



# National Infrastructure Resilience Demonstrator (NIRD)

## *Stress-testing road networks against extreme floods*

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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



# OPSIS

Shaping the future of resilient and sustainable infrastructure

The Oxford Programme for Sustainable Infrastructure Systems (OPSIS) provides research and education to enable sustainable and resilient infrastructure. We are at the forefront of methodologies for analysing infrastructure systems (energy, transport, water and telecommunications) and their interactions with the natural environment, people and the economy.

We believe that the choices made about infrastructure, urbanization and land use change are fundamental to the sustainability of the planet and the well-being of all its peoples. We aim to improve decision making by providing evidence and tools to analyse infrastructure systems' resilience, explore possible futures and plot out pathways to sustainability.

<https://opsis.eci.ox.ac.uk/>





# Background – Increased flooding

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England | Local News

### Heavy rain and flooding prompts driving warning



LUKE DEAL/BBC

The A1214 through Kesgrave in Suffolk was flooded

**Alice Cunningham**  
BBC News, East of England

21 July 2025

Drivers are being urged to be cautious as heavy rainfall has led to a number of roads flooding.

Rain has hit parts of Suffolk, Norfolk and Essex after weeks of sunshine and warm temperatures.

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## NEWS

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Scotland | Scotland Politics | Scotland Business | Edinburgh, Fife & East | Glasgow & West | Highlands & Islands | NE, O

Alba

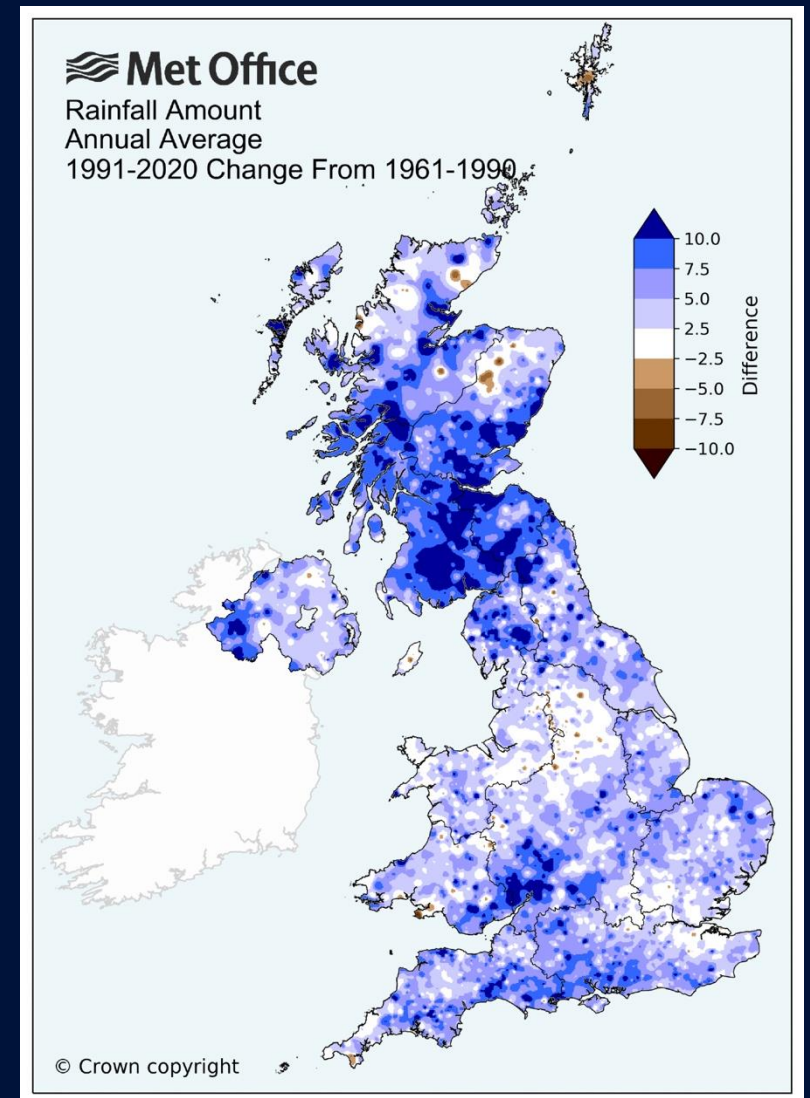
### Severe flooding causes road and rail disruption in Scotland

30 December 2022



Heavy rain causing floods in parts of Scotland

Flooding has caused travel disruption across Scotland after heavy rain in many parts of the country.



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

- Office of Budget Responsibility

# 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:

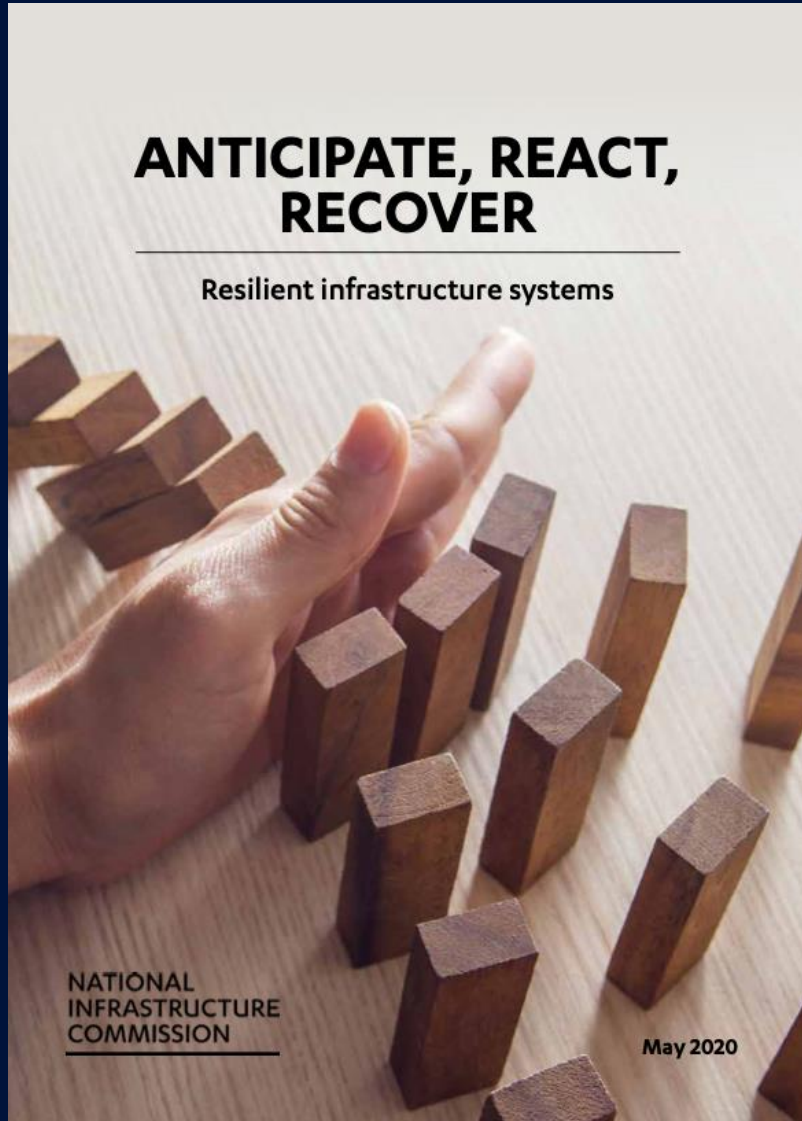
- 50% is assumed to be for **economic damages** for the local and strategic road networks
- 50% is assumed to be for **welfare damages (delay and disruption)** for the local and strategic road networks

### Key uncertainties

- The assumptions on welfare damages



# Motivation – *Stress-testing infrastructures*



## Recommendation

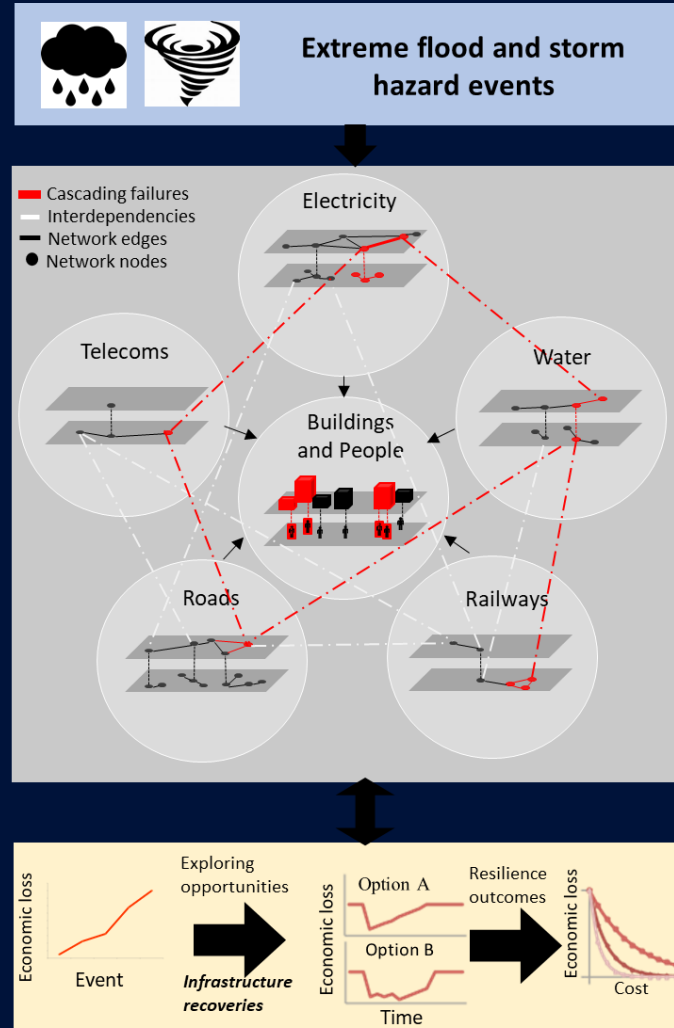
- Regulators should require a **system of regular stress testing by 2024 for infrastructure** operators, to ensure resilience standards for infrastructure services

## 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



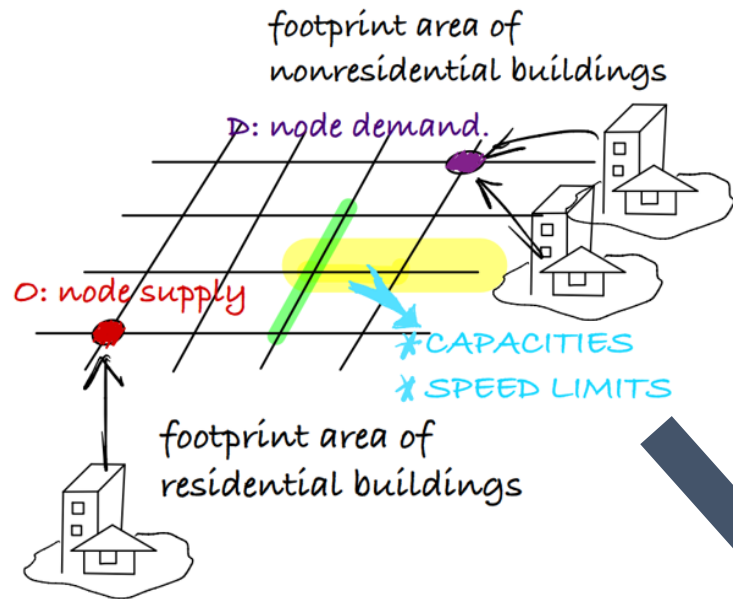
### Objectives

- (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



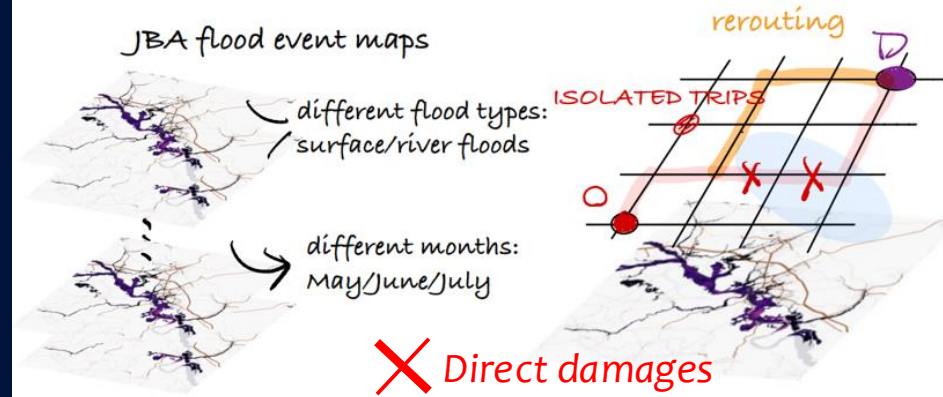
## Road Disruption and Rerouting Analysis



spatial flow changes

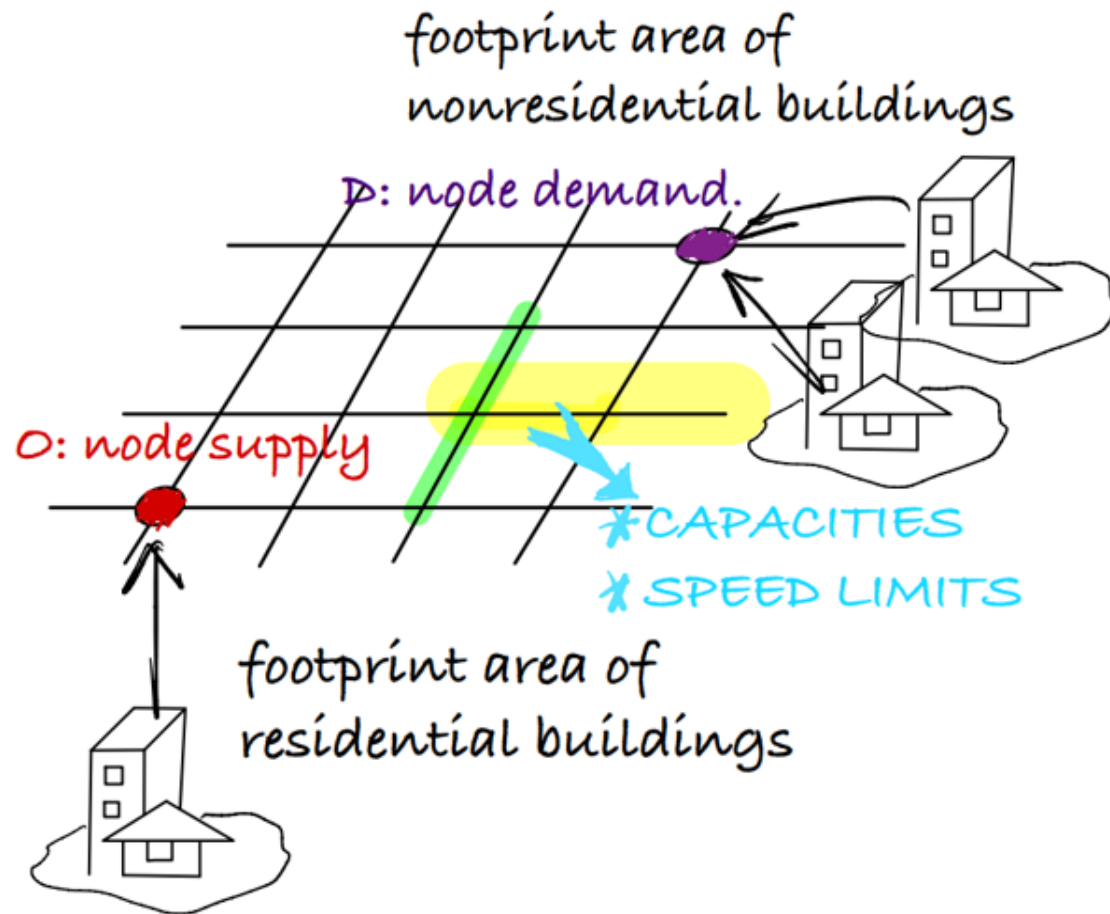


spatial trip isolation heatmap





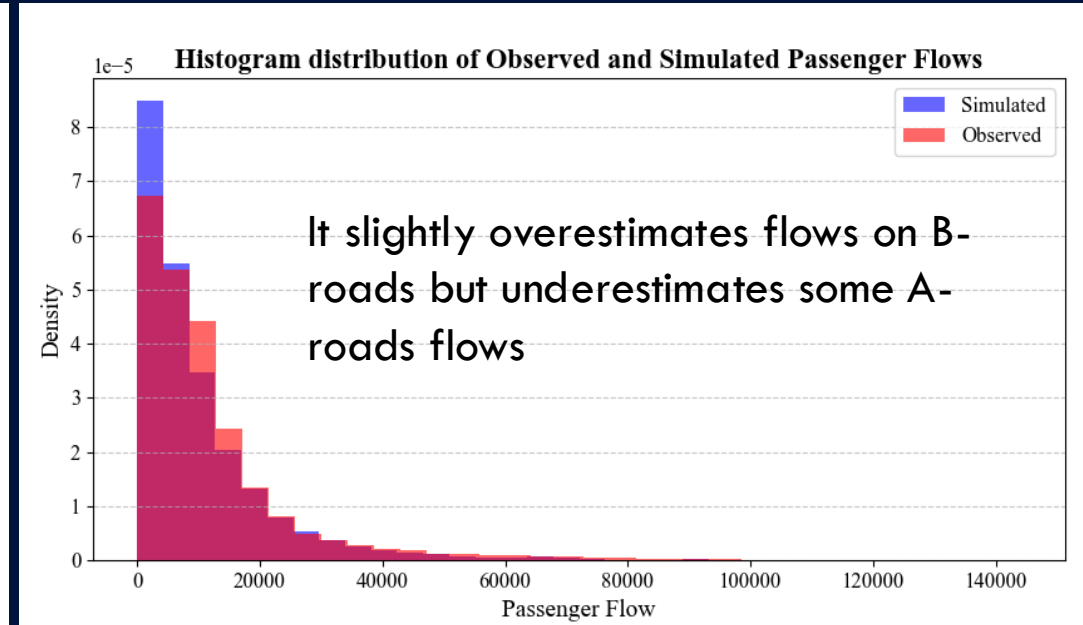
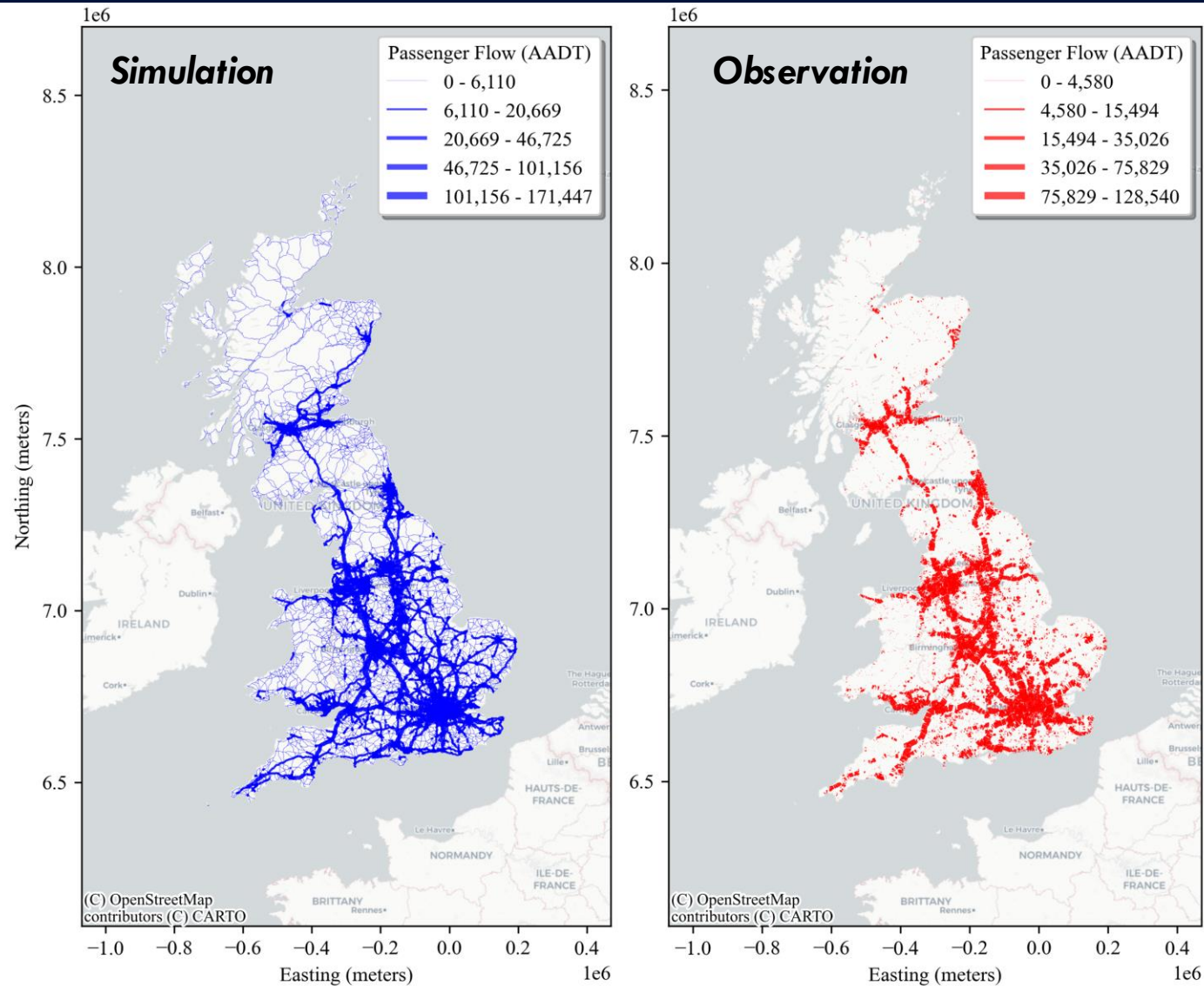
# Demonstration – GB scale trip allocation



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

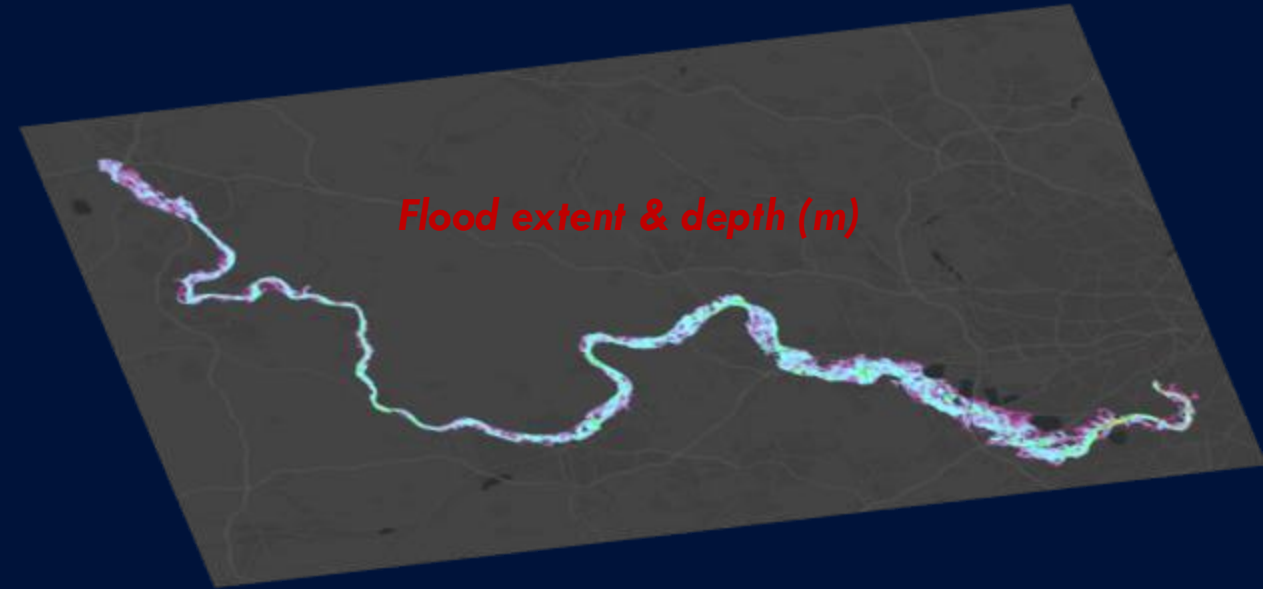


## Gaps addressed

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

# Introducing flood events

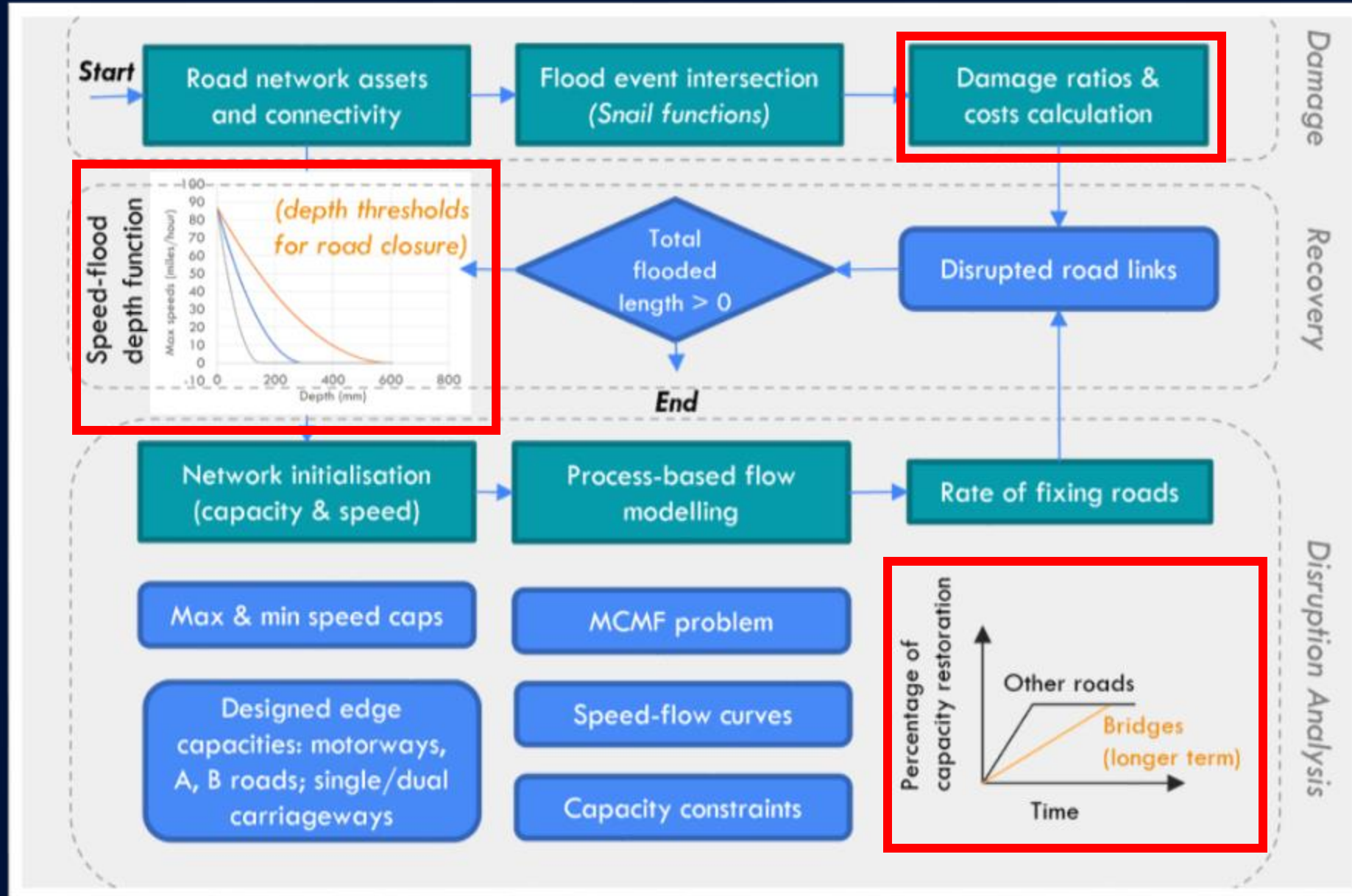
Year	Events
1953	1953 UK
1998	1998 Easter UK Floods
2007	2007 Summer UK Floods/May
2007	2007 Summer UK Floods/June
2007	2007 Summer UK Floods/July
2013	2013 December UK Storm Xaver
2014	2014 February UK Southern England
2015	2015 December UK Storm Desmond
2015	2015 December UK Storm Eva
2015	2015 December 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**



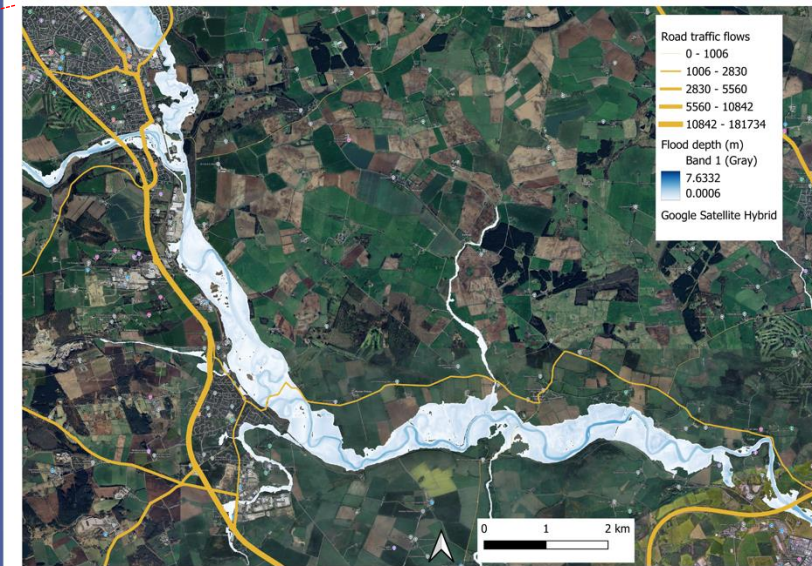
# Damage and disruption assessment





# Demonstration – *Example flood event*

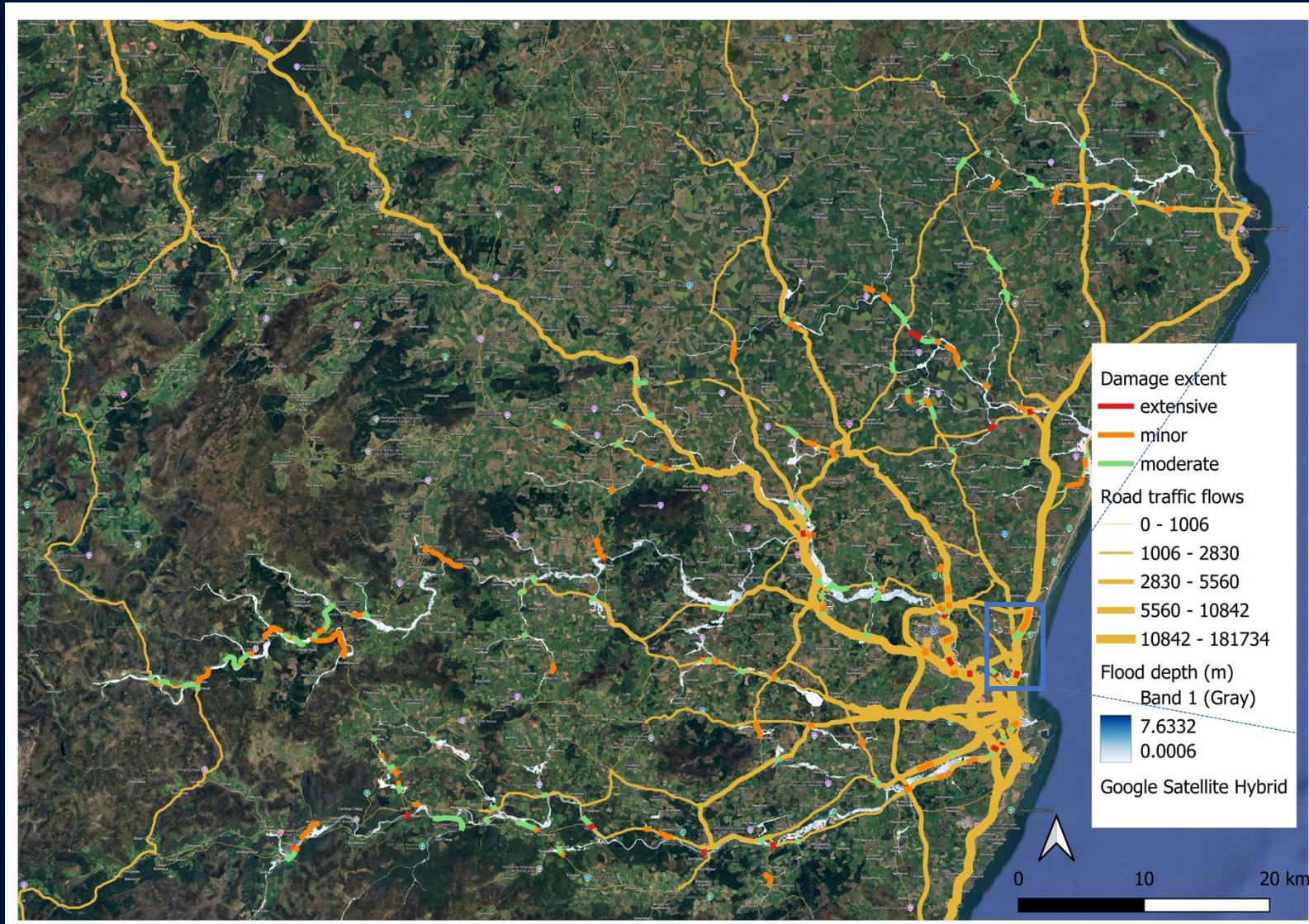
## 2016 Floods in Scotland





# Demonstration – Flood damages

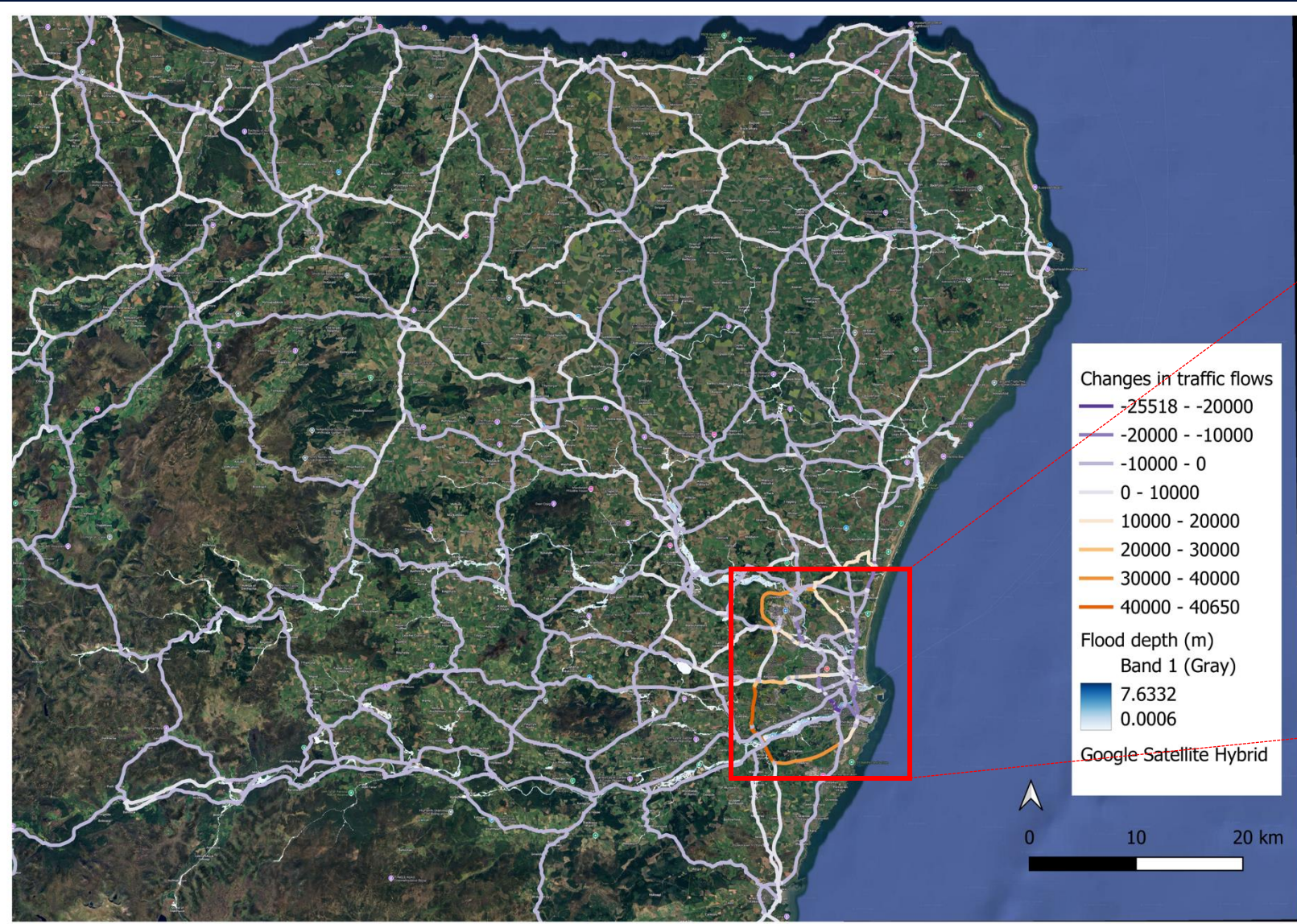
## 2016 Floods in Scotland



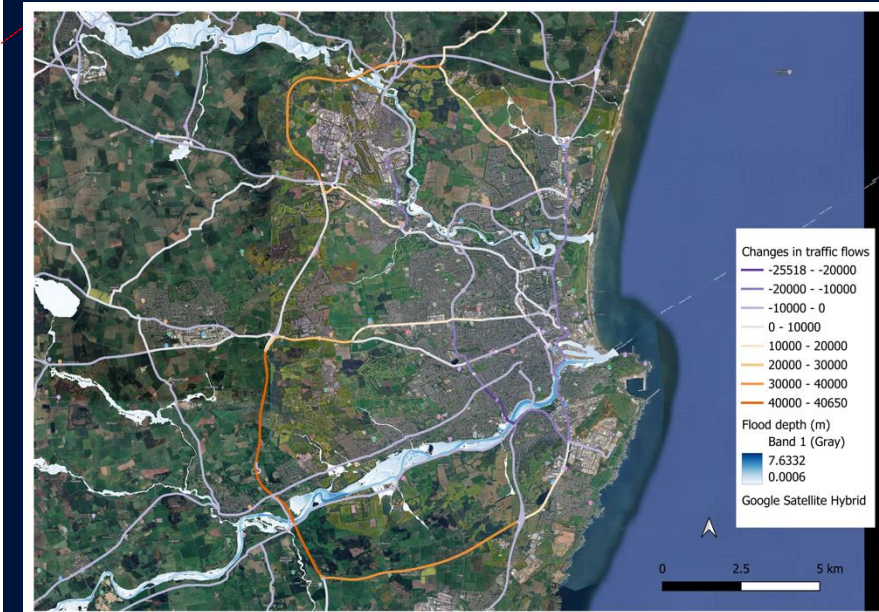
**Estimated direct damages  
£12.3 – 17.7 million**



# Demonstration – Flood disruption



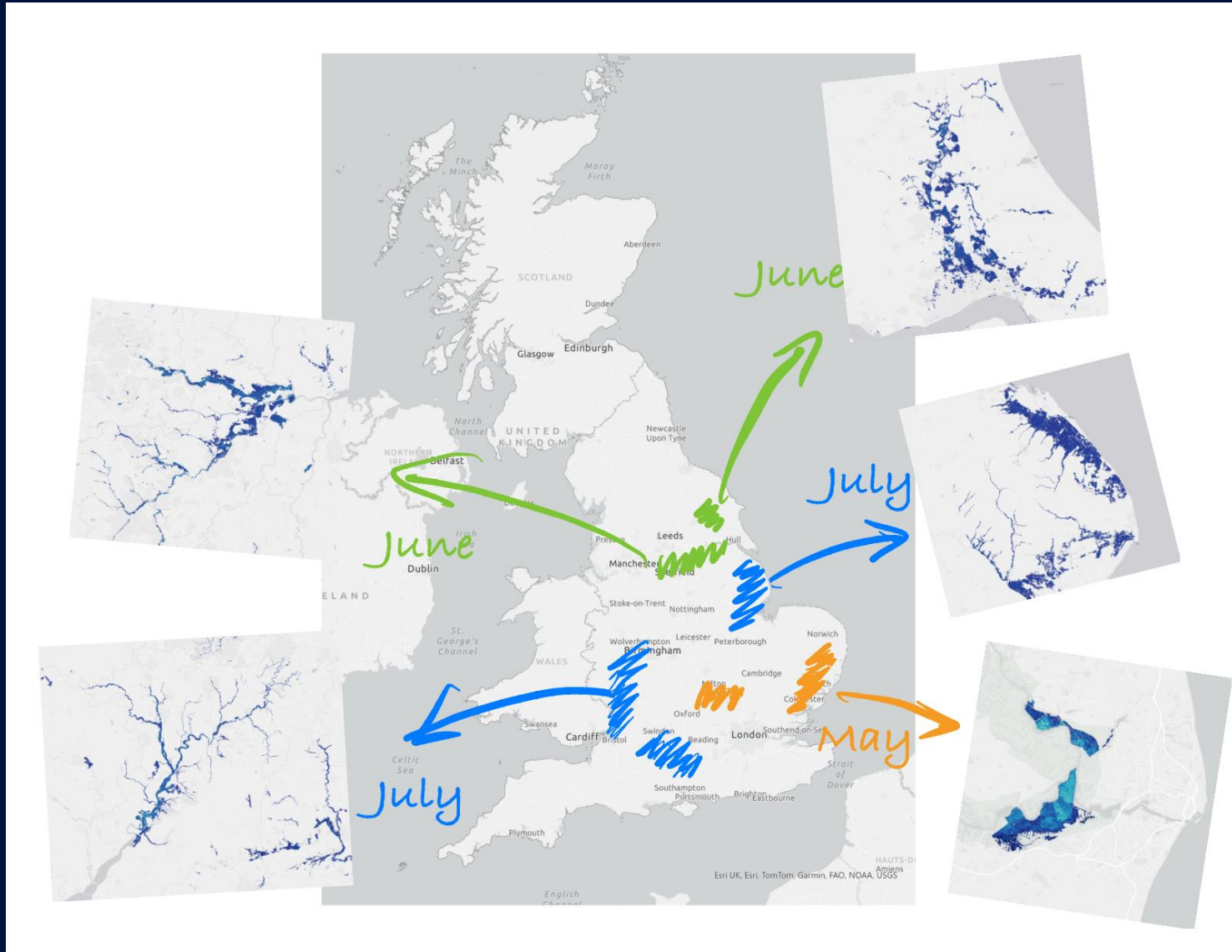
## 2016 Floods in Scotland



**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*

**May 2007**

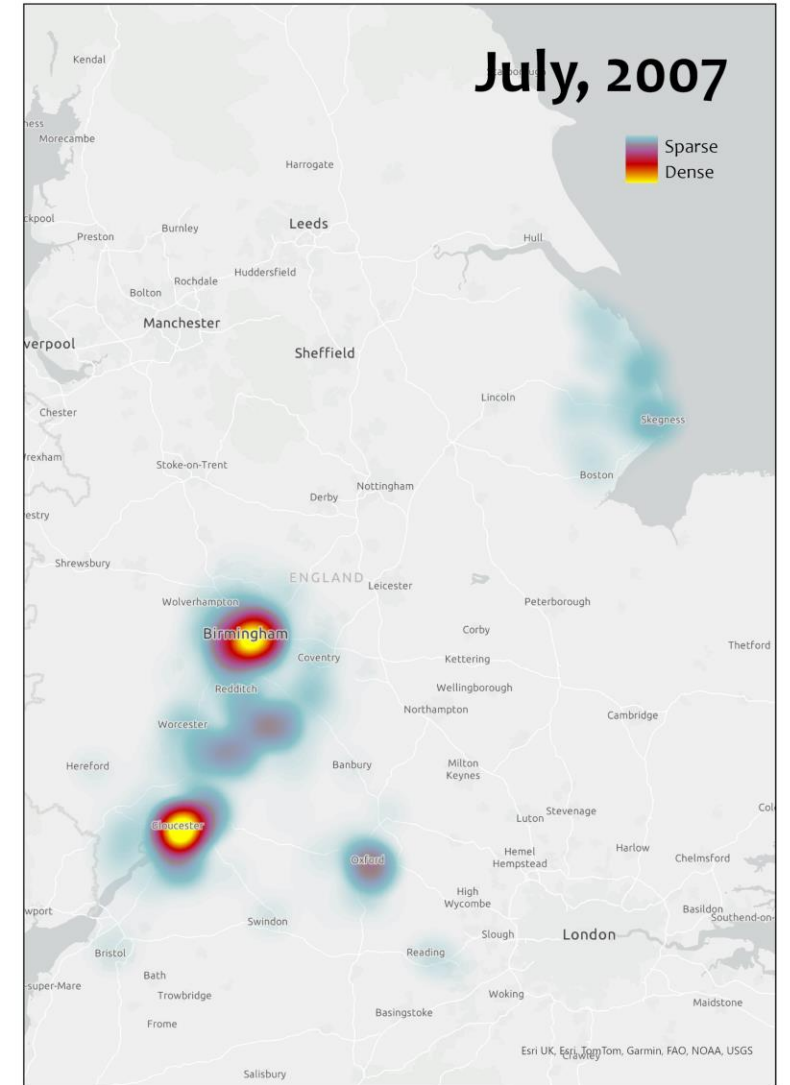
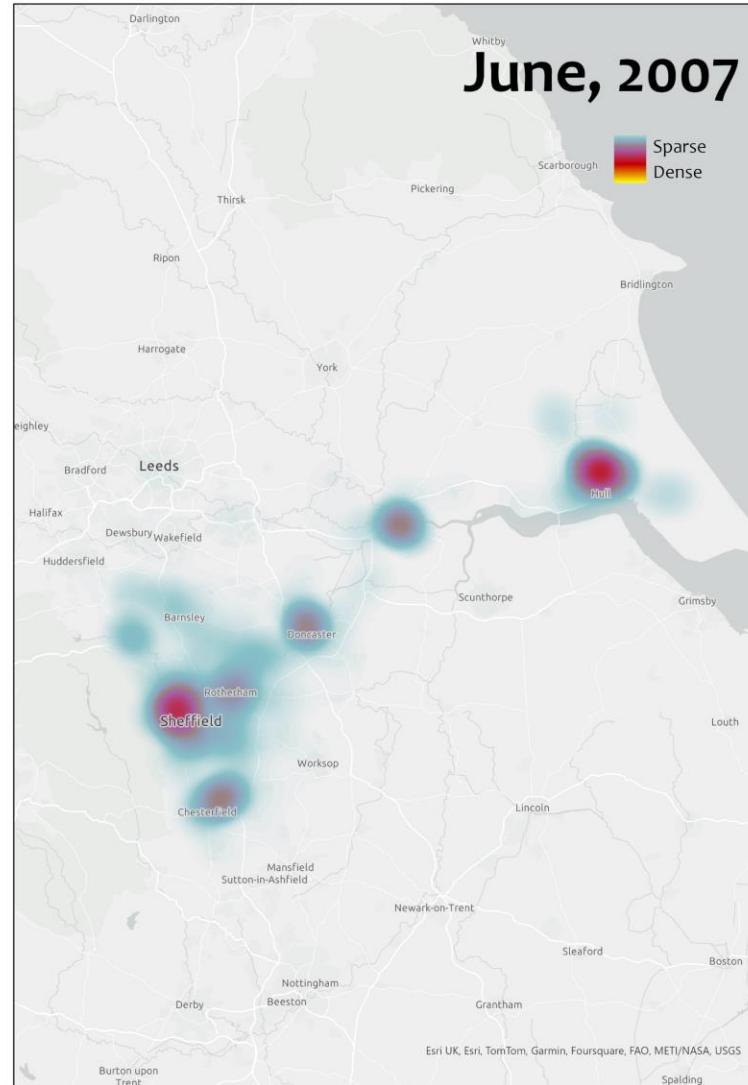
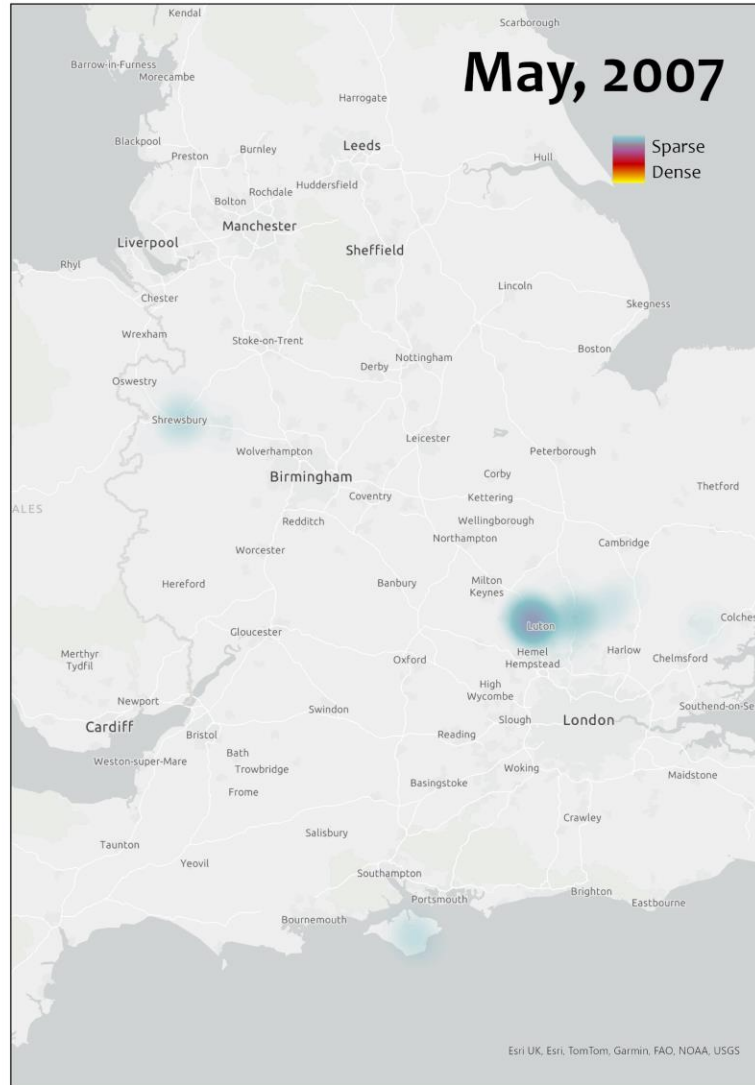


**June 2007**

**July 2007**

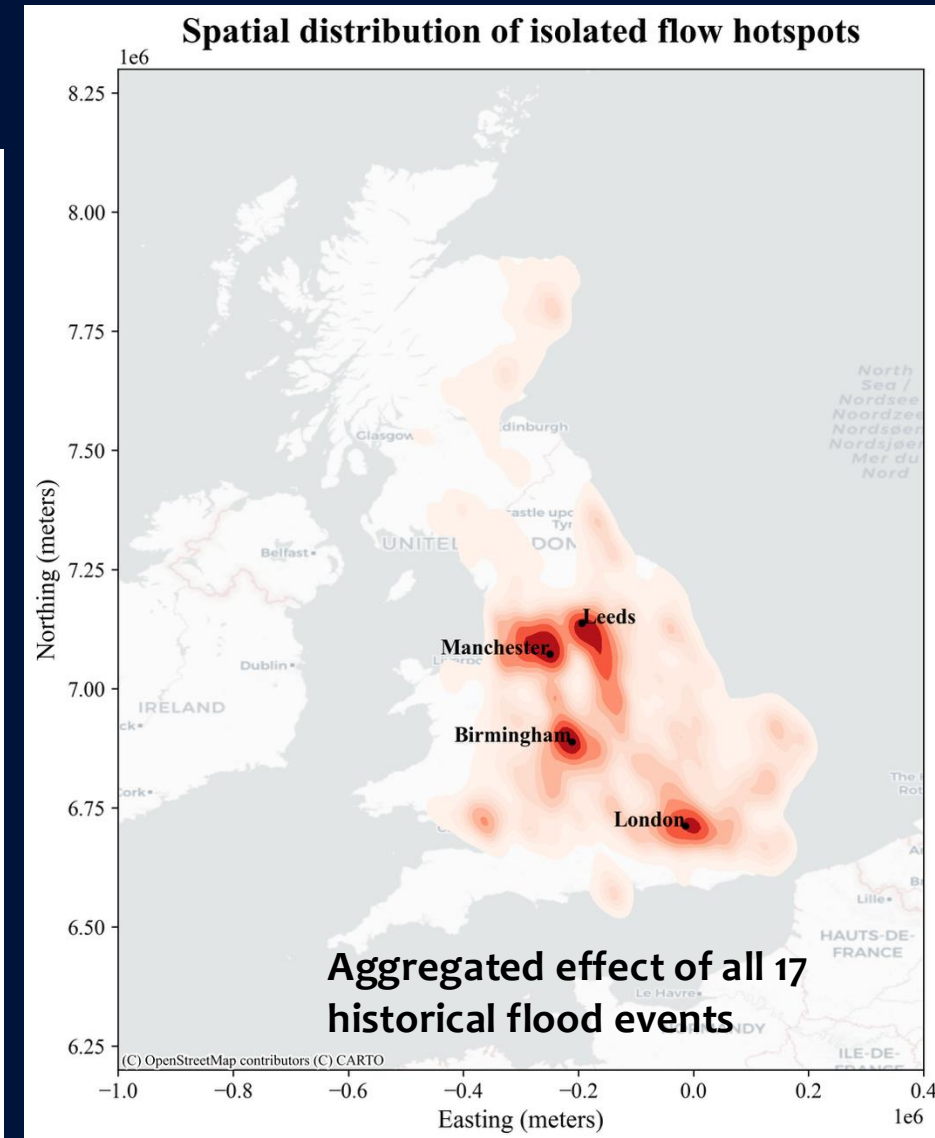
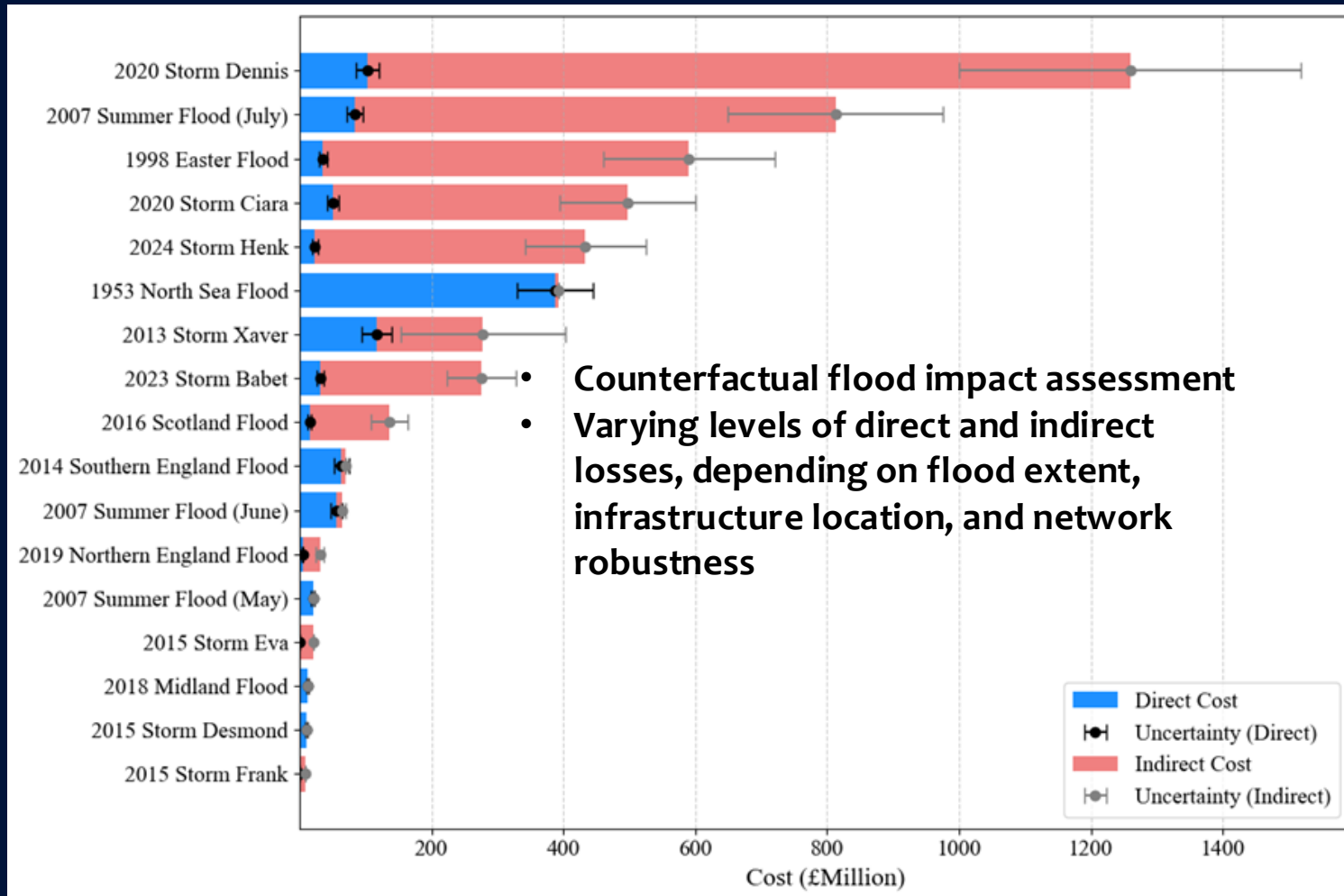


# Demonstration - *Isolated Passenger Flow Heatmap*



# Demonstration – National scale

## Direct vs indirect damages





# 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*

 This is a preprint article, it offers immediate access but has not been peer reviewed.

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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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JBA Trust; Lancaster University - Lancaster Environment Centre

**Paul J. Young**  
*affiliation not provided to SSRN*

### 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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PlumX Metrics



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Sustainable Transport eJournal

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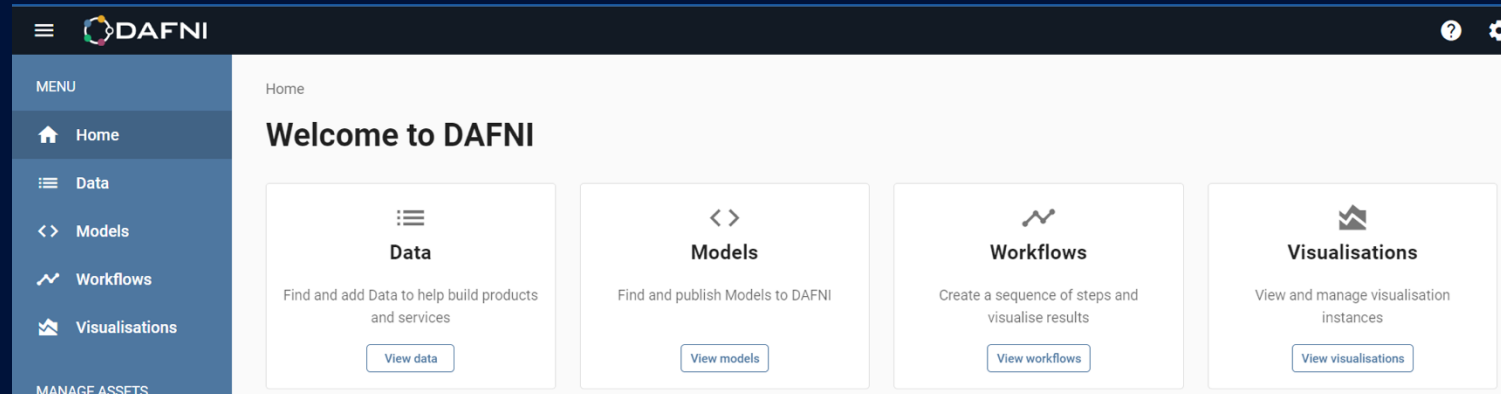
Urban & Regional Resilience eJournal

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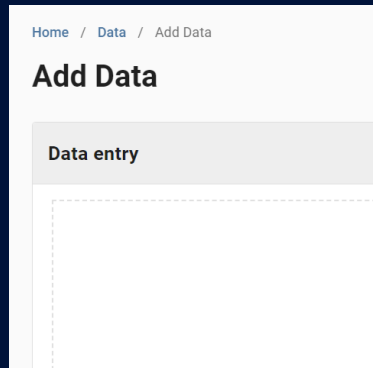
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[https://papers.ssrn.com/sol3/papers.cfm?abstract\\_id=5312777](https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5312777)

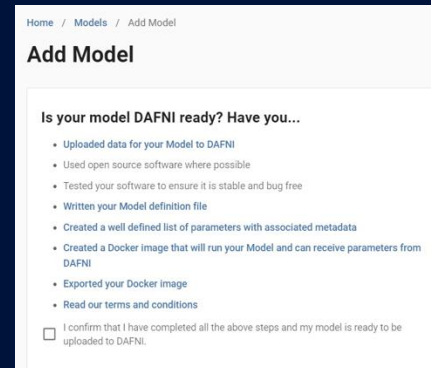
# Project outcomes – *Implementation on DAFNI Platform*



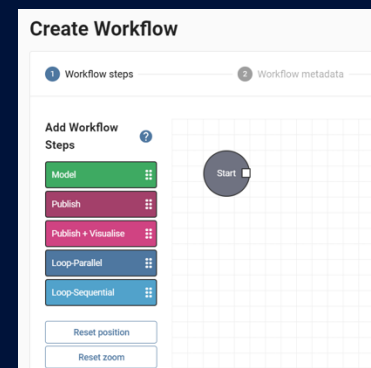
Data Packaging  
and Uploading



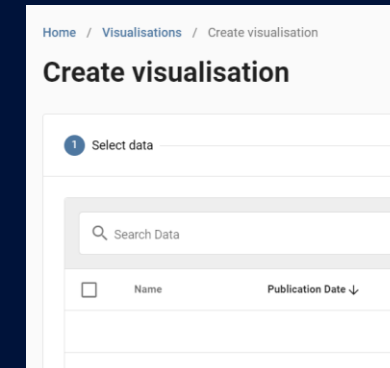
Use Docker to Manage  
Model Scripts



Define the Connection  
between Models



Create Instance for  
Visualisation



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

Create an Instance to run the  
workflow and generate outputs

# Project Outcomes – Open-access data and code

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© DAFNI

Manage group access to data, models and workflows.

Data

Models

Workflows

Delete data

Add data

<input type="checkbox"/>	Name	Access	Publication date ↓	Version message
<input type="checkbox"/>	GB Road Passenger OD Flows	<a href="#">View, read and update</a>	February 2nd 2025	Initial Dataset version
<input type="checkbox"/>	GBRFM Outputs - Base Scenario	<a href="#">View, read and update</a>	January 8th 2025	For NIRD model test
<input type="checkbox"/>	GBRFM Outputs - Disruption Analysis	<a href="#">View, read and update</a>	January 8th 2025	For NIRD model test.
<input type="checkbox"/>	GBRFM Outputs - Disruption Analysis	<a href="#">View, read and update</a>	January 8th 2025	Update attributes of roa
<input type="checkbox"/>	GBRoadFlowModel (GBRFM) - Parameters	<a href="#">View, read and update</a>	January 7th 2025	Initial Dataset version
<input type="checkbox"/>	GB Passenger Travel-to-work OD Flows (2021)	<a href="#">View, read and update</a>	January 7th 2025	Initial Dataset version
<input type="checkbox"/>	Road Flood Damage Ratios	<a href="#">View, read and update</a>	January 7th 2025	Initial Dataset version

Owner

Tom Russell

Created

October 10th 2023

DAFNI-NIRD

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Go to file

Add file

Code

YueeeeeLi

Change the default root directory ✓

930702a · 3 months ago

45 Commits

.github/workflows	Drop install types, add deps	3 months ago
containers/nird_road	Create the python environment for NIRD	3 months ago
docs	Sketch out sphinx docs	8 months ago
scripts	Change the default root directory	3 months ago
src/nird	Change the default root directory	3 months ago
tests	Example test for nird.road.select_partial_roads	3 months ago
.gitignore	Add GB flow simulation script	4 months ago
.pre-commit-config.yaml	Add GB flow simulation script	4 months ago
LICENSE	Update license authors	9 months ago
README.md	Add note on building docs	8 months ago
environment_nird.yaml	Add GB flow simulation script	4 months ago
environment_skmob.yaml	Add snkit	3 months ago
pyproject.toml	Ignore typing in tests	3 months ago

README

MIT license

About

National Infrastructure Resilience Demonstrator (NIRD)

[nismod.github.io/DAFNI-NIRD/](#)

Readme

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Report repository

Releases

No releases published

[Create a new release](#)

Contributors 3

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YueL

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

# Project Outcomes – Outputs on DAFNI platform

**DAFNI**

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## NIRD Road Direct Damage Workflow Latest

Accessed as the owner of the asset Full access Duplicate workflow View workflow Edit workflow

Versions: View all No default Go to latest Make Default Deprecate

**Published by: University of Oxford**

**Date** February 2nd 2025 - 17:28  
**ID** 619a7cfe-312c-47ef-b9a5-778b831c4ee9  
**Parent ID** 70fbc5ec-5591-4430-96d0-c0c12f6cf1c1

**Contact**  
Yue Li

**Summary**  
Road direct damages calculation.

**Description**  
Road direct damages calculation (using Thames Lloyd's RDS as case study) considering asset types (e.g., bridges, tunnels, ordinary roads) and flood types (e.g., river, surface floods)...

**Project details**

**Parameter sets** Create

The different parameter sets that can be run with this Workflow.

Name	Published by	Date published ↓	Last updated with Workflow version	Actions
Test <sup>1</sup>	University of Oxford	January 23rd 2025	4e08c78a-8e70-4103-b240-06ba7358187d <sup>1</sup>	<span>⋮</span>

Rows per page: 5 1-1 of 1

**Instances**

The runs of this workflow

Workflow version	Parameter set	Started	Finished ↓	Status	Actions
Updated	Test	February 2nd 2025 - 17:44	February 2nd 2025 - 17:53	Succeeded	<span>⋮</span>

**NIRD Road Direct Damages**

Publisher: DAFNI Workflows (nird-road-direct-damage-workflow) From: N/A To: N/A

Road asset direct damages caused by Thames Lloyd's RDS (synthetic flood event) in Great Britain to test the model.

CSV

**Outputs (automatically saved to the Data catalogue)**



# Ongoing and future work

## NIRD + OpenCLIM



UK SSPs: future population grids

ent/publications/national-assessment-of-flood-and-coastal-erosion-risk-in-england-2024/national-assessment-of-flood-and-coastal-erosion-risk-in-england-2024

**Contents**

1. Executive Summary
2. The context: flooding and coastal erosion risk in a changing climate
3. Flood and coastal erosion risk information
4. Our updated assessment of flood and coastal erosion risk in England
5. The new national flood risk assessment
6. Rivers and sea: how our assessment of flood risk from rivers and the sea is changing
7. Surface water: how our assessment of flood risk from surface water is changing
8. Flood risk from multiple sources – rivers, the sea and surface water
9. The new national coastal erosion risk map
10. Coastal erosion: how our assessment of coastal erosion risk is changing
11. How the new national flood and coastal erosion risk information and data will be made available
12. Next steps: continuous improvement in our understanding of risk
13. How we will use the new risk information to inform future investments

• covers all sources of flood risk – rivers, the sea and surface water

• includes future flood risk due to climate change projections

• combines national models with local flood risk models from the Environment Agency and local authorities to provide more detail

• has clearer detail on the areas at risk through much higher resolution maps

• shows characteristics such as potential flood depths, and the likelihood and impacts, including the economic damages of flooding

• provides better information

**DataMapWales**

Home > Data catalogue > Flood Risk Assessment Wales

**Flood Risk Assessment Wales**  
Natural Resources Wales

Sign in

Display in map viewer >

Or display data on an existing map >

Type: Spatial data  
Category: Environment >  
Publication date: 22 May 2025  
Licence: Open Government Licence for Public Sector Information (OGL) >  
Point of contact: opendata@naturalresourceswales.gov.uk  
Read full metadata

Flood Risk Assessment Wales provides a national assessment of risk flooding from Rivers, the Sea and Surface Water and Small Watercourses (replacing the Risk of Flooding Rivers and Sea, or RoFRS, dataset).

The assessment takes into account flood defences and combines new, national-scale modelling with detailed local-scale models to categories risk into 3 bands, labelled 'High', 'Medium' and 'Low' risk.

For Rivers and Surface Water and Small Watercourses:

- 'High' risk means that each year, this area has a chance of flooding of greater than 1 in 30 (3.3%)
- 'Medium' risk means that each year, an area has a chance of flooding of between 1 in 100 (1%) and 1 in 30 (3.3%)
- 'Low' risk means that each year, an area has a chance of flooding of between 1 in 1000 (0.1%) and 1 in 100 (1%).

**sepa**

Home Return to sepa.org.uk

**Download SEPA Flood Data**

Back SEPA Data publication

**SEPA Flood Maps**

**SEPA Coastal Flood Maps v3.0 – ESRI Geodatabase**

156 MB Zip file (1.07 GB uncompressed) contains:

- 1 x .GDB file
- 1 x Dataset guidance document (PDF)
- 2 x Dataset attribution statements (PDF)
- 1 x Release Notes (PDF)

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**SEPA Surface Water & Small Watercourses Flood Maps (Extent) v3.0 – ESRI Geodatabase**

134 MB Zip file (7.1 GB uncompressed) contains:

- 1 x .GDB file
- 1 x Dataset guidance document (PDF)
- 2 x Dataset attribution statements (PDF)
- 1 x Release Notes (PDF)

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**SEPA River Flood Maps v3.0 – ESRI Geodatabase**

135 MB Zip file (8.12 GB uncompressed) contains:

- 1 x .GDB file
- 1 x Dataset guidance document (PDF)
- 2 x Dataset attribution statements (PDF)
- 1 x Release Notes (PDF)

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**SEPA Surface Water & Small Watercourses Flood Maps (Depth High Prob) v3.0 – ESRI Geodatabase**

651 MB Zip file (4.74 GB uncompressed) contains:

- 1 x .GDB file
- 1 x Dataset guidance document (PDF)
- 2 x Dataset attribution statements (PDF)
- 1 x Release Notes (PDF)

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

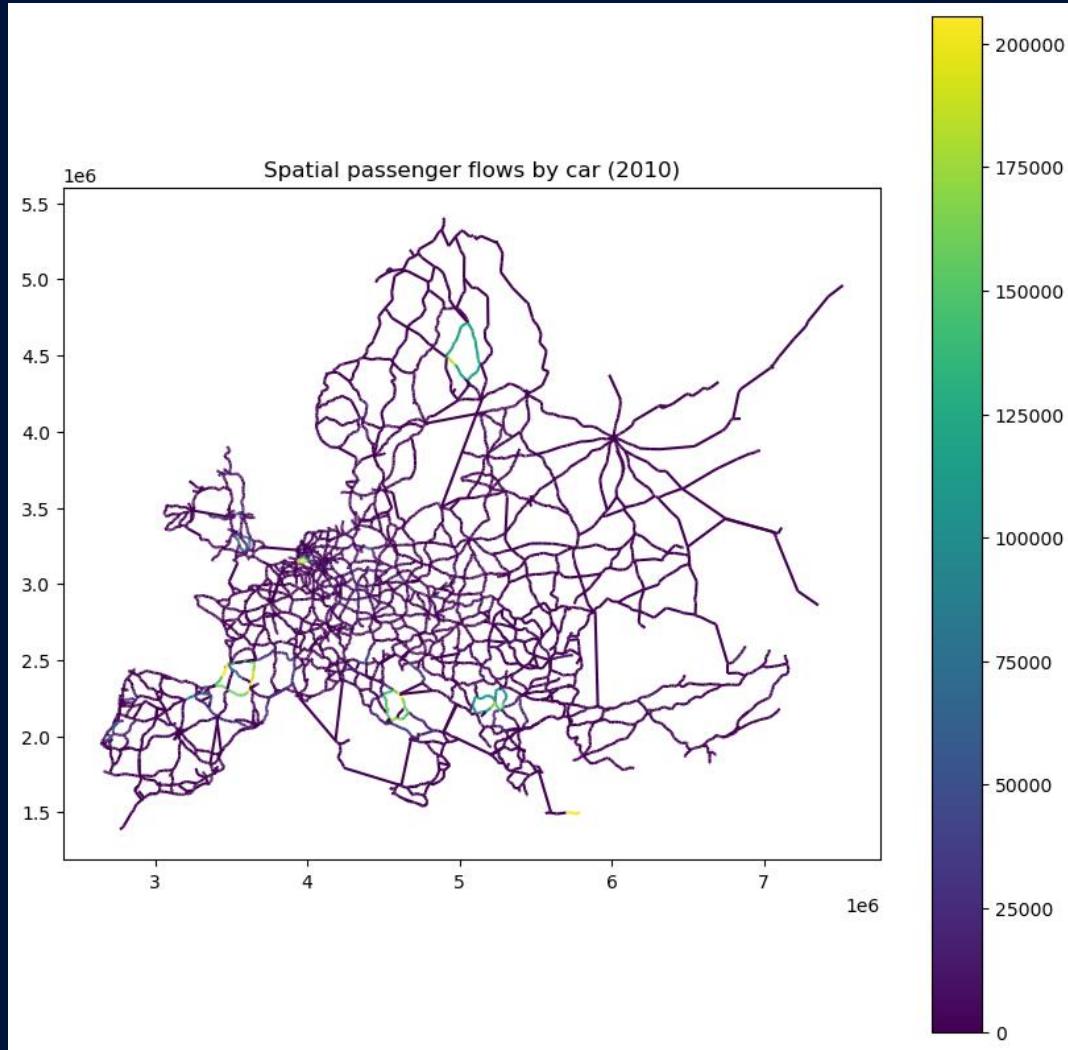
## OpenCLIM population scenarios

- 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*

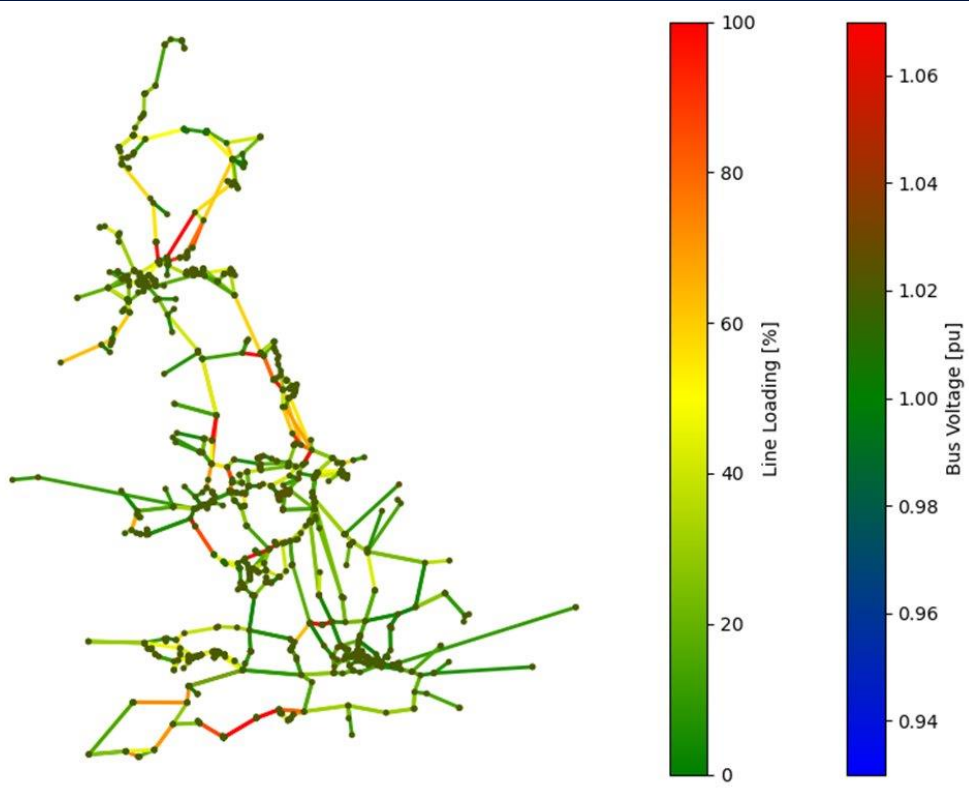


## Multi-hazards Risk Assessment for Climate Adaptation (MIRACA)

- 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**

Contact:

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[yue.li@ouce.ox.ac.uk](mailto:yue.li@ouce.ox.ac.uk)

