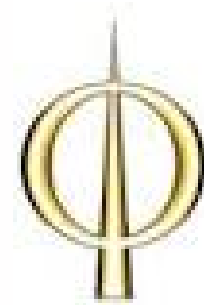




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# Modelling and Forecasting of Compound Coastal-Fluvial Floods in Urban Built Environment



Compound coastal-fluvial urban flooding –  
combining statistical, hydrodynamic and machine learning models

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# Floods are the costliest and most pervasive natural hazard

## Societal Challenge

### Globally:

- 1.8bn people (1-in-4) exposed



October 2024



September 2023



July 2021





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# Floods are the costliest and most pervasive natural hazard

## Societal Challenge

### In Ireland:

- 750,000 people
- 300+ communities



November 2009



Storm Betty - August 2023



Storm Babet - October 2023



Storm Debi- November 2023





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# Floods are the costliest and most pervasive natural hazard

## Societal Challenge

### Globally:

- 1.8bn people (1-in-4) exposed

### In Ireland:

- 750,000 people
- 300+ communities

Perfect storm → imperfect flood defences

*“We can’t keep building our way out of trouble”*

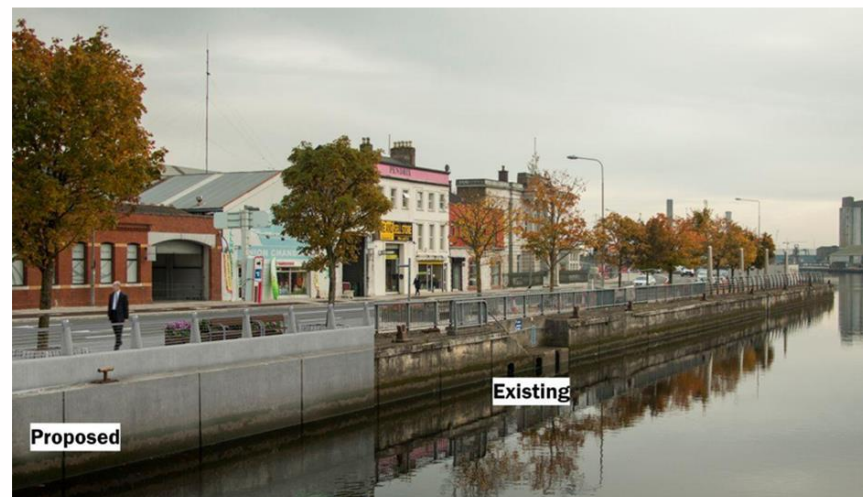
Climate adaptation + impact mitigation=  
Hard & soft engineering+  
early warning



September 2023



October 2023



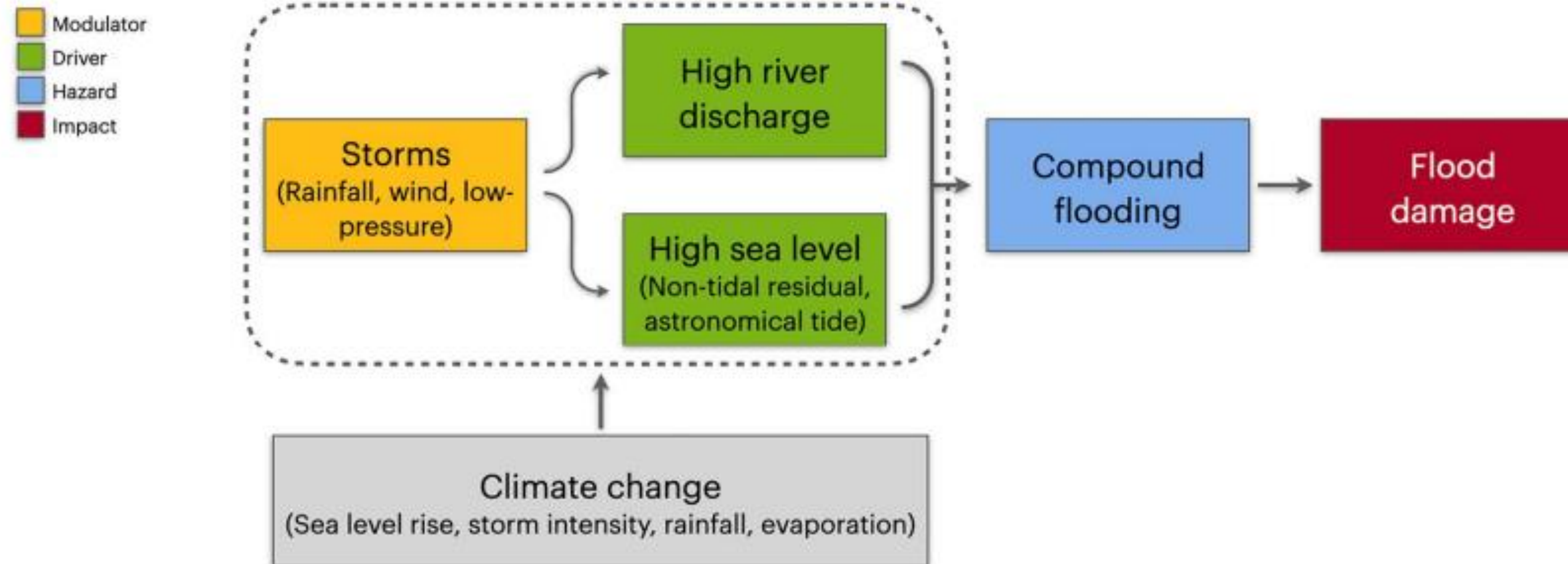




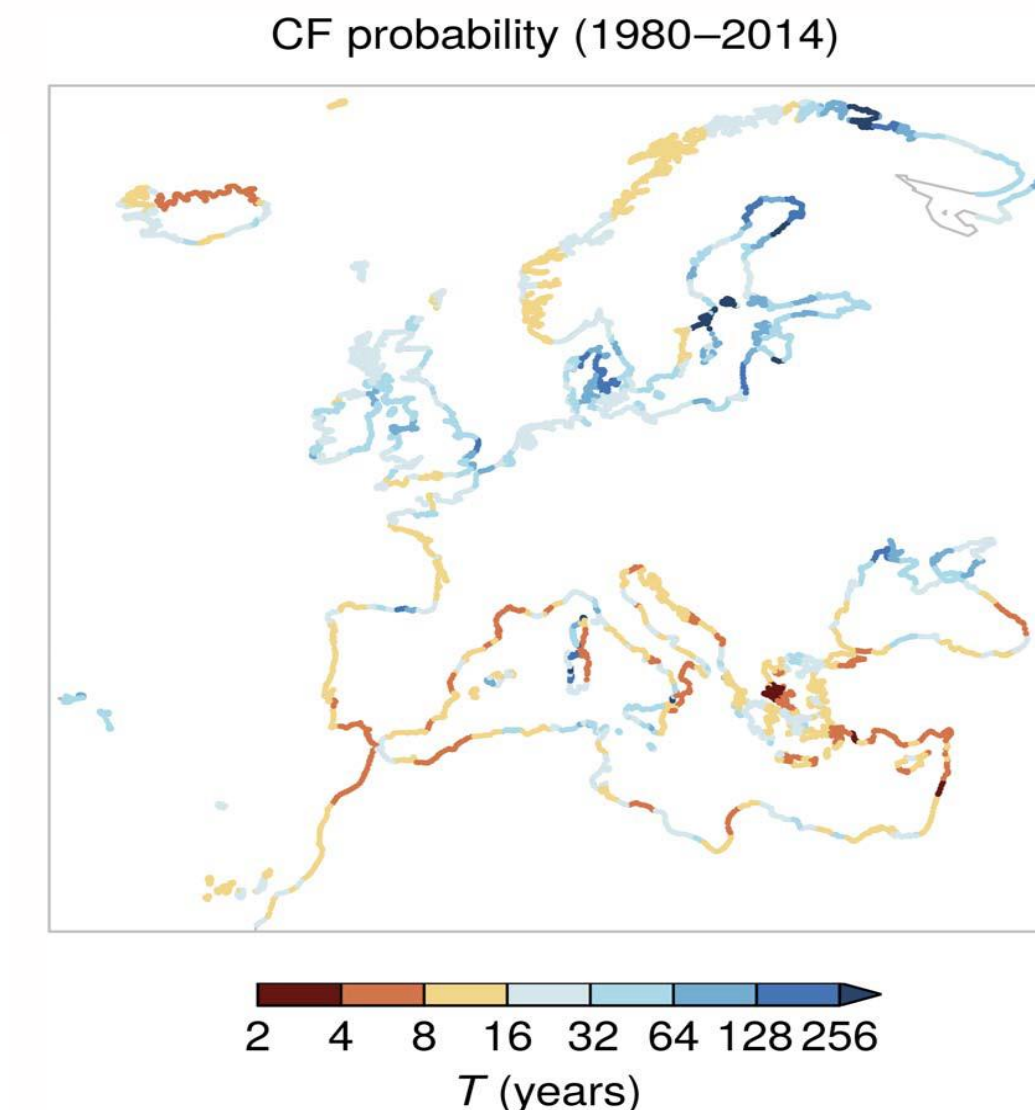
# Floods are tricky to forecast!

## Motivation

Compound events are combinations of drivers and/or hazards that contribute to societal or environmental risk and impact



Bevacqua et al. 2022



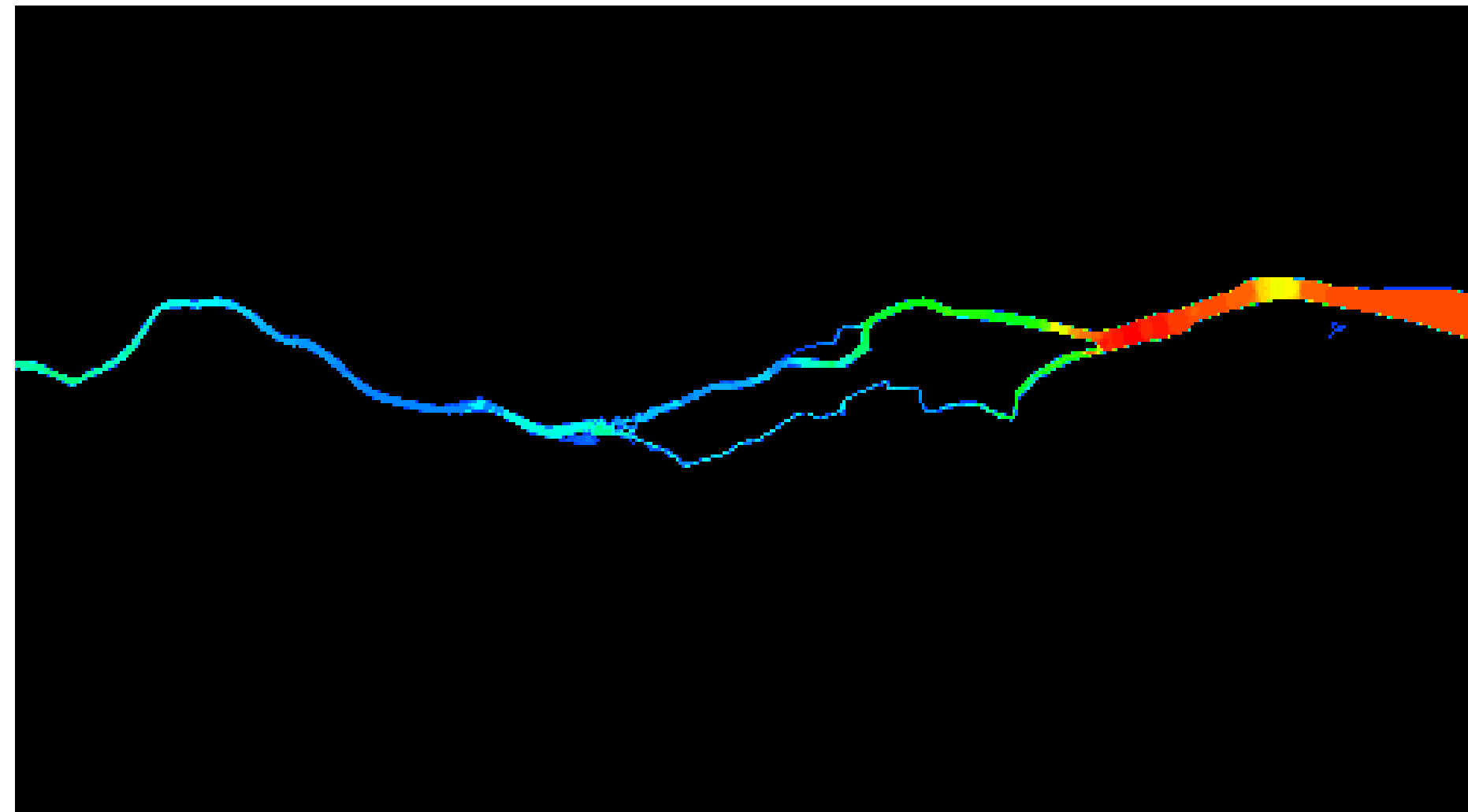
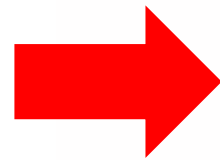
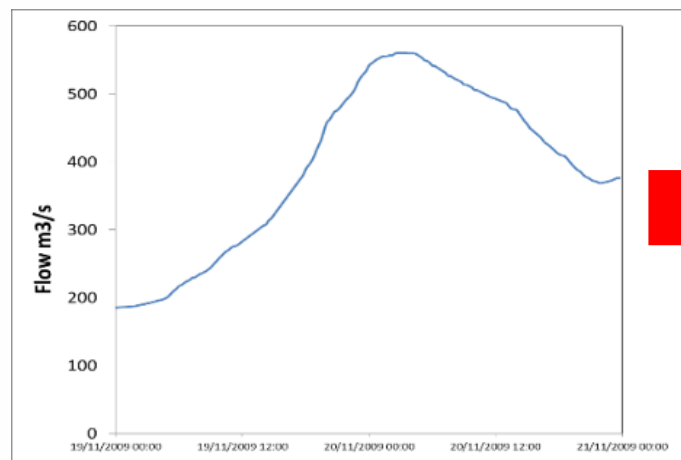
Bevacqua et al. 2019



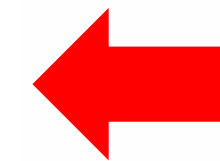
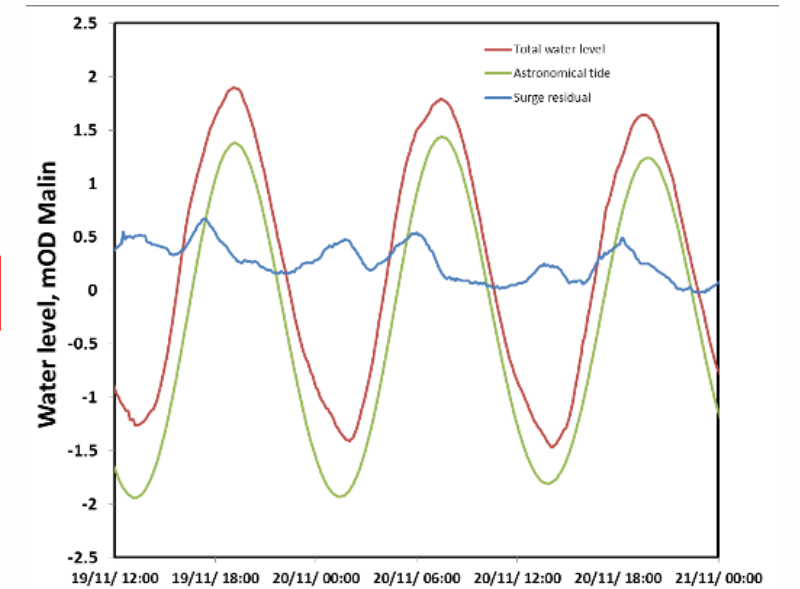
# Motivation

# Coastal-fluvial flooding

Fluvial driver



Coastal driver



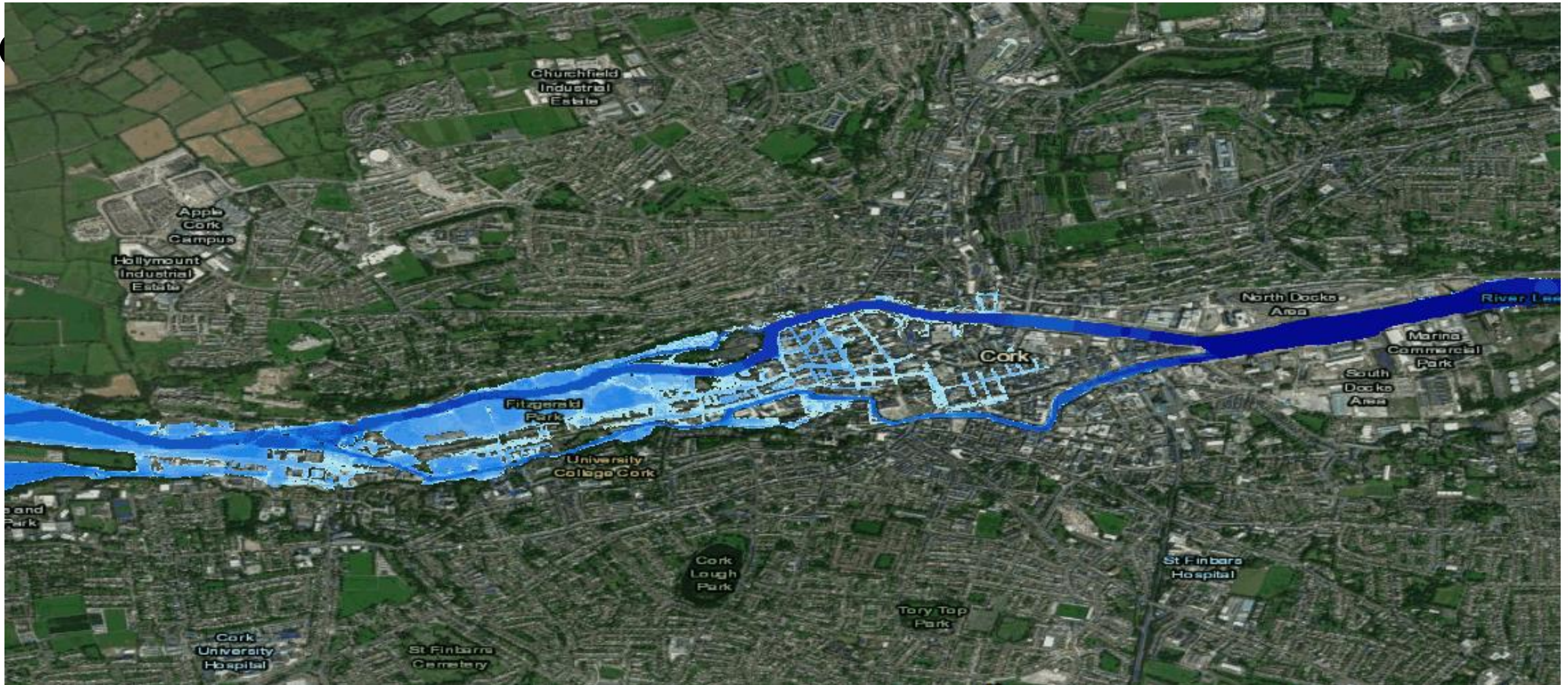




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# Coastal-fluvial flooding

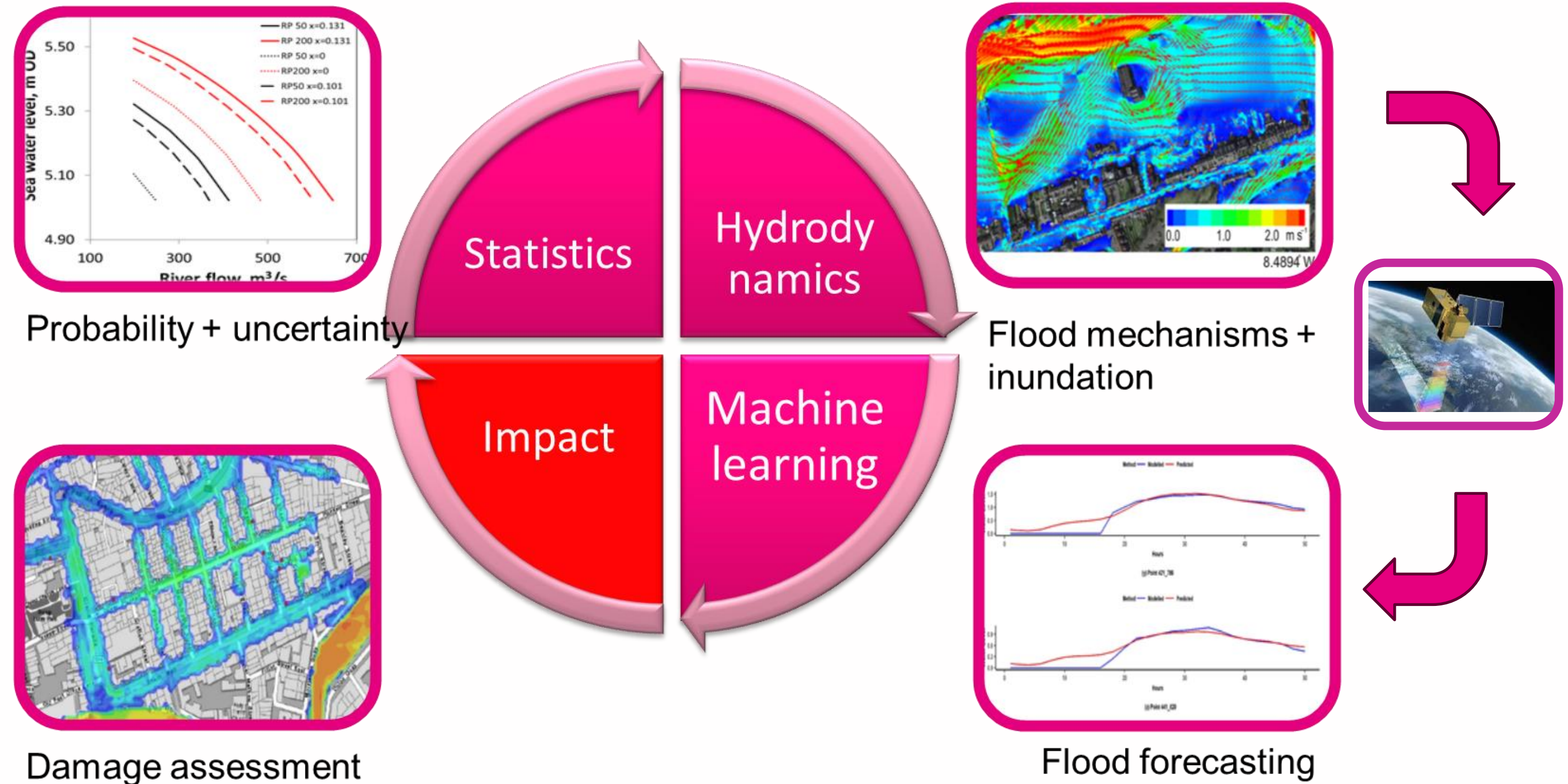
Mo







# Methodology







# How do we determine coastal flood risks?

## 1. Statistical model

### Flood risk assessment:

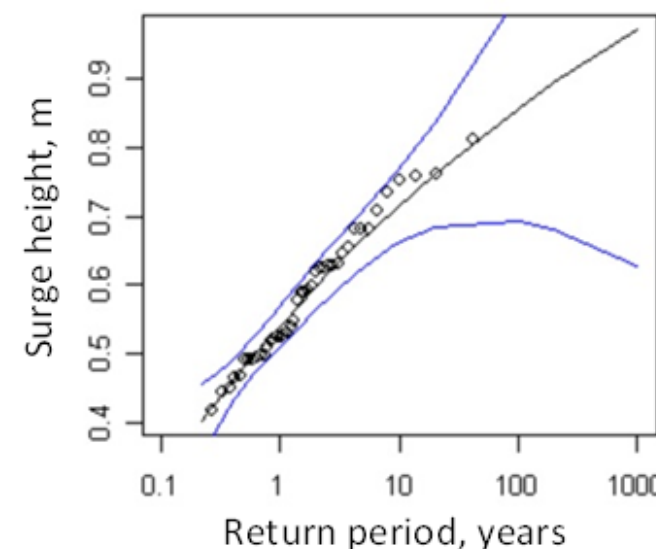
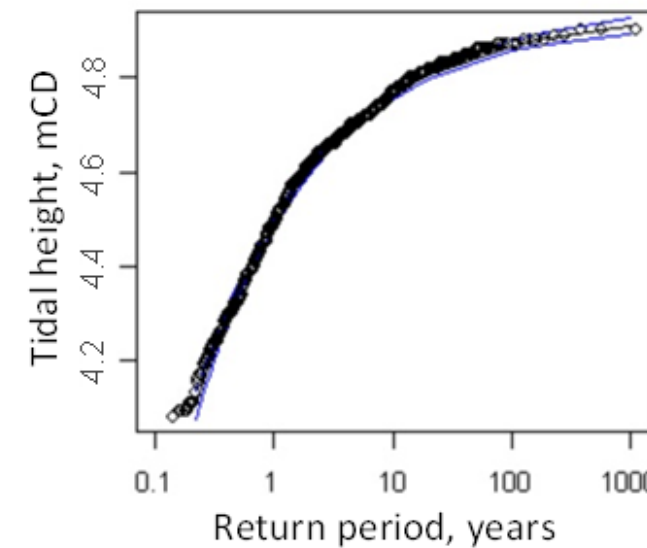
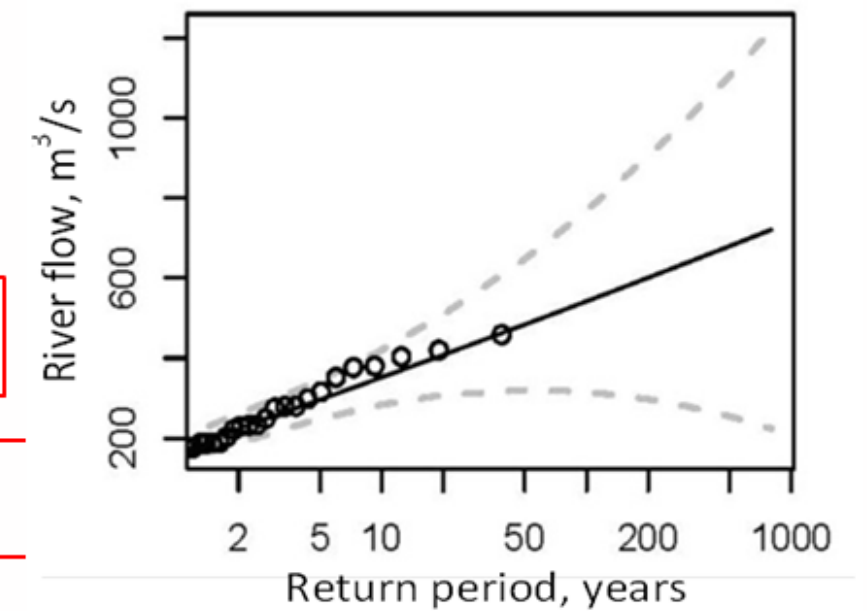
- Dependencies
- Interactions
- Marginal RPs
- Joint Probabilities

1. Data Collection

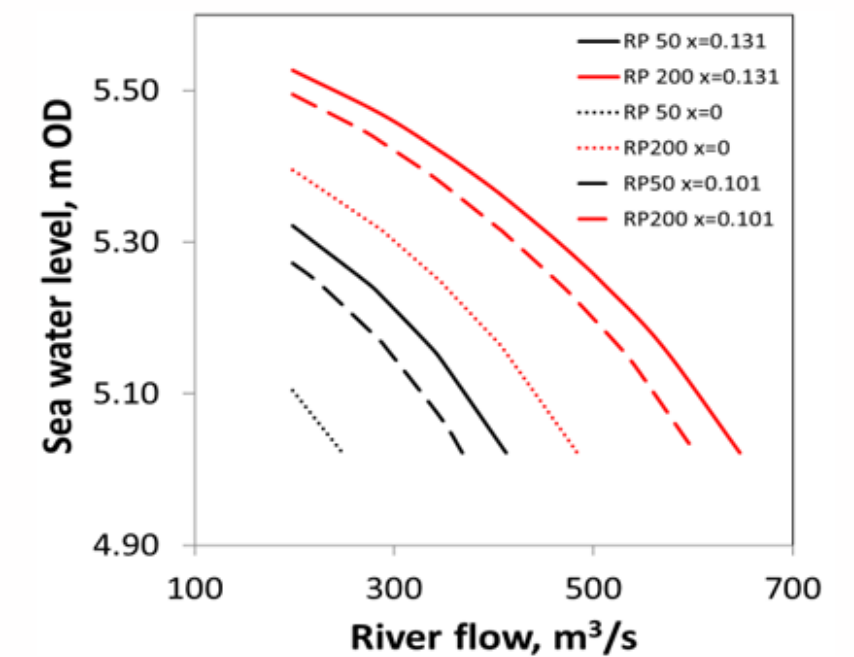
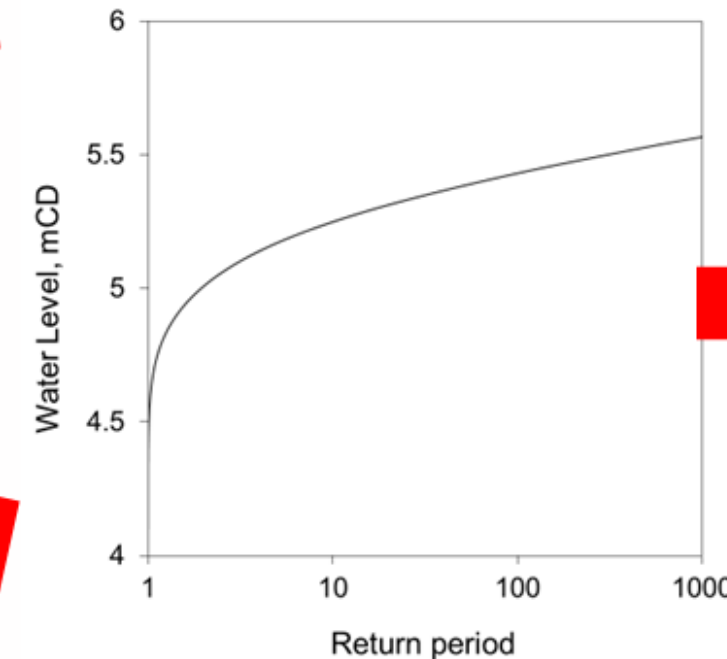
2. Extreme value analysis

3. Multivariate dependence analysis

4. Joint probability of extremes



Trivariate joint probability







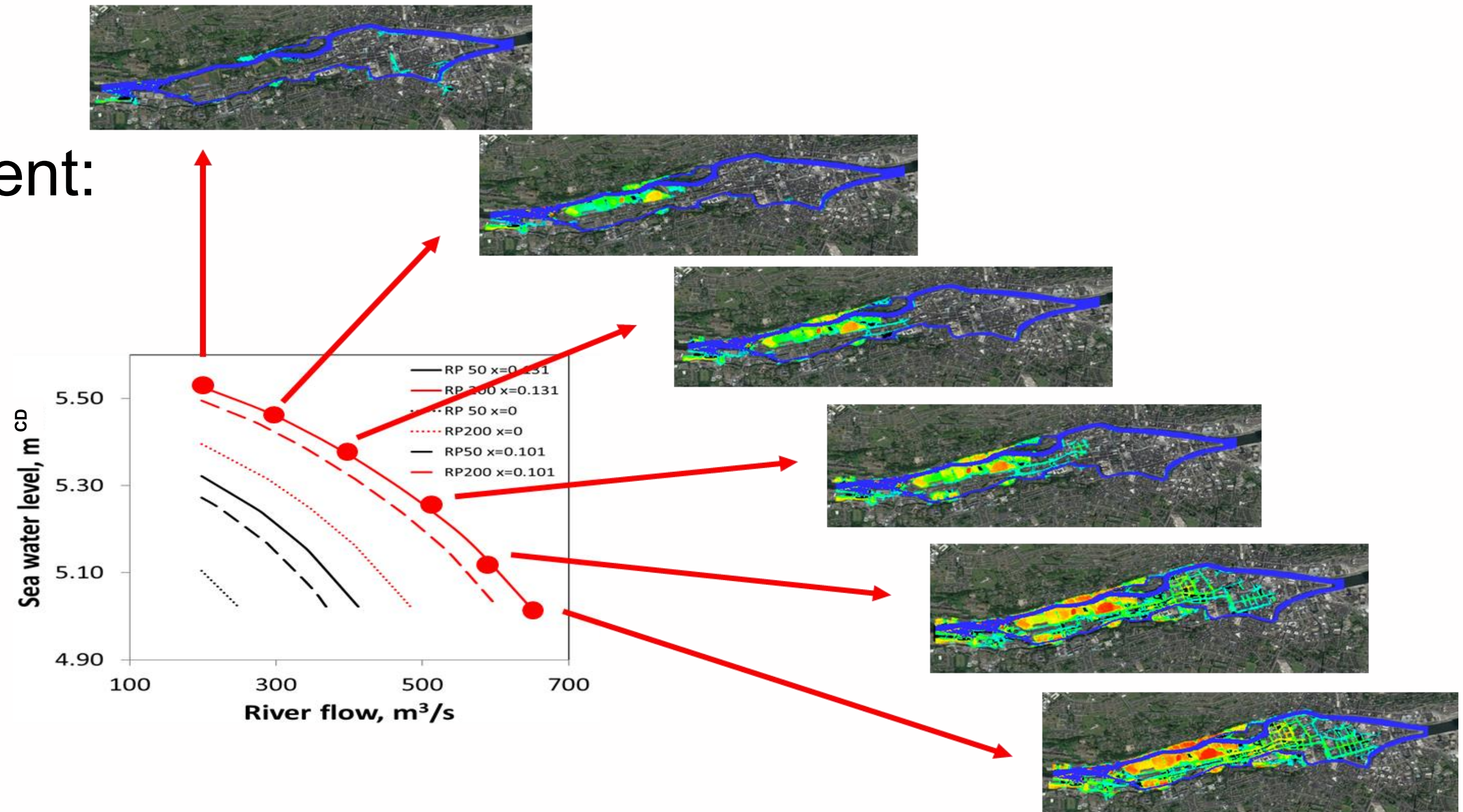
# How do we determine coastal flood risks?

Need to consider a range of scenarios

## 2. Hydrodynamic Model

Flood risk assessment:

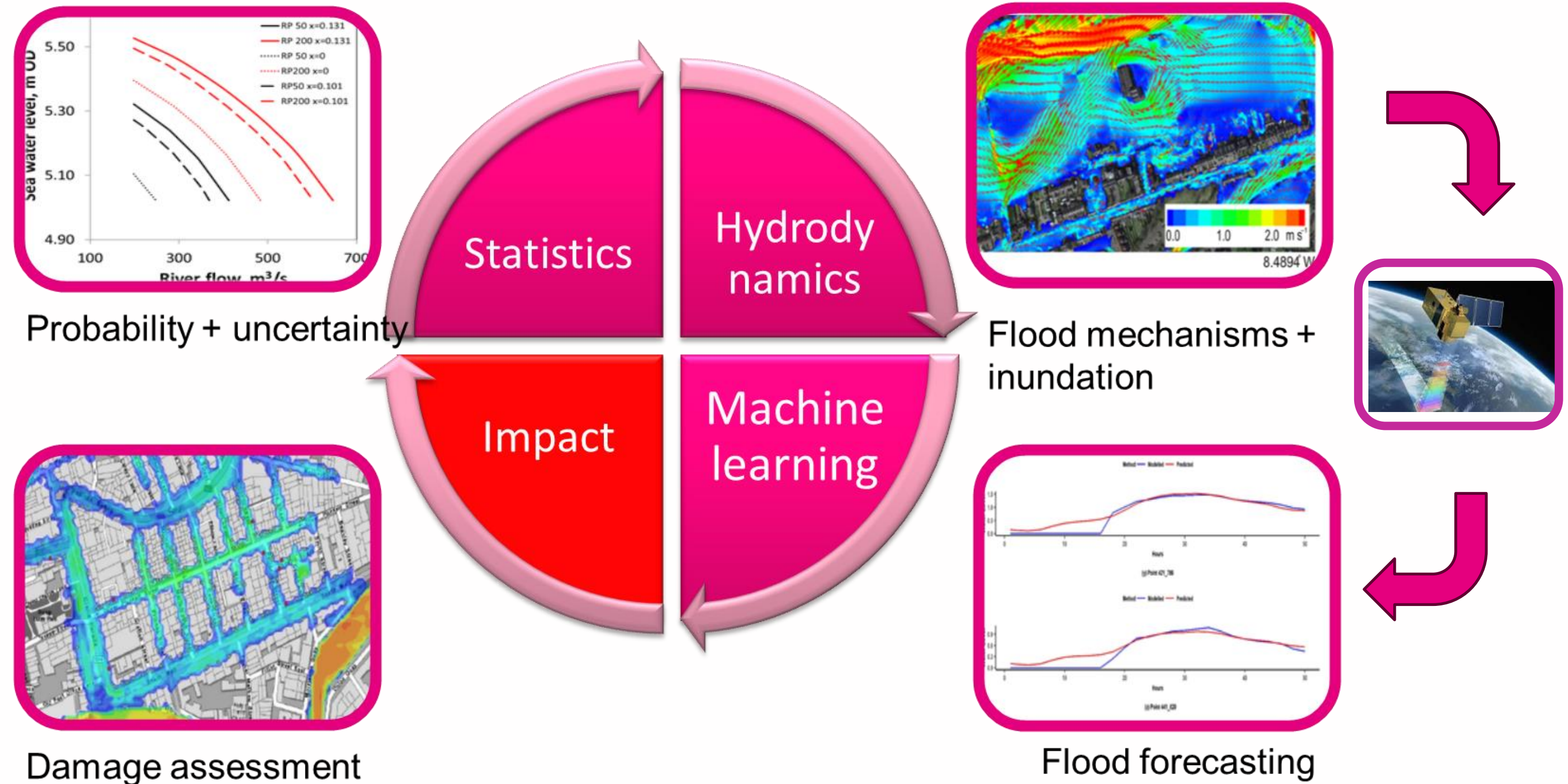
- Dependencies
- Interactions
- Marginal RPs
- Joint Probabilities







# Methodology



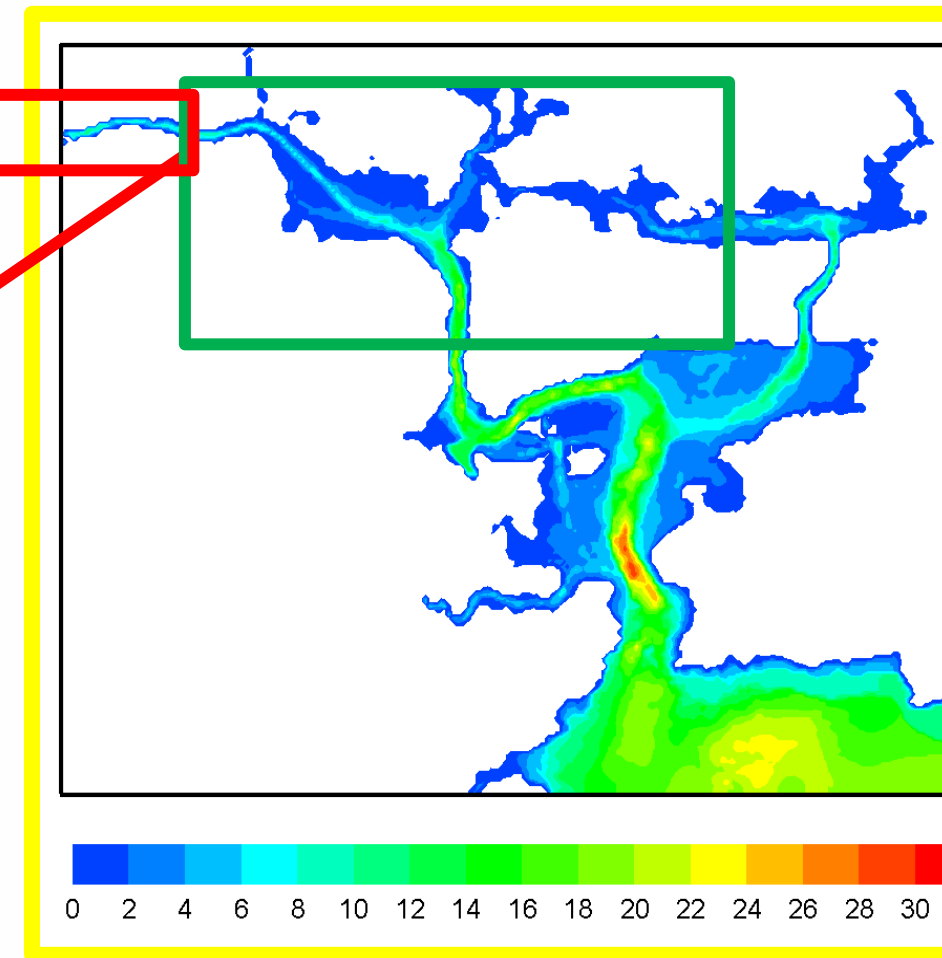




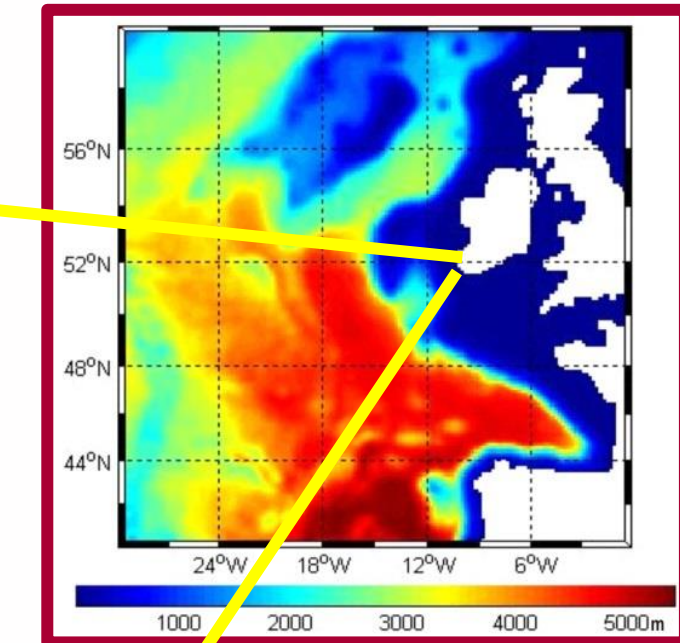
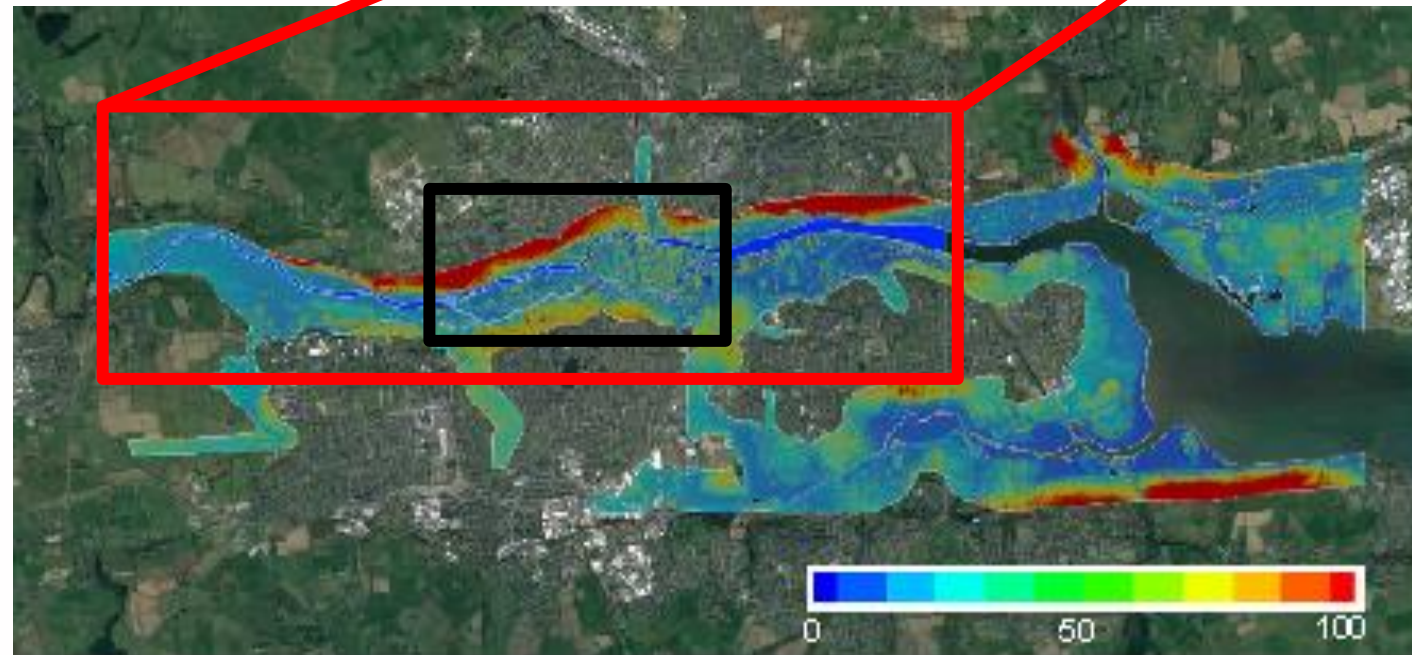
## 2. Hydrodynamic Model

MPIOM → POM → MNS\_Flood

3. Lough Mahon 30m



5. Cork City 2m



1. NE Atlantic  
~5km

2. Cork Harbour  
90m

4. Cork County 6m





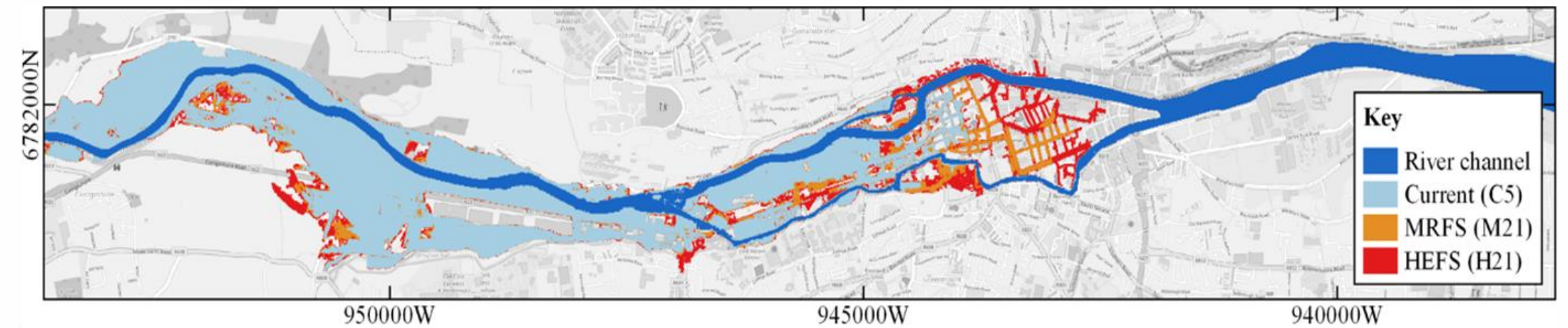
# Coastal-fluvial flooding

## 2. Hydrodynamic Model

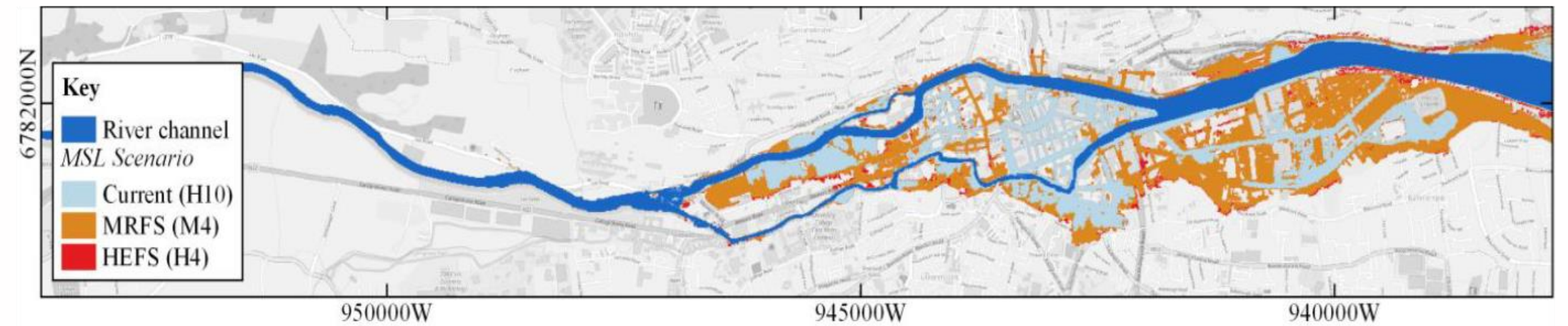
### Flood mapping:

- Water depth
- Inundation area
- Flood evolution

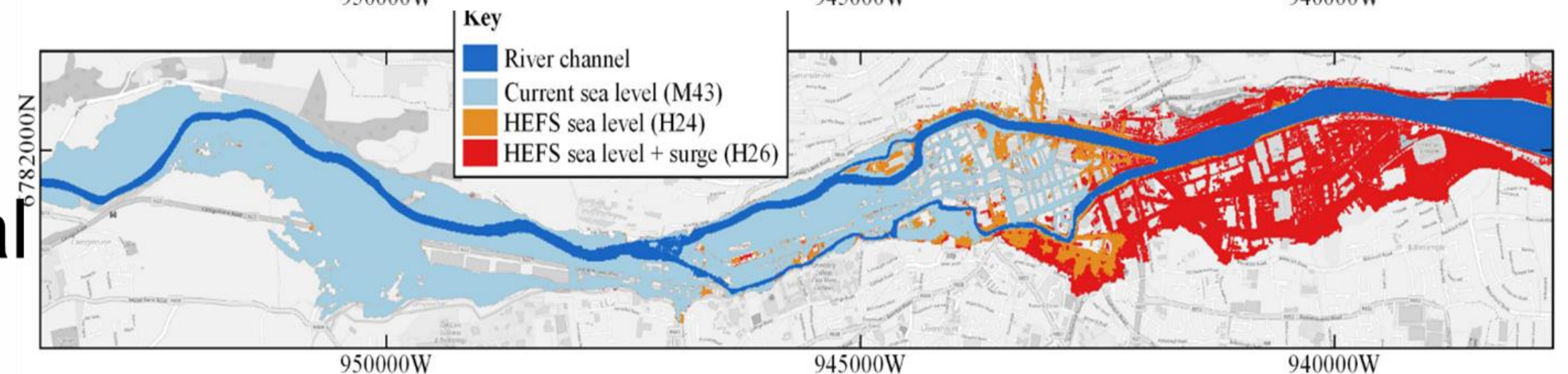
Fluvial



Coastal



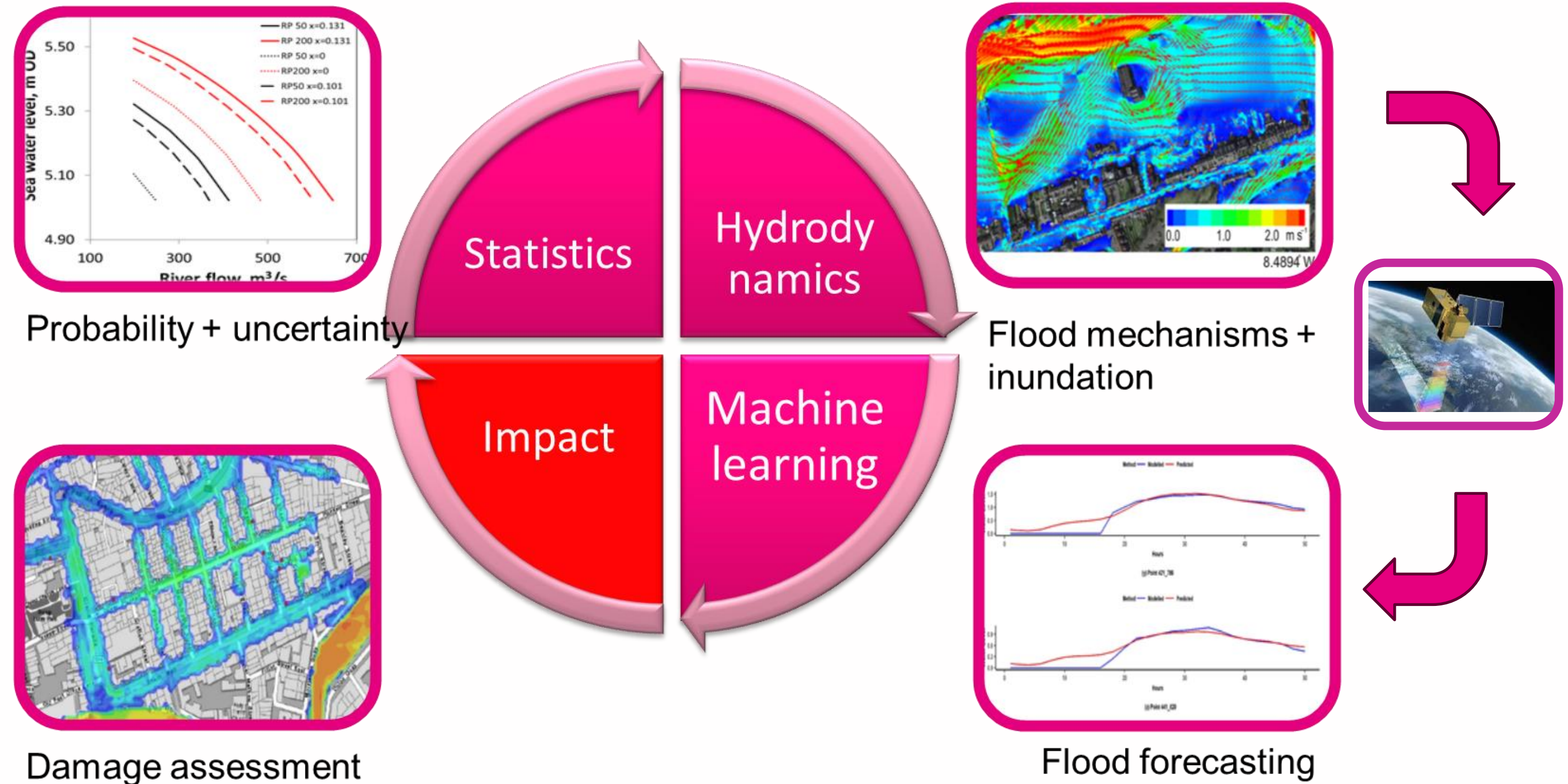
Coastal-fluvial







# Methodology



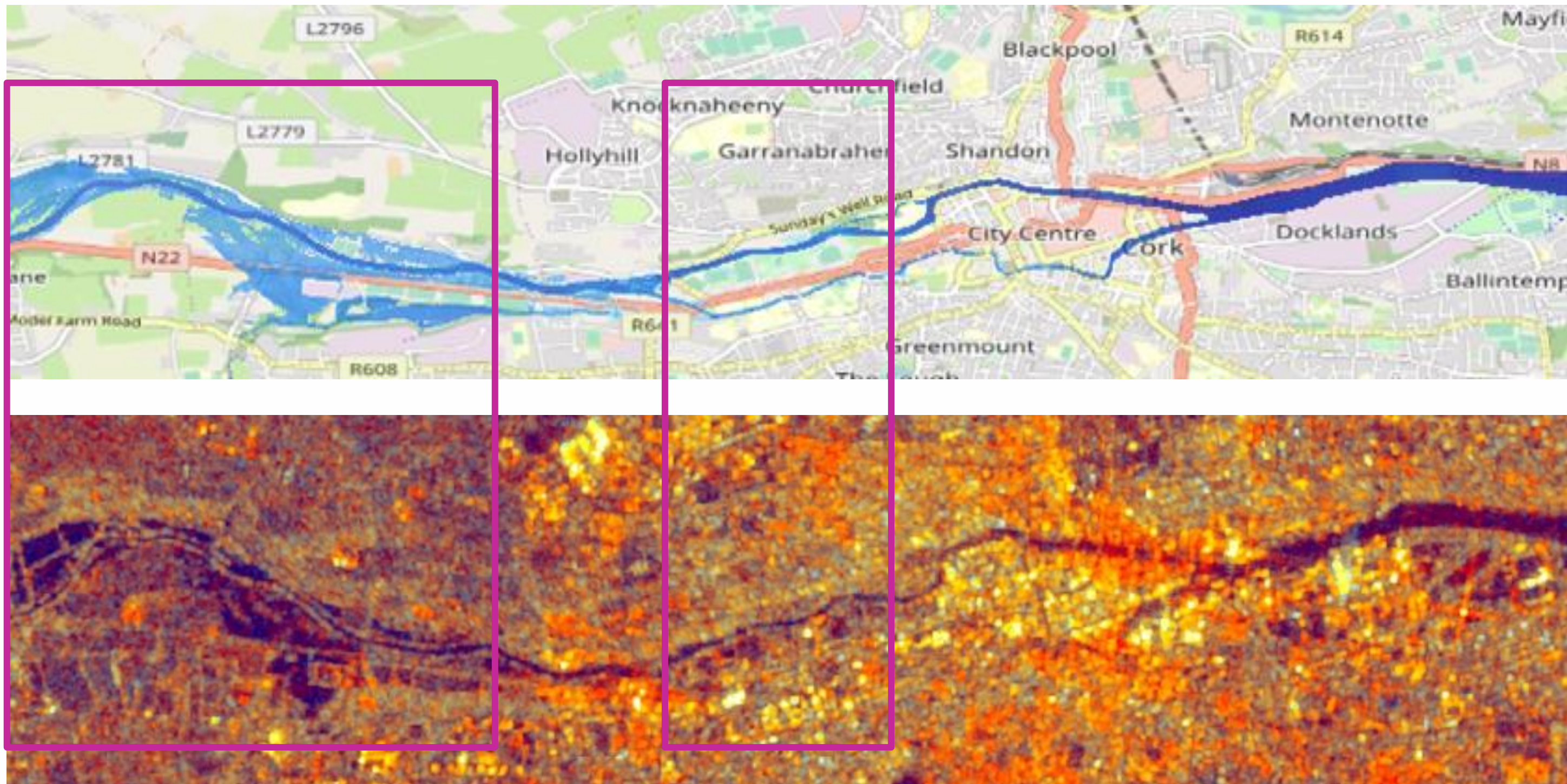




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# Flood detection

## 4. Earth Observation





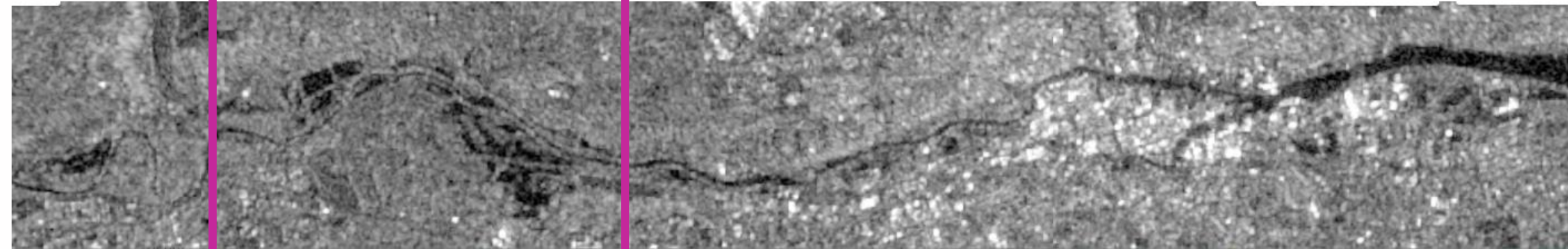


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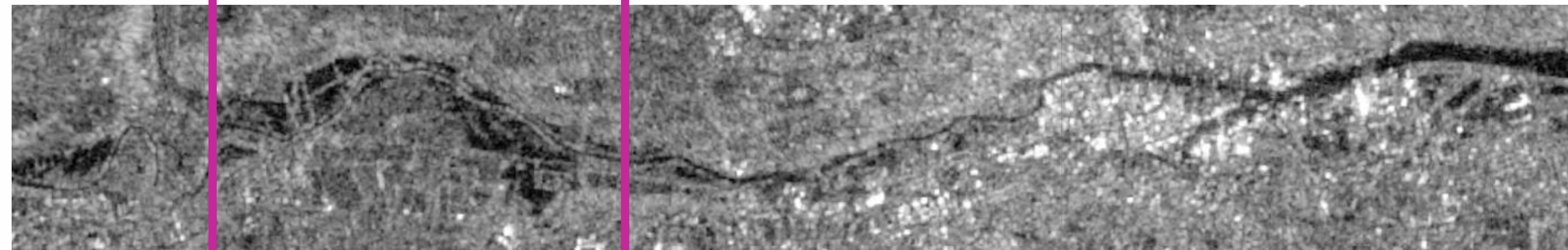
# Flood detection

## 4. Earth Observation

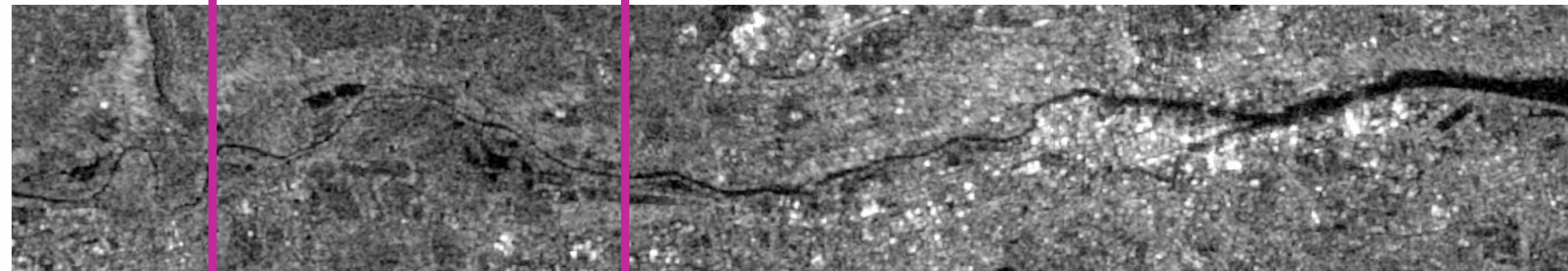
**October 2023:**



**February 2021:**



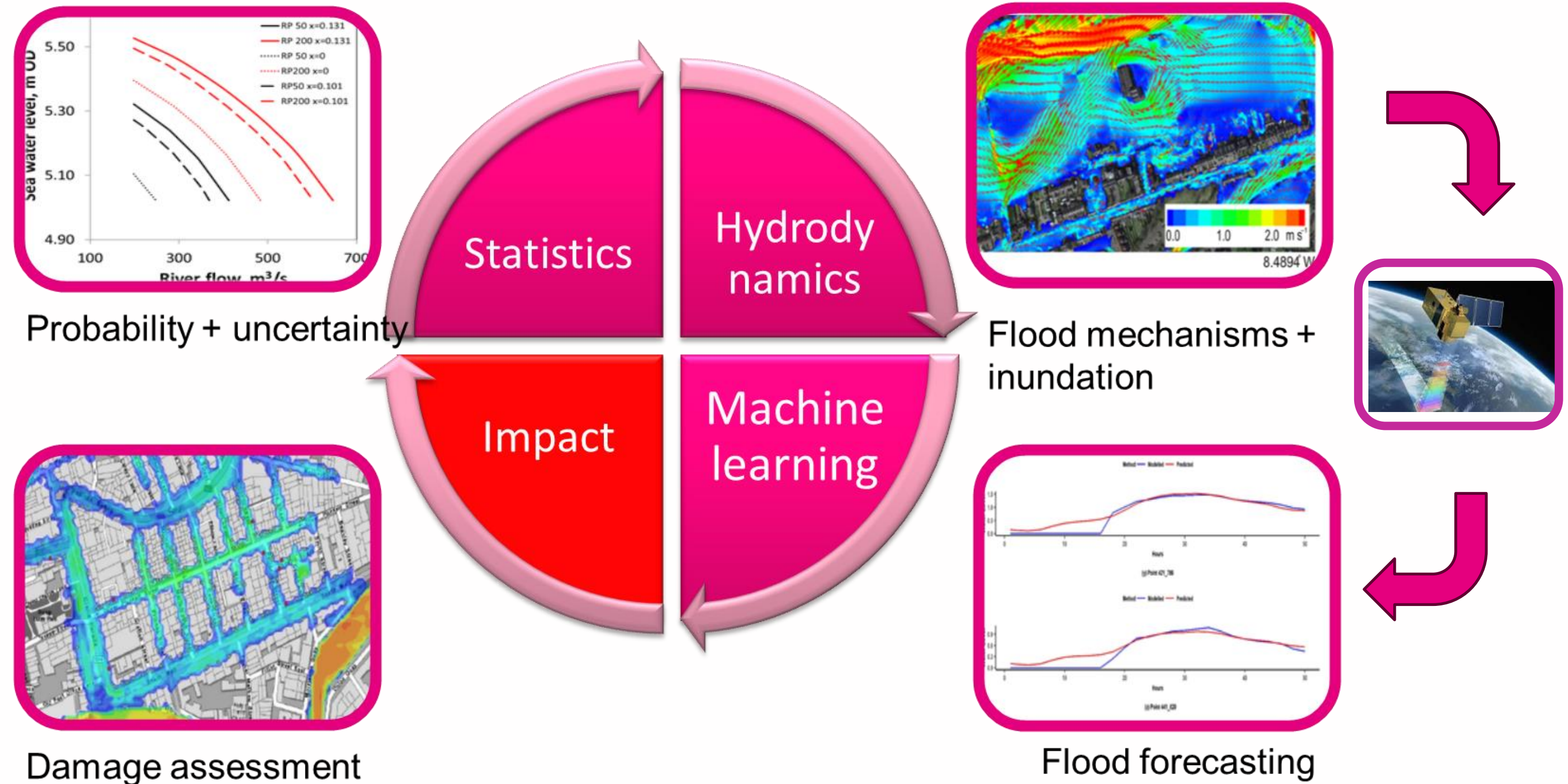
**October 2016:**





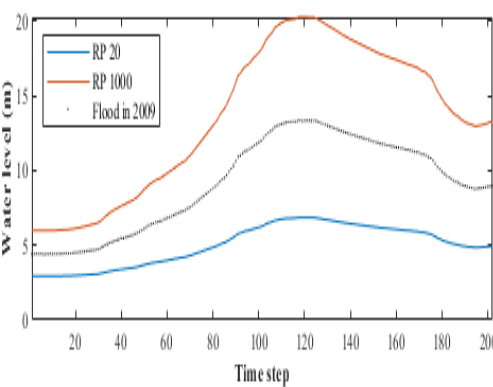


# Methodology



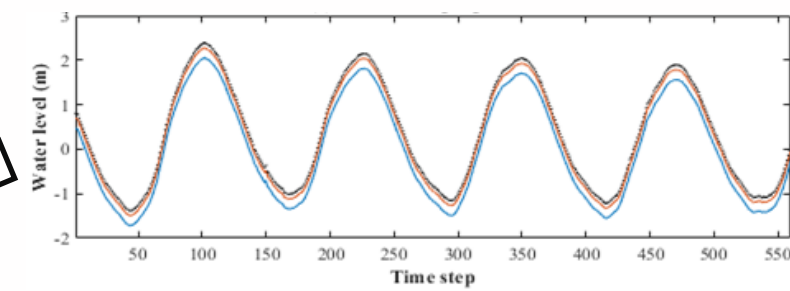


# Advanced Compound Flood Forecasting Using a Machine Learning Approach

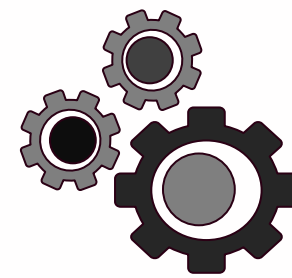


River Lee flow data for the fluvial part

**Hydrodynamic model**

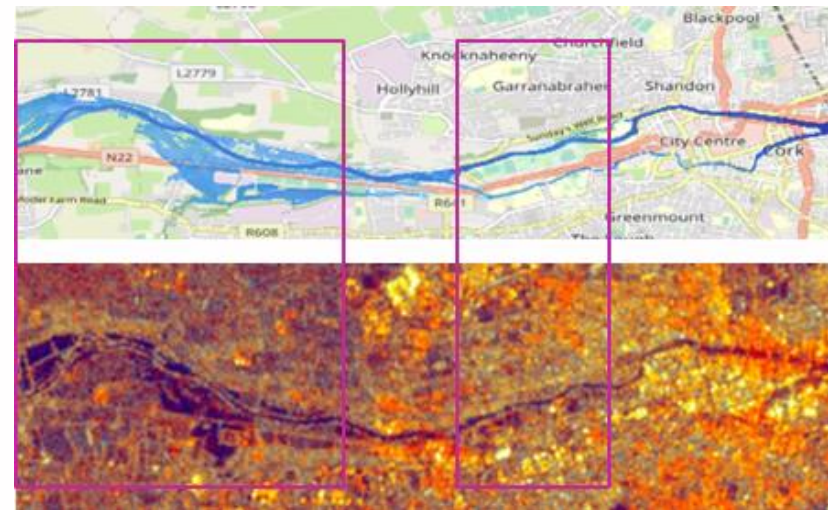


Tidal water levels for the coastal part

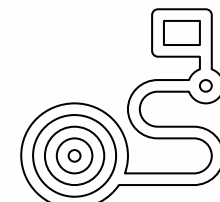


**Machine learning algorithms**

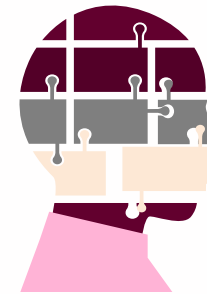
1. Artificial Neural Network (ANN)
2. Decision Tree (DT)
3. Gaussian Process Regression (GPR)
4. Linear Regression (LR)
5. Radial Basis Function (RBF)
6. Support Vector Machine (SVM)
7. Support Vector Regression (SVR)
8. LSTM
9. GRU
10. RNN



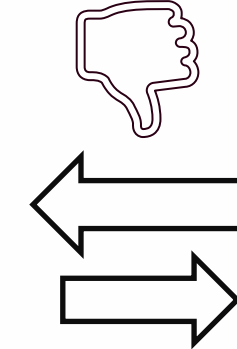
Model validation: OPW data and historical flood maps from satellite data (Earth Observation)



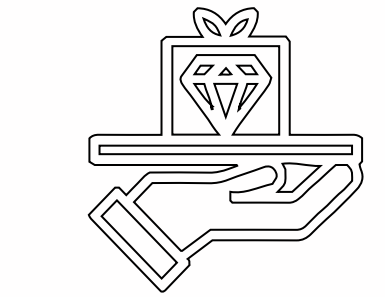
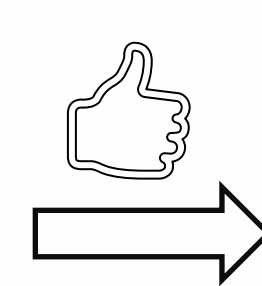
**Target flood depth data**



**Machine learning models**



**Performance evaluation of the projections**



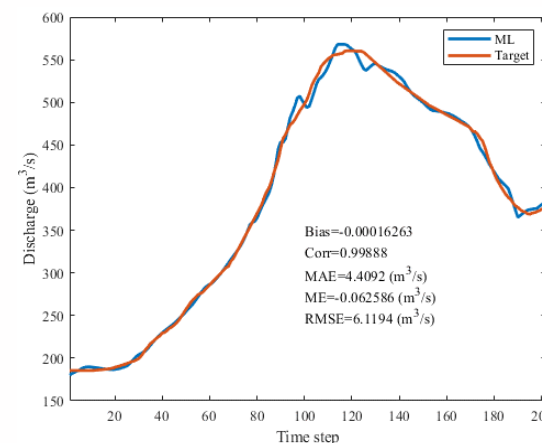
**Multi-criteria decision making**

**Data from Met Éireann**

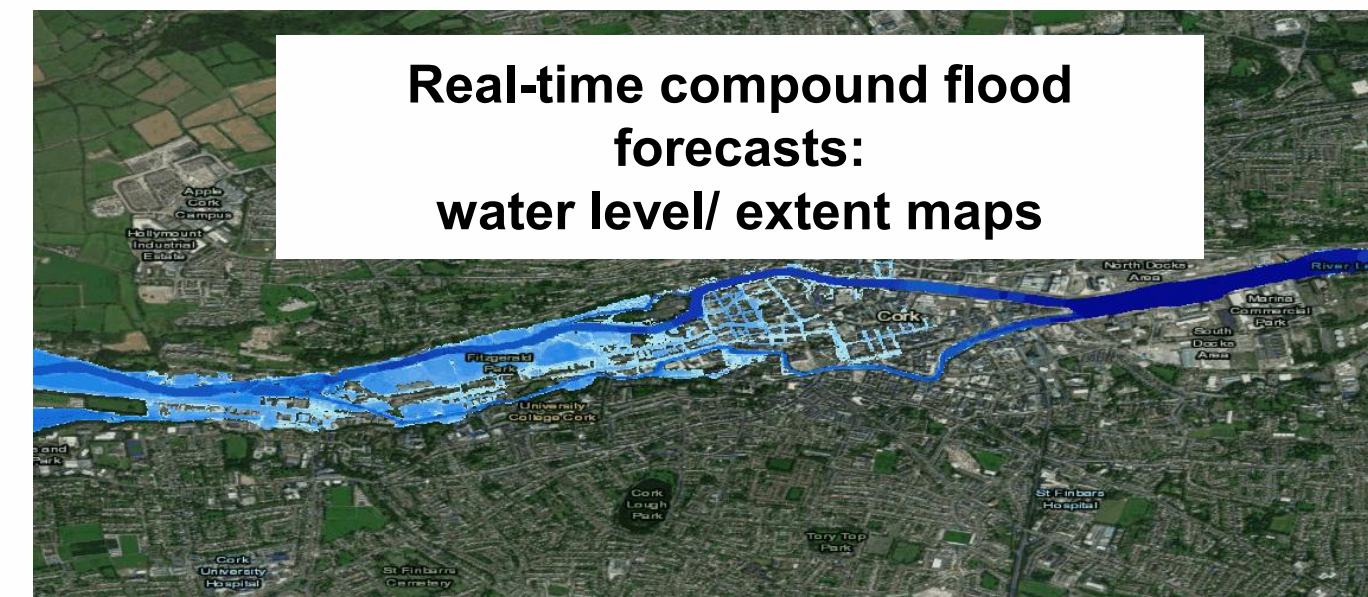
1. Pmsl- Pressure above mean sea level
2. rh2- Relative humidity
3. sm- Soil moisture content
4. st- Surface temperature
5. t2- Temperature above ground
6. tp- Total precipitation



**Input data**



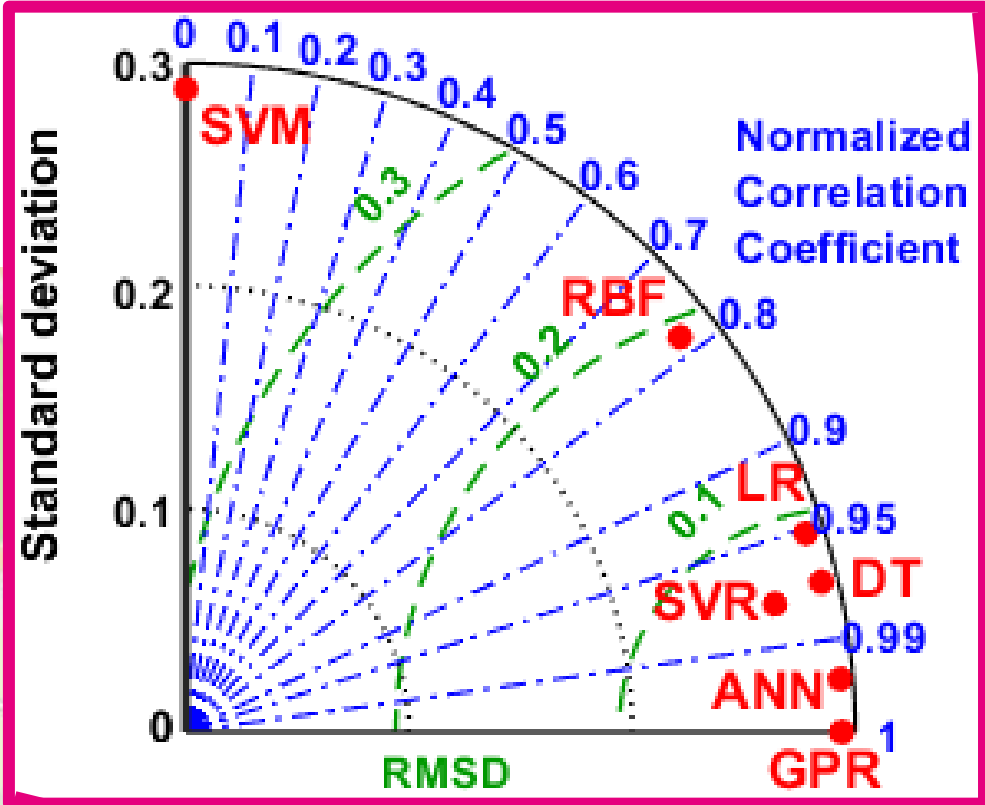
**Runoff data**



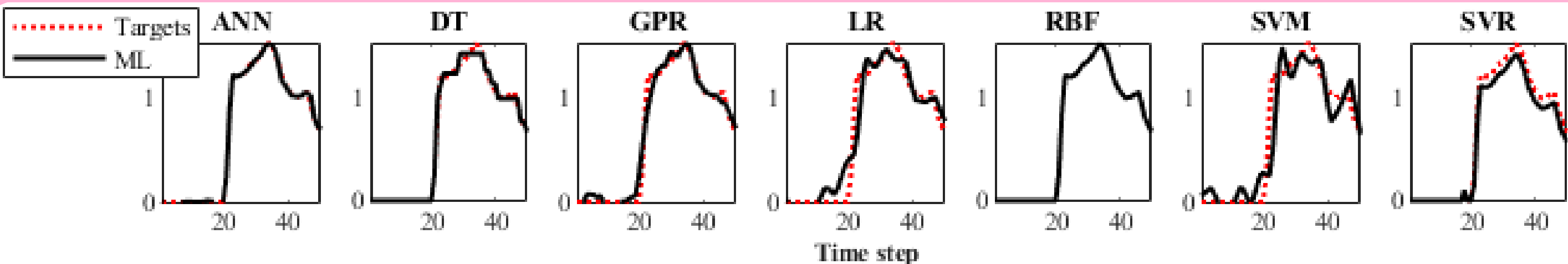
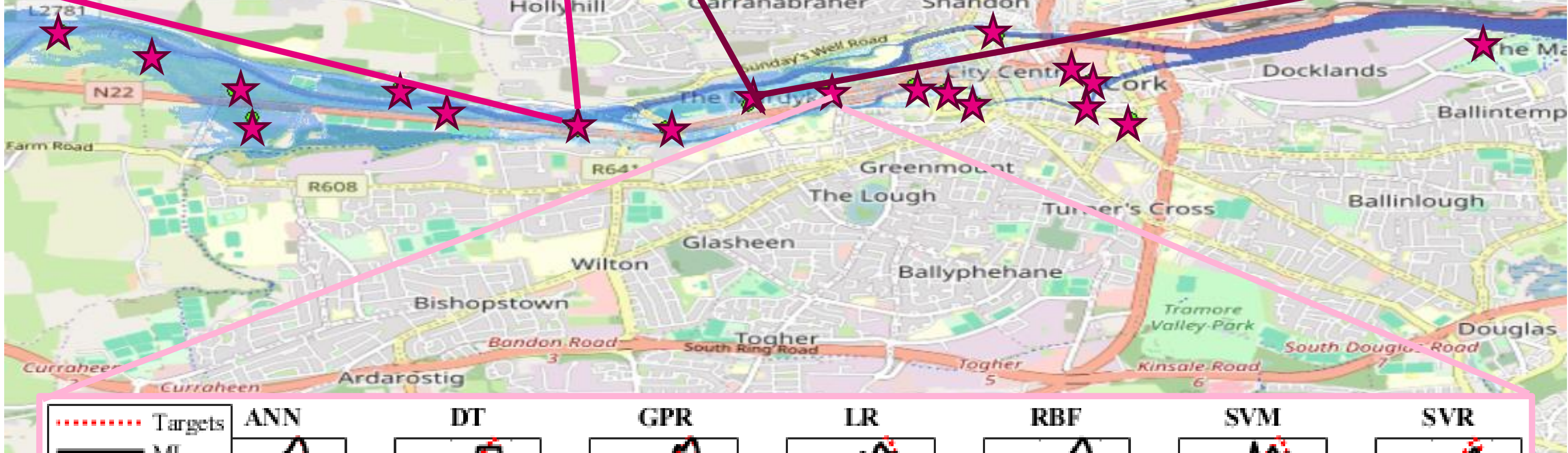
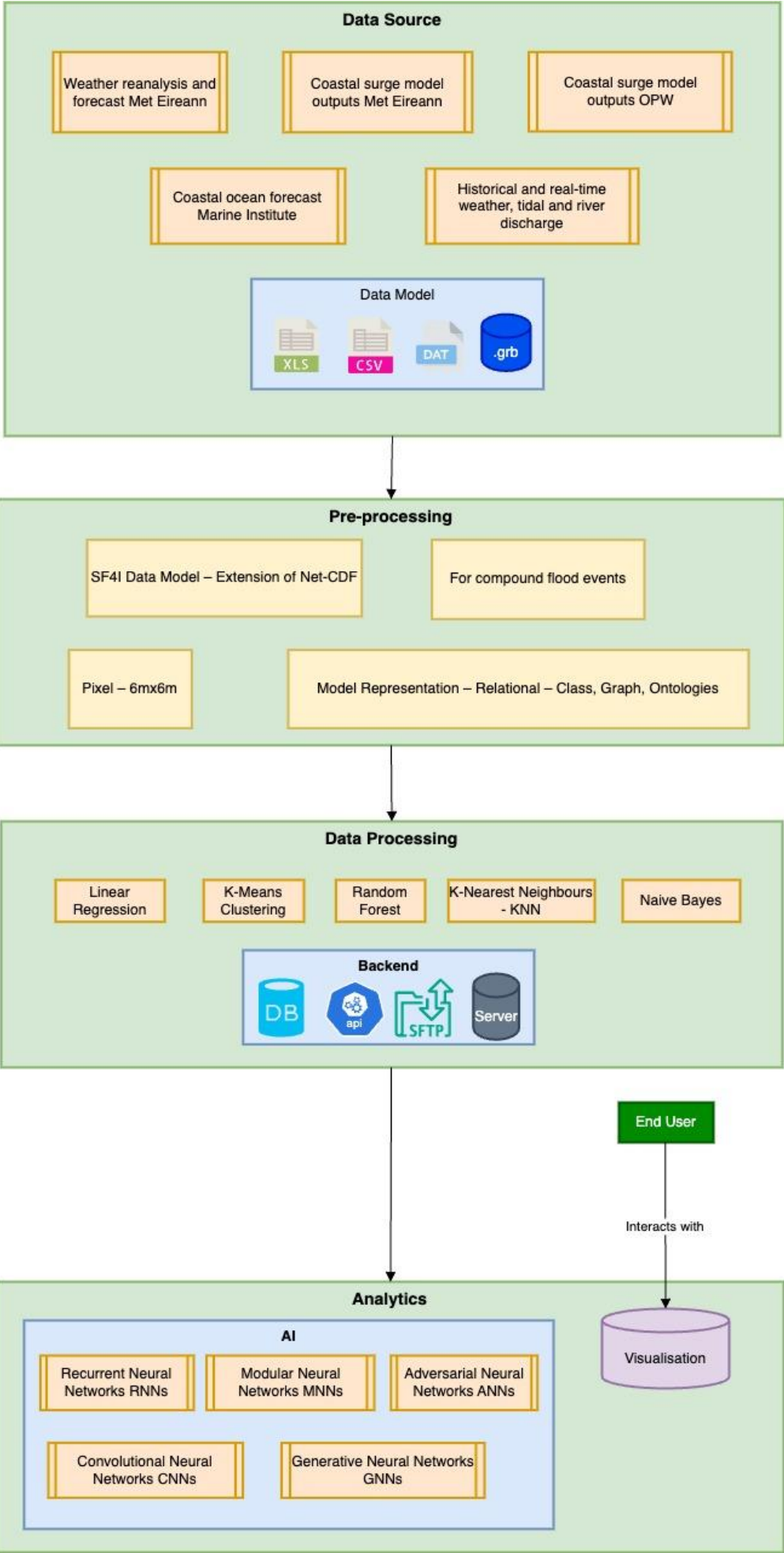
**Real-time compound flood forecasts: water level/ extent maps**



# Model results and system architecture



Model	BIAS	Corr	MAE	ME	RMSE	StD
Targets	0	1	0	0	0	0.27034
ANN	0.037387	0.99531	0.020976	0.010434	0.027945	0.27066
DT	<b>0.00000</b>	0.99417	0.018051	<b>-1.17E-17</b>	0.028856	0.26876
GPR	6.66E-16	0.99569	0.016781	1.52E-16	0.024822	0.26858
LR	-2.72E-14	0.96422	0.054727	-7.66E-15	0.070947	0.26066
RBF	-1.11E-16	<b>1.00000</b>	<b>1.83E-14</b>	-9.28E-17	<b>6.58E-14</b>	<b>0.27034</b>
SVM	-0.25899	0.61222	0.37528	-0.07228	0.41283	0.51605
SVR	-0.20751	0.99429	0.058065	-0.05791	0.076144	0.22803



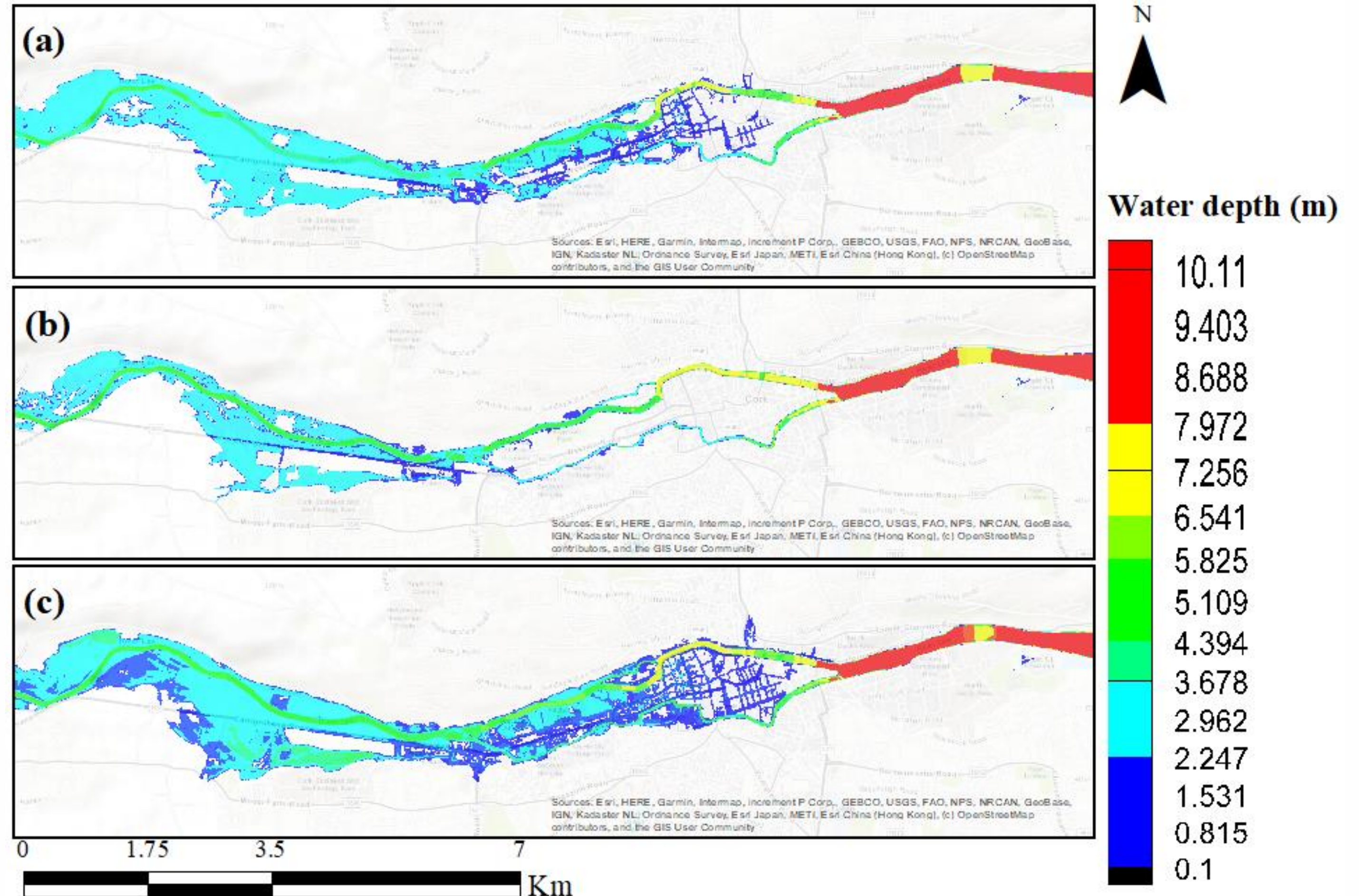




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# 3. Machine learning

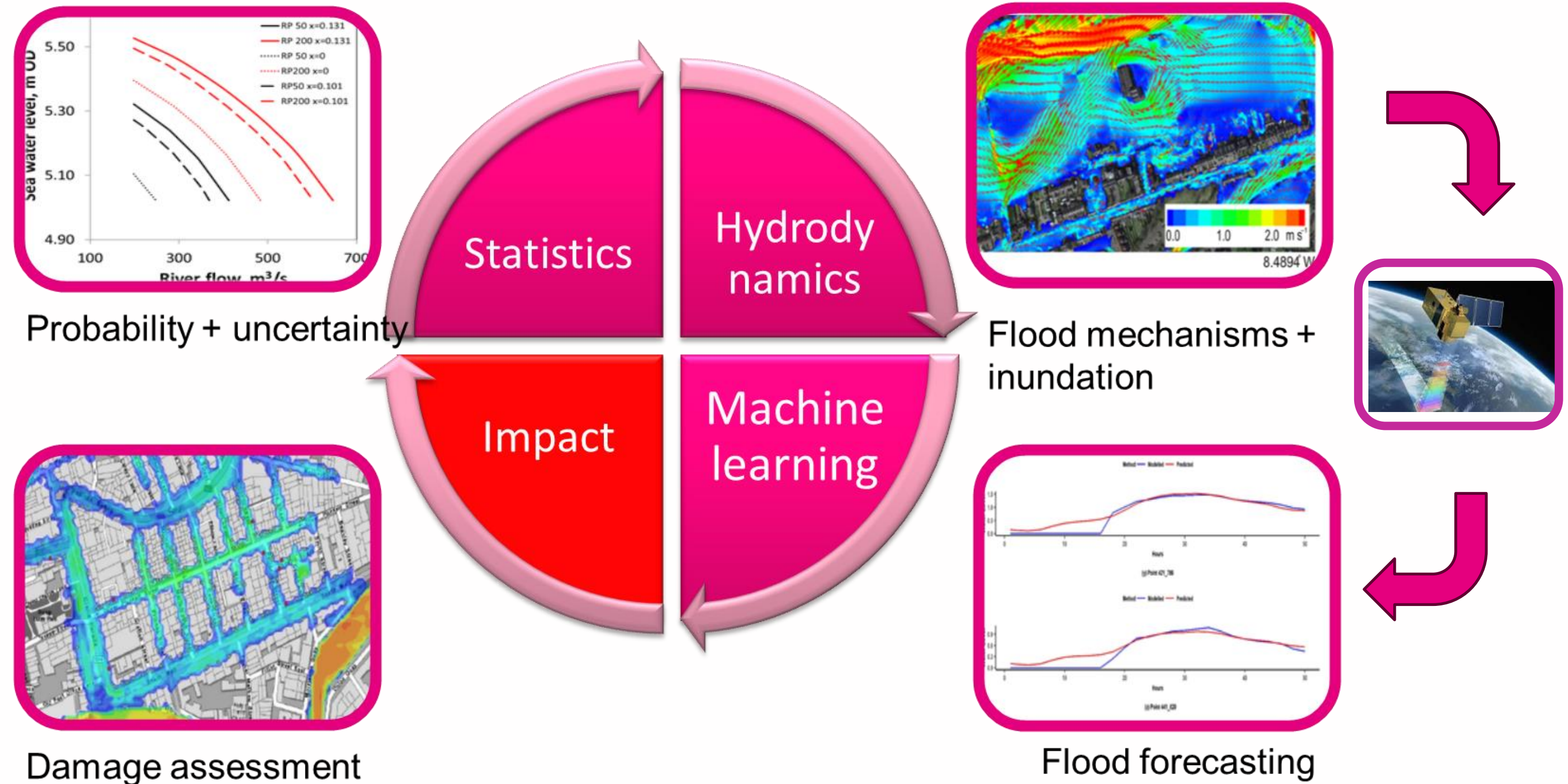
University  
ofGalway.ie







# Methodology



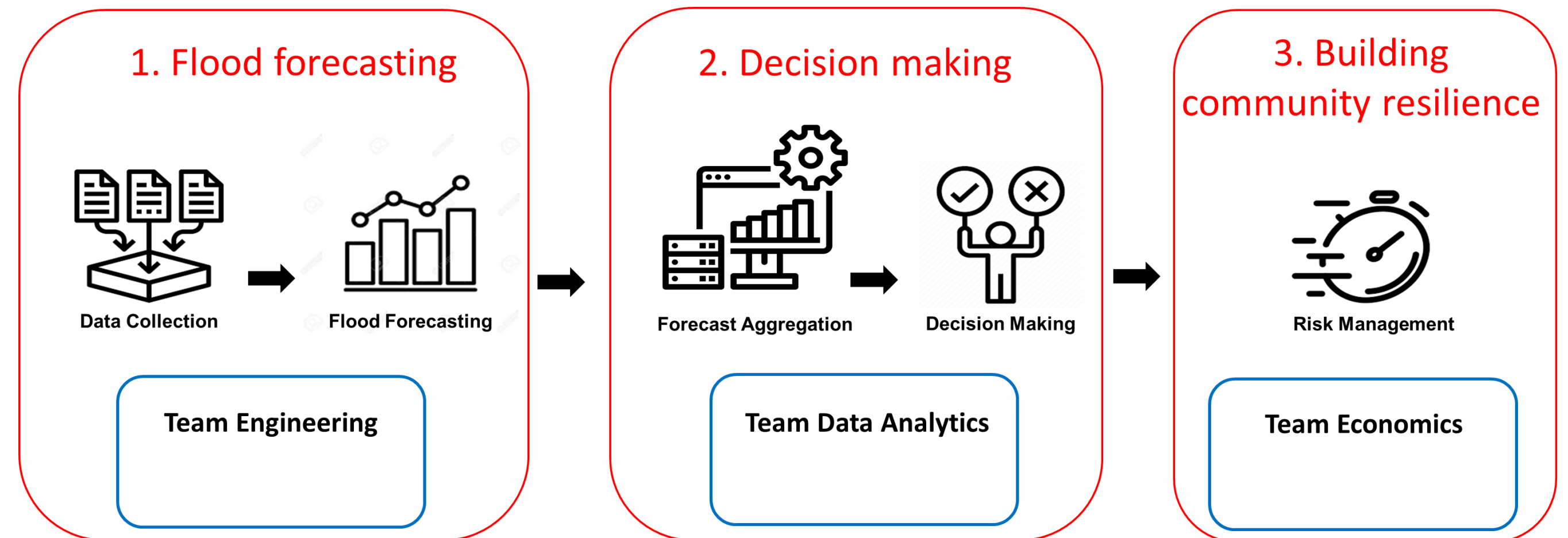
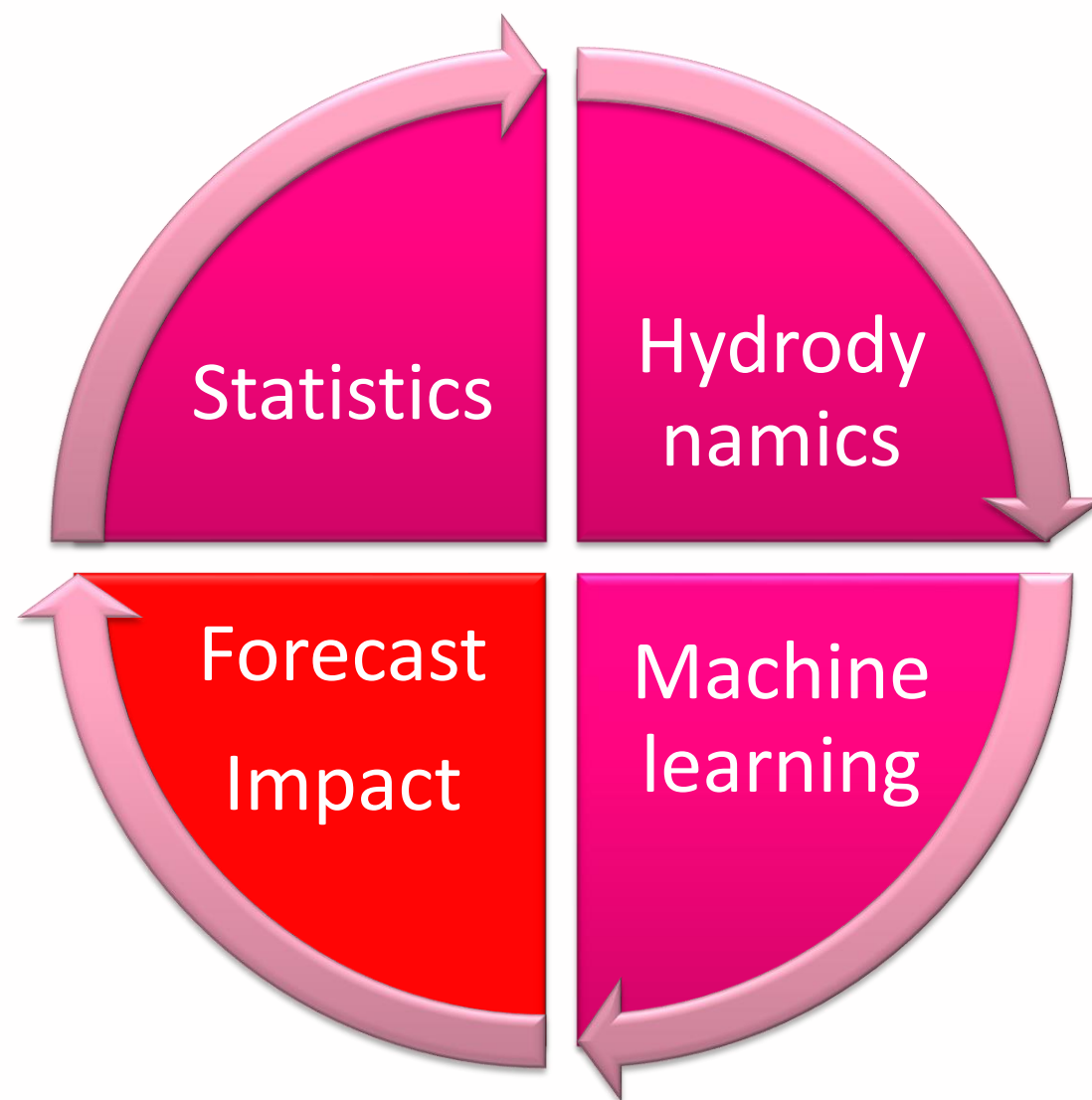




# How we determine coastal flood risks?

## Solution

Local scale decision-support system for flood management







# Dashboard (alpha )

## 5. Decision making

StopFloods4.ie Monitoring

Location Selector

Choose a location:

A

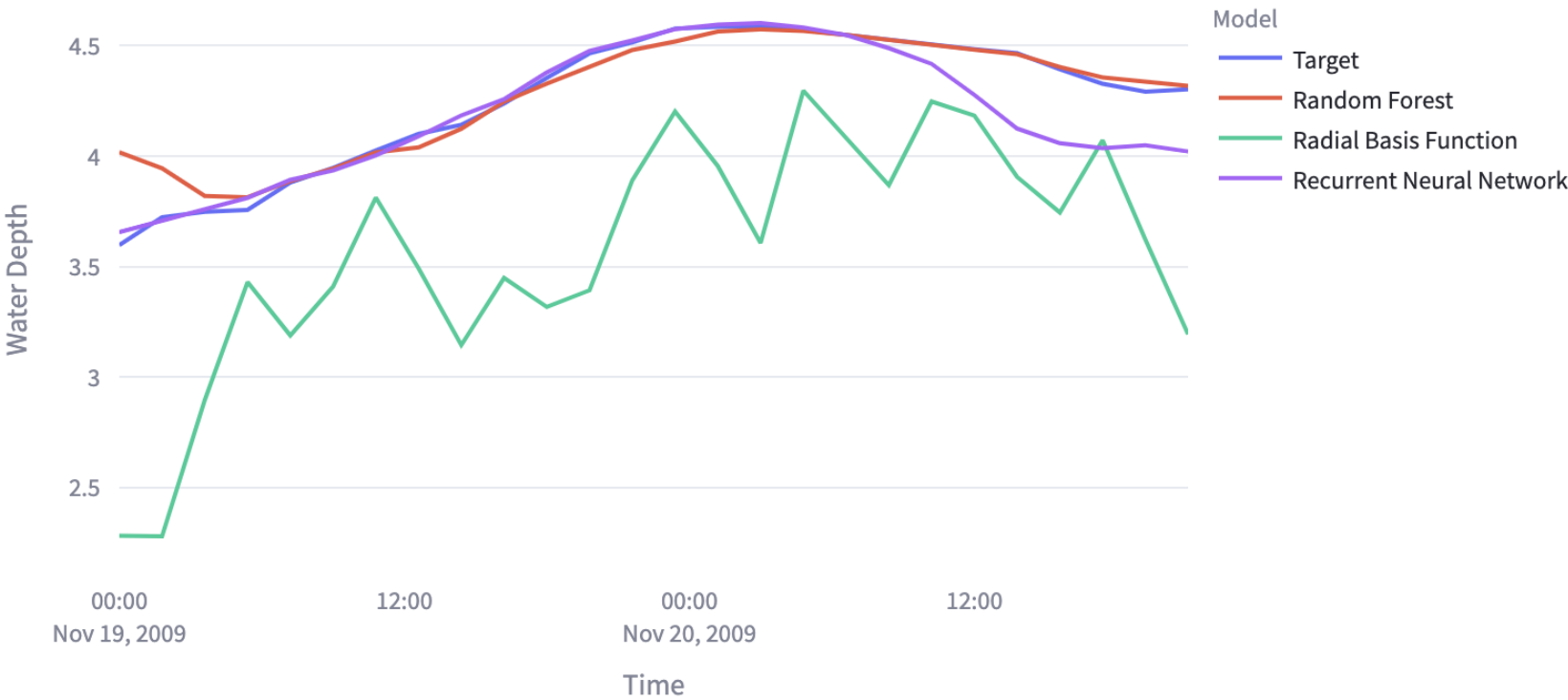
Predicted Water Depth

	Algorithm	Max Depth
0	Water Depth (Target)	4.5870
1	RF	4.5744
2	RBF	4.2966
3	RNN	4.6025

Flooding Risk Keys

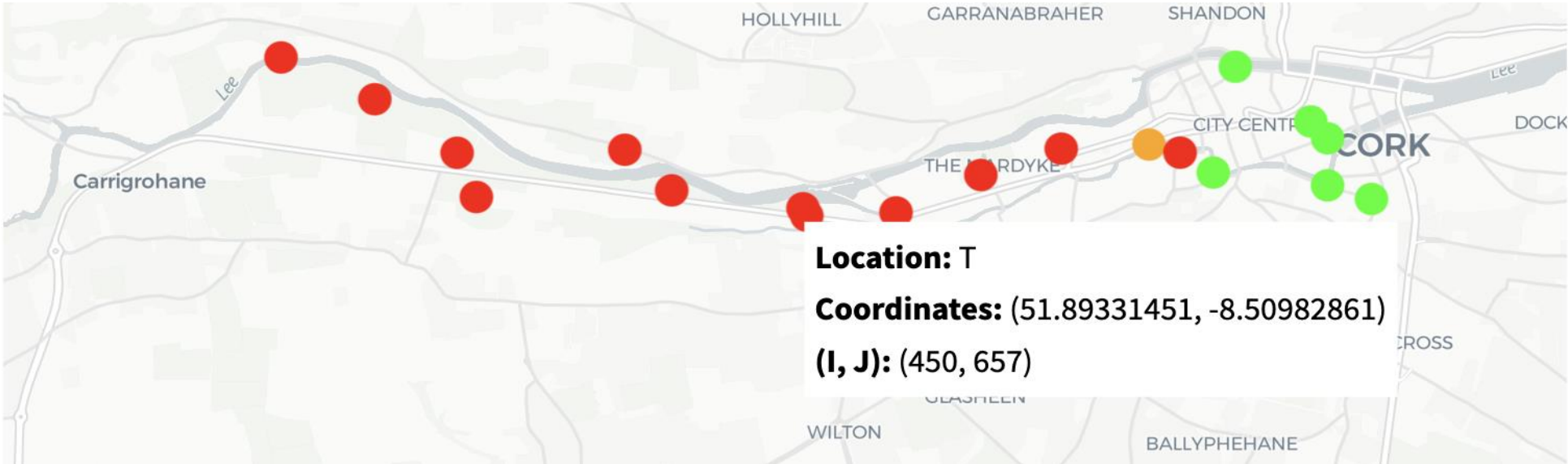
	Condition	Color
0	Water Depth < 0.5	Green
1	Water Depth < 0.75	Amber
2	Water Depth > 0.75	Red

Water Depth Predictions for A



Features

	Feature	Max Value
0	Pressure	101,196.8100
1	Humidity	0.9427
2	SoilMoisture	0.2888
3	Temperature	285.0501
4	Temperature2	286.5320
5	Precipitation	0.0000
6	Wind	12.0688
7	RiverDischarge	13.3434
8	Tide	2.3100

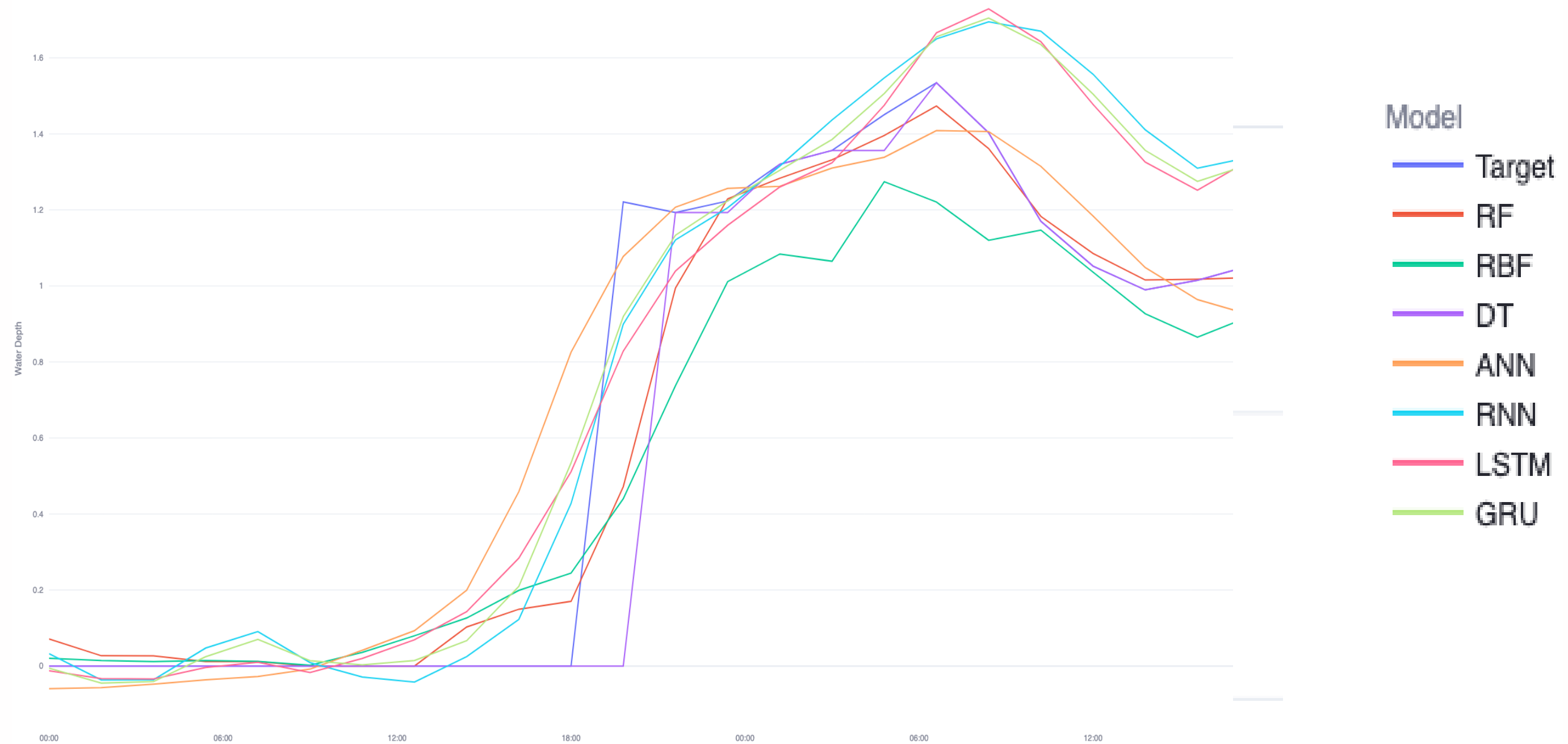






# Dashboard (alpha )

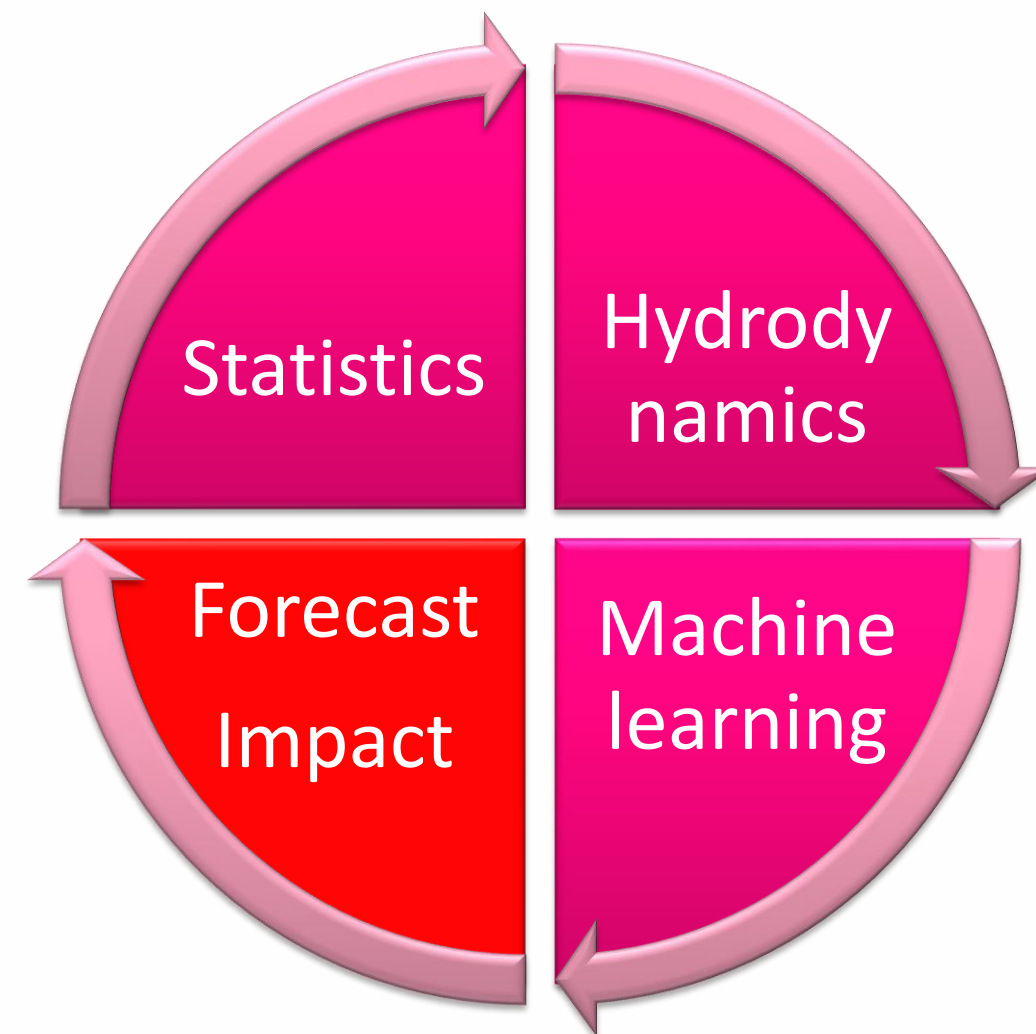
## 5. Decision making







# Flood forecasting



## Societal Impacts

### Forecasting

- Better preparedness by LAs and communities
- Increased confidence in forecast

### Decision-making

- Reduction of false alarms
- Flood prevention

### Management

- Better allocation of resources
- Damage reduction
- Reduction in emotional stress



Middleton, Co. Cork, Oct 2023

Three-model system can improve flood  
resilience and wellbeing of at-risk communities





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IRELAND



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# Thank you

Indiana.Olbert@universityofgalway.ie



Marine Institute  
*Foras na Mara*



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