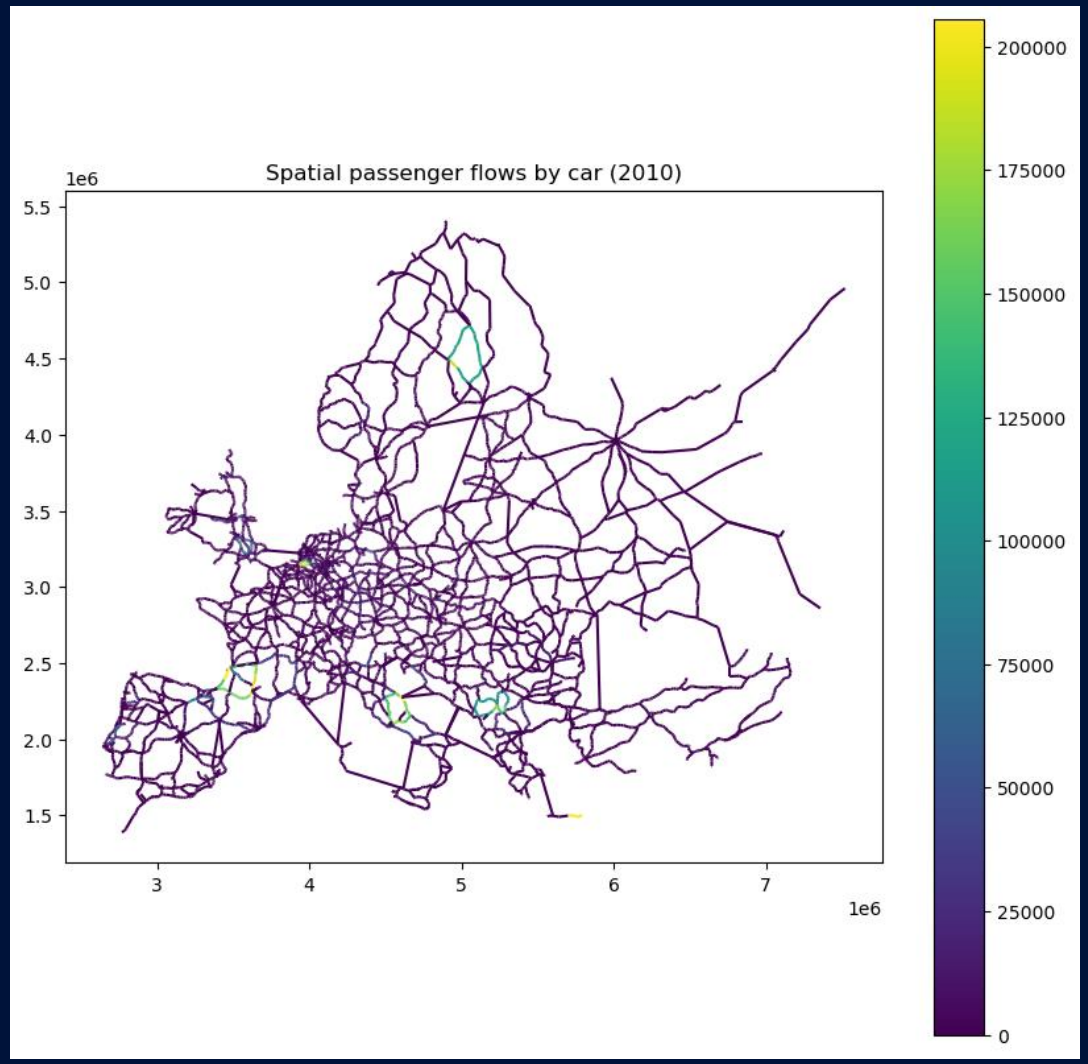
- SSP 1-5 for 2030, 2050 and 2080

Implementation – Work in progress

- Recreate road flows by **extrapolating existing journey-to-work patterns** to future populations
- Stress-test with NAFRA2 flood maps with climate scenarios

Ongoing and future work – *pan European analysis*

miraca

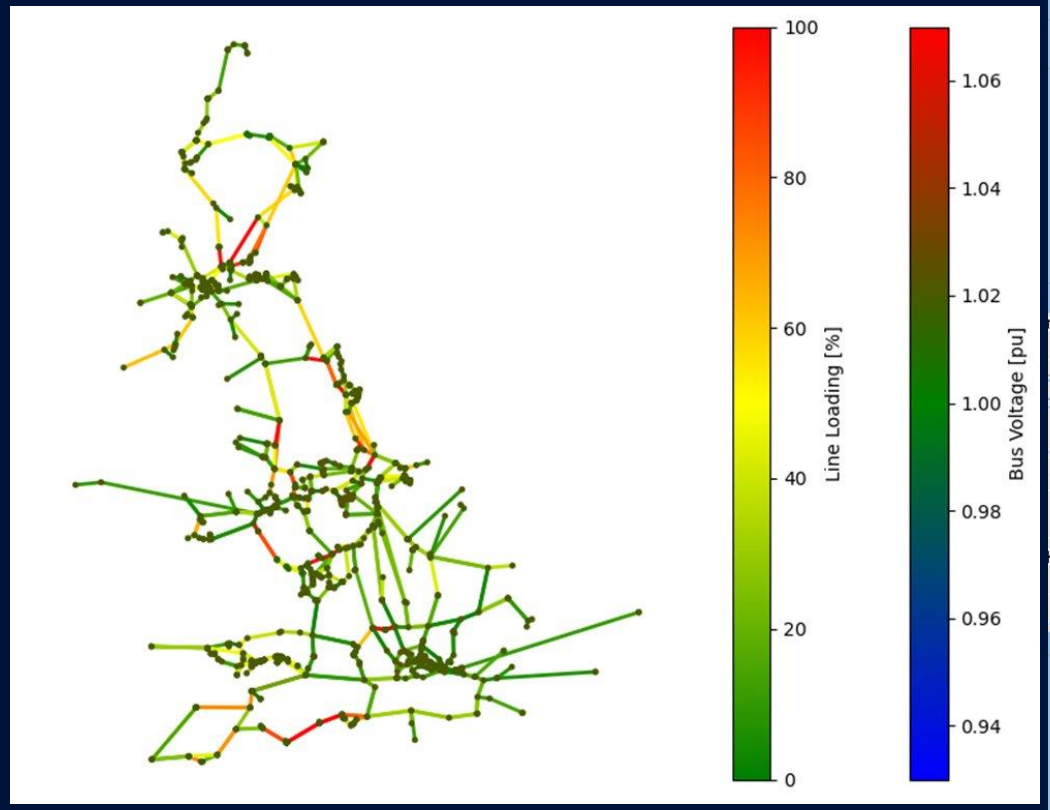


Multi-hazards Risk Assessment for Climate Adaptation (MIRACA)

- Extend event-based stress test from floods to **multiple hazardous events**
- Extend our methods further to the **pan-EU scale**
- Extend the methods to multi-modal transport networks – **Roads, Railways, Inland waterways, Maritime and Airlines**

Ongoing and future work – *Other sectors*

GB electricity transmission network



GB railway network

- **Process-based network flow models** from other sectors
- Resilience options for recovery
- Interdependency assessment

Conclusions – *Key learnings*

Value of work

- Development of **national-scale road disruption model**
- Workflow creation for **stress-testing under various hazard events** for counterfactual analysis
- Useful for improving understanding of **systemic failure impacts**

Further developments

- Extend to **synthetic flood events with future climate scenarios**
- Extend to other scales such as **pan-European**
- Produce similar metrics for **other sectors**

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