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Predictive groundwater flood hazard mapping in lowland karst

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Ireland | Éireann

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Groundwater Flooding

"Flooding caused by the emergence of water originating from sub-surface permeable strata induced by exceptional and/or prolonged recharge" (Morris 2007)

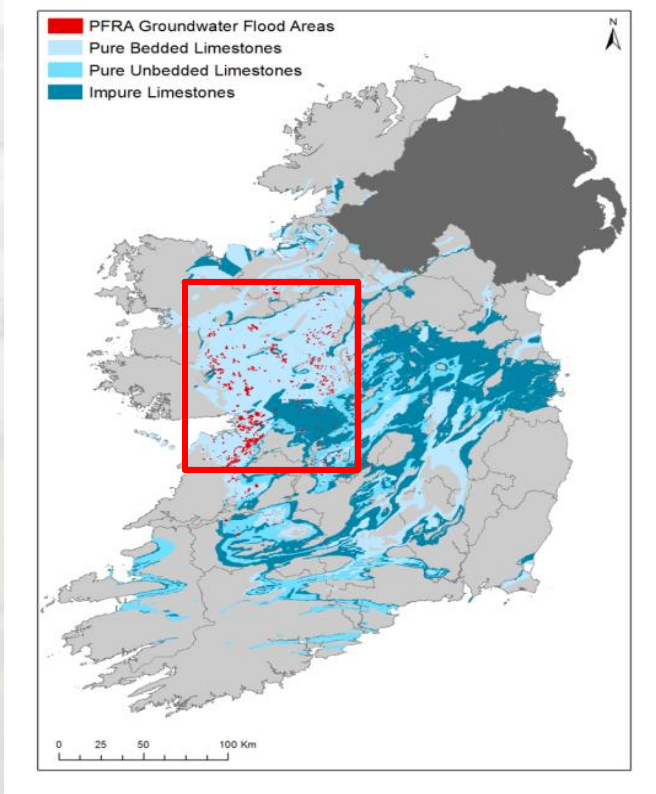
- Not usually a risk to life
- Discontinuous and difficult to predict
- Generally requires sustained rainfall over relatively longer durations than other forms of flooding
- Increases the risk from other forms of flooding

Groundwater flooding has some distinct characteristics in comparison to fluvial, pluvial and coastal flooding.

Groundwater Flooding in Ireland

Karst Flooding

- Primarily occurs on the pure, well-bedded limestones in west and northwest Ireland
    - Well-developed karst GW systems
    - Low storage and high transmissivity
    - Discontinuous or absent SW drainage
    - Low-lying; high levels of GW-SW interaction
    - Turloughs



GW flooding common in carboniferous limestones of the western lowlands due to the nature of the karst groundwater systems.

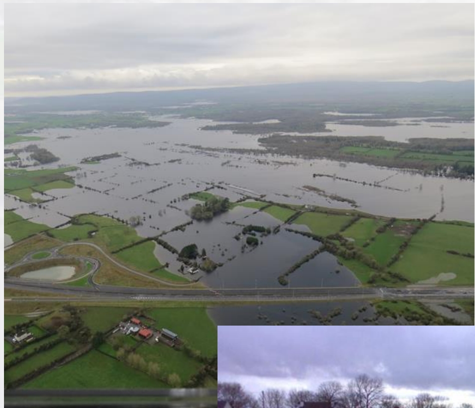
GW flooding primarily associated with turloughs, topographic depressions which are intermittently inundated from groundwater on an annual basis.

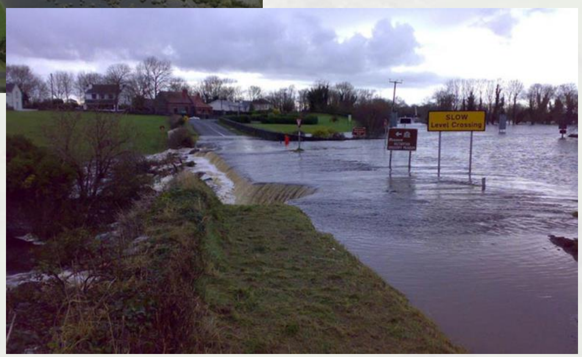
At a site level, here's an example of a GW flood during summer conditions

The same site during winter conditions, with flood depths of up to 15m and volumes in excess of 14 million m3

Motivation

The 2nd Cycle of the EU Floods Directive: 'Review and, if necessary, Update'





- Existing maps found to be not representative of scale and distribution of groundwater flooding

Challenges:

Absence of historical records

Lack of methods for estimating flood frequency

Following the floods of 2015/2016, we reviewed the Preliminary Flood Risk Assessment (PFRA) flood maps for Ireland and found they were not representative of the scale and distribution of groundwater flooding in affected regions.

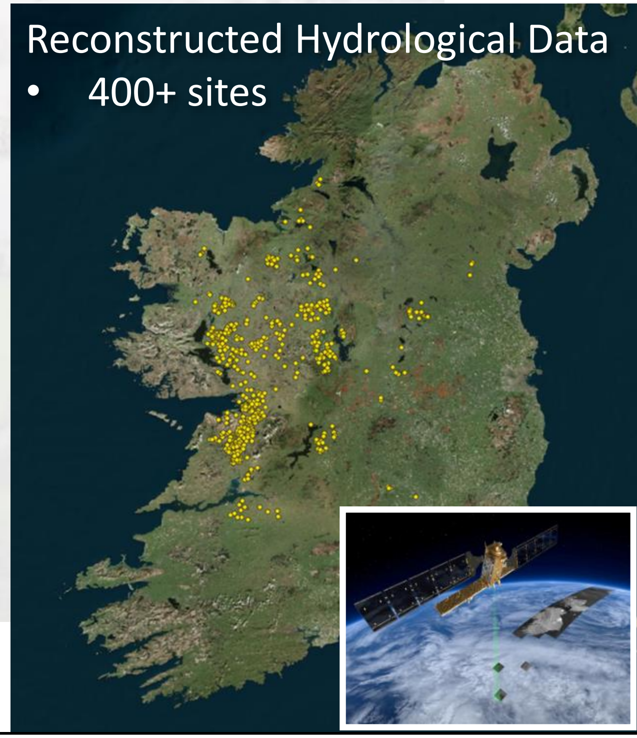
Specific issues relating to GW flooding that had to be addressed were:
1. Absence of historical records, both long-term hydrological series and evidence of historic flooding
2. Absence of predictive mapping, or a way to quantify return period of gw floods.

While GW flood mapping can be limited to extreme events under the Floods Directive, the lack of predictive element was seen as an impediment to flood relief works following recent severe flood events. This project addressed this limitation.

Predictive Mapping Methodology

Input Data
- Rainfall / ET
- Topography

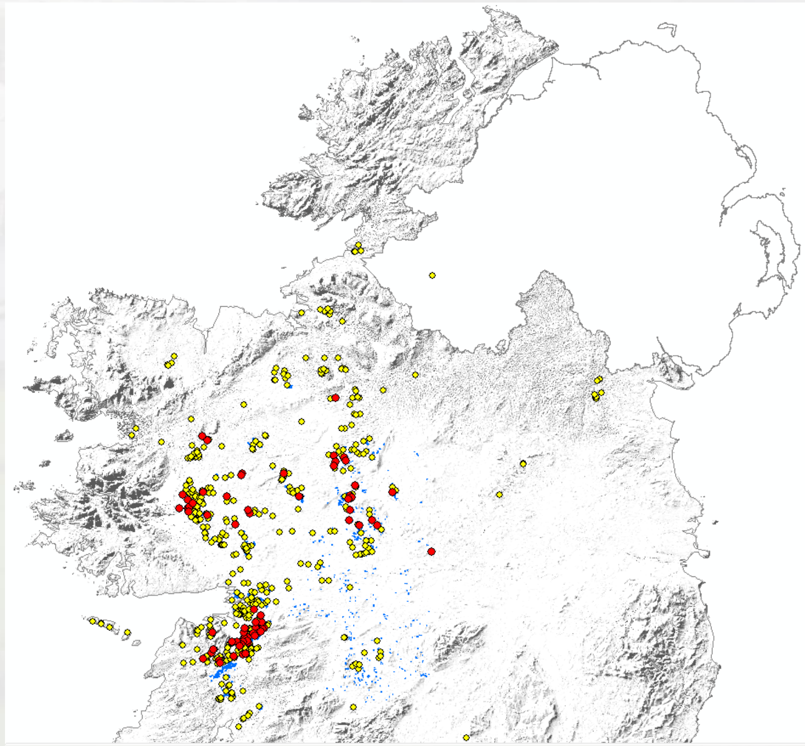
Calibration Data
- Observed
- SAR



The first step in the process was collecting and generating observational data for the training of hydrological models. This was derived from direct measurement and also from remote sensing derived water levels.

Observation: In Situ

- 65 exploratory sites
- 20 long-term telemetric sites



Observation: Remote Sensing

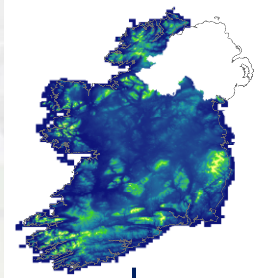
Sentinel-1 Synthetic Aperture Radar

- Flood detection
- Advantages:
  - Spatial coverage
  - All weather, day and night
  - Systematic data collection

- Novel methodology to derive water levels from time series of SAR images and Digital Terrain Models (DTM) used to generate hydrographs at over 400 groundwater flood locations

SAR images

DTM



GIS Filters
Forestry mask
Rivers and lakes
Fill Difference
…

SAR Generated Hydrographs

SAR images were used to delineate water (flat surface) and not water (rough surfaces).

Time series of SAR images and Digital Terrain Models (DTM) were then used to generate hydrograph at over 400 groundwater floods in Ireland. The resulted hydrograph agreed with the sites monitored using dataloggers, having Nash Sutcliffe (Volume) efficiencies above 0.8 for most of the sites.

Predictive Mapping Methodology

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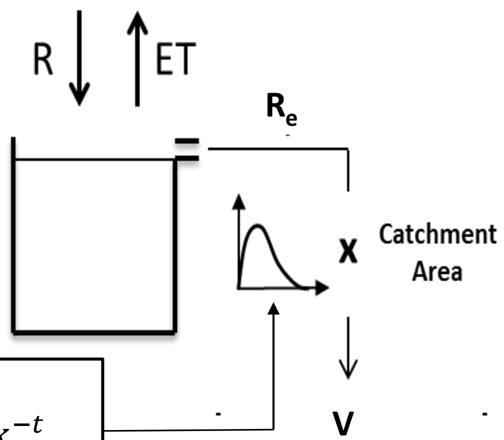
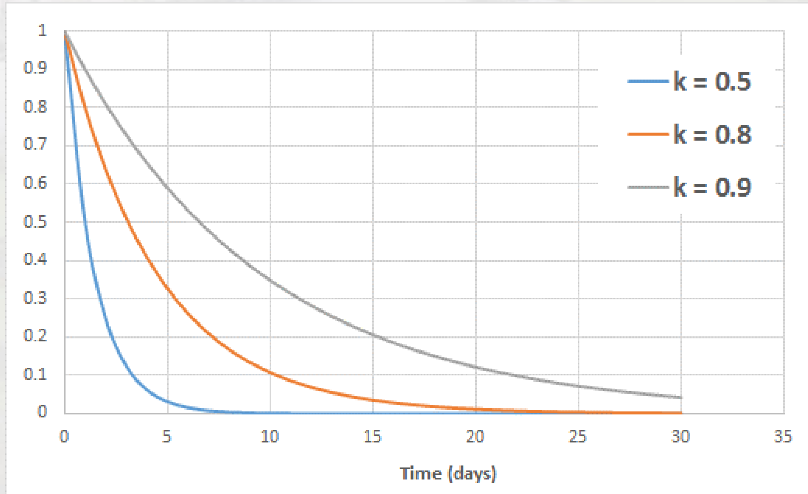
Hydrological Model



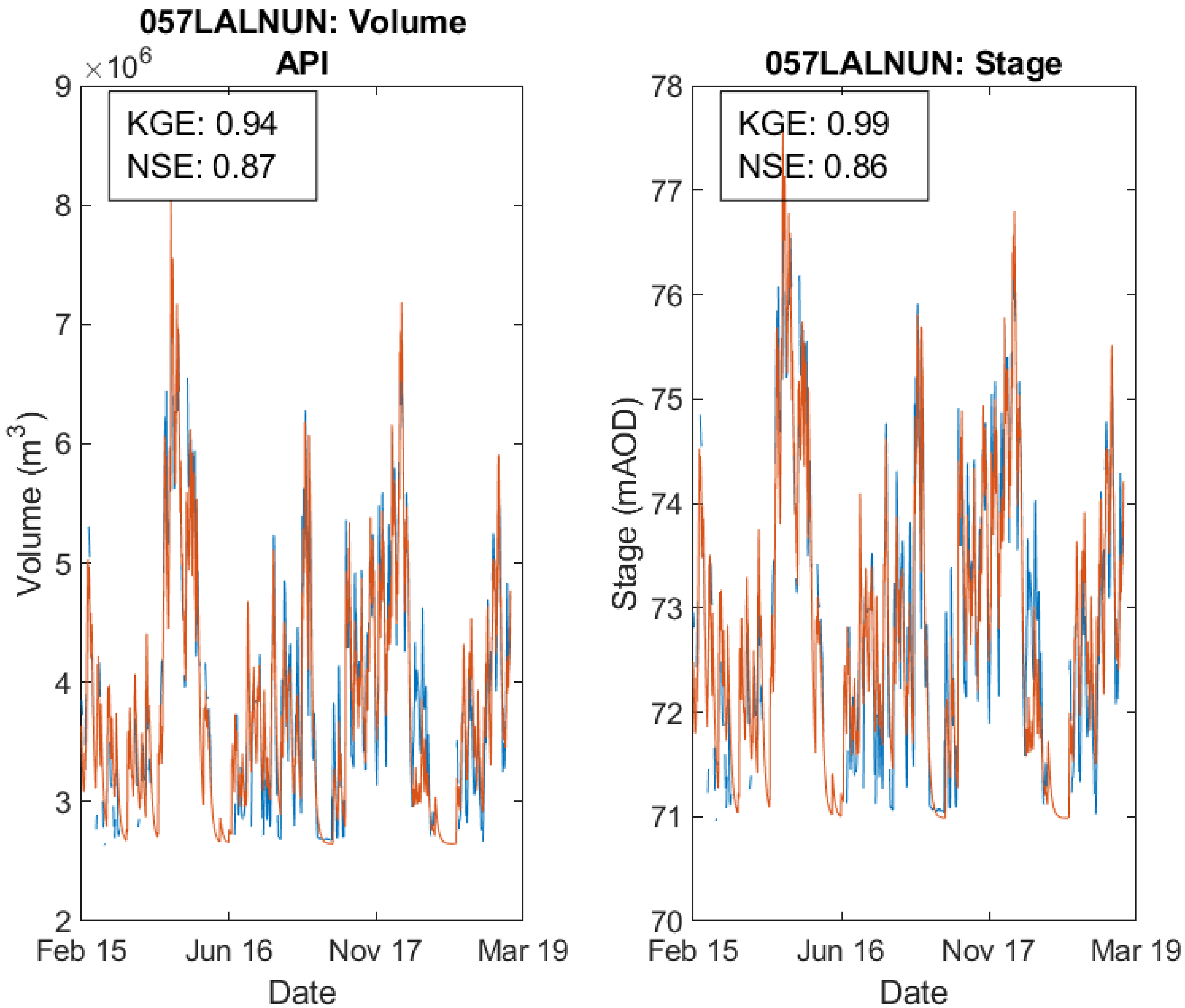
Transfer Function

$$API = \sum_{t=-1}^{-i} P_t k^{-t}$$

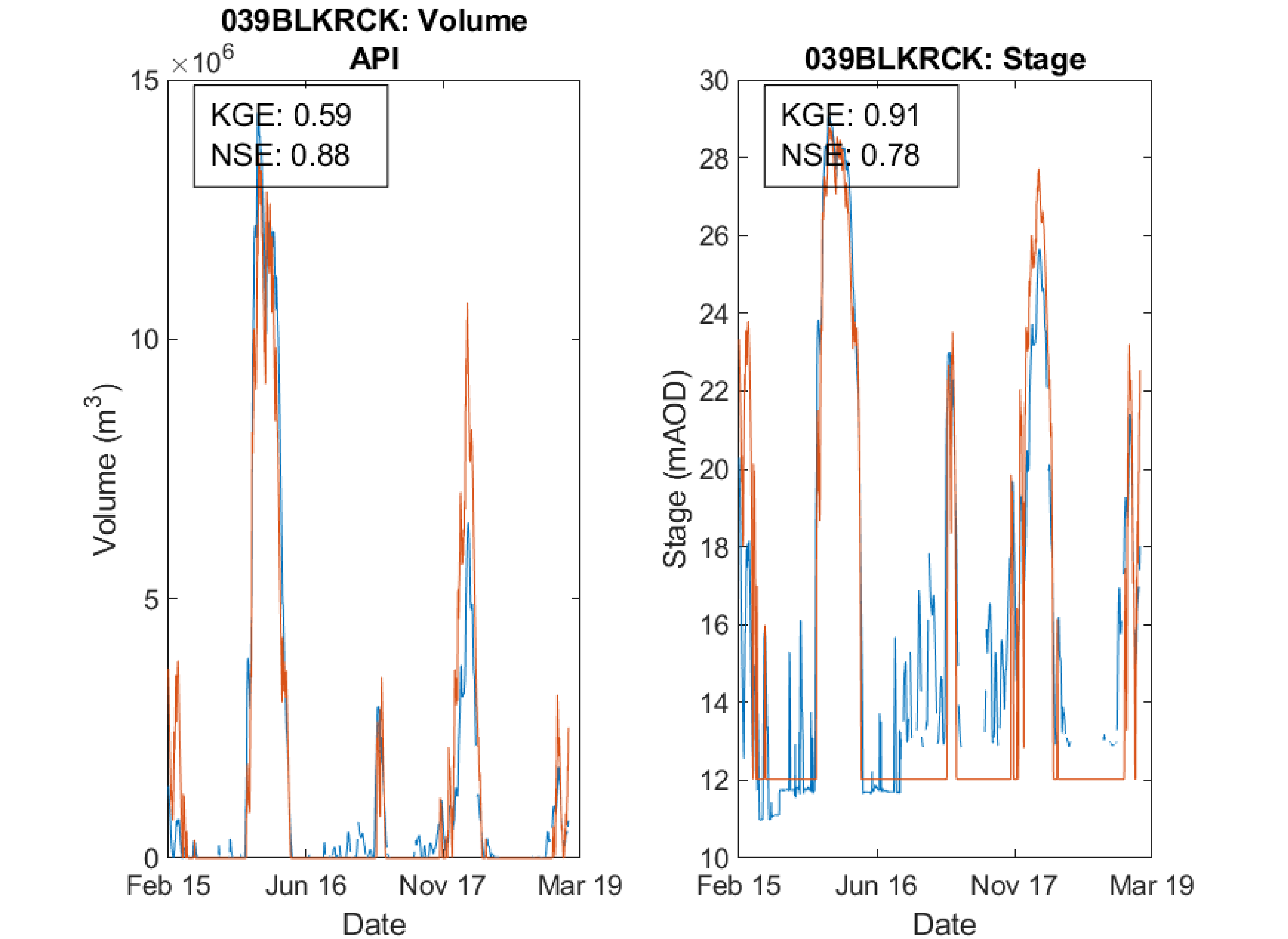


A hydrological modelling methodology was developed to predict flood volume based on antecedent rainfall and reference evapotranspiration.

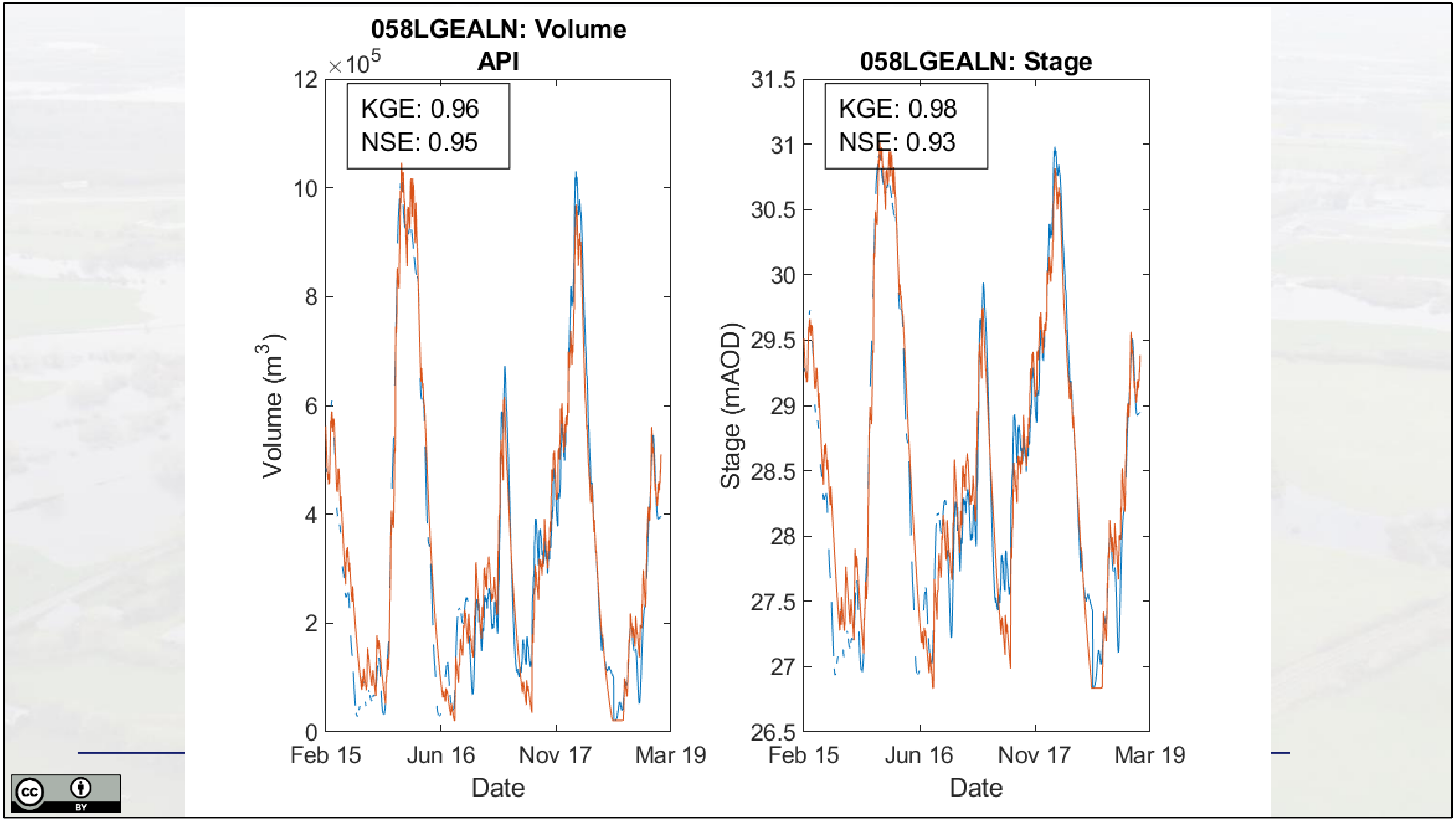
The model was based on the antecedent precipitation index (API) given, where i is the number of antecedent days, k is a decay constant and Pt is rainfall on day t. The coefficient k represents the percentage water that remains after a specified time interval; a large k leads to a slow recession after the cessation of rainfall while a small k indicates a quick recession.



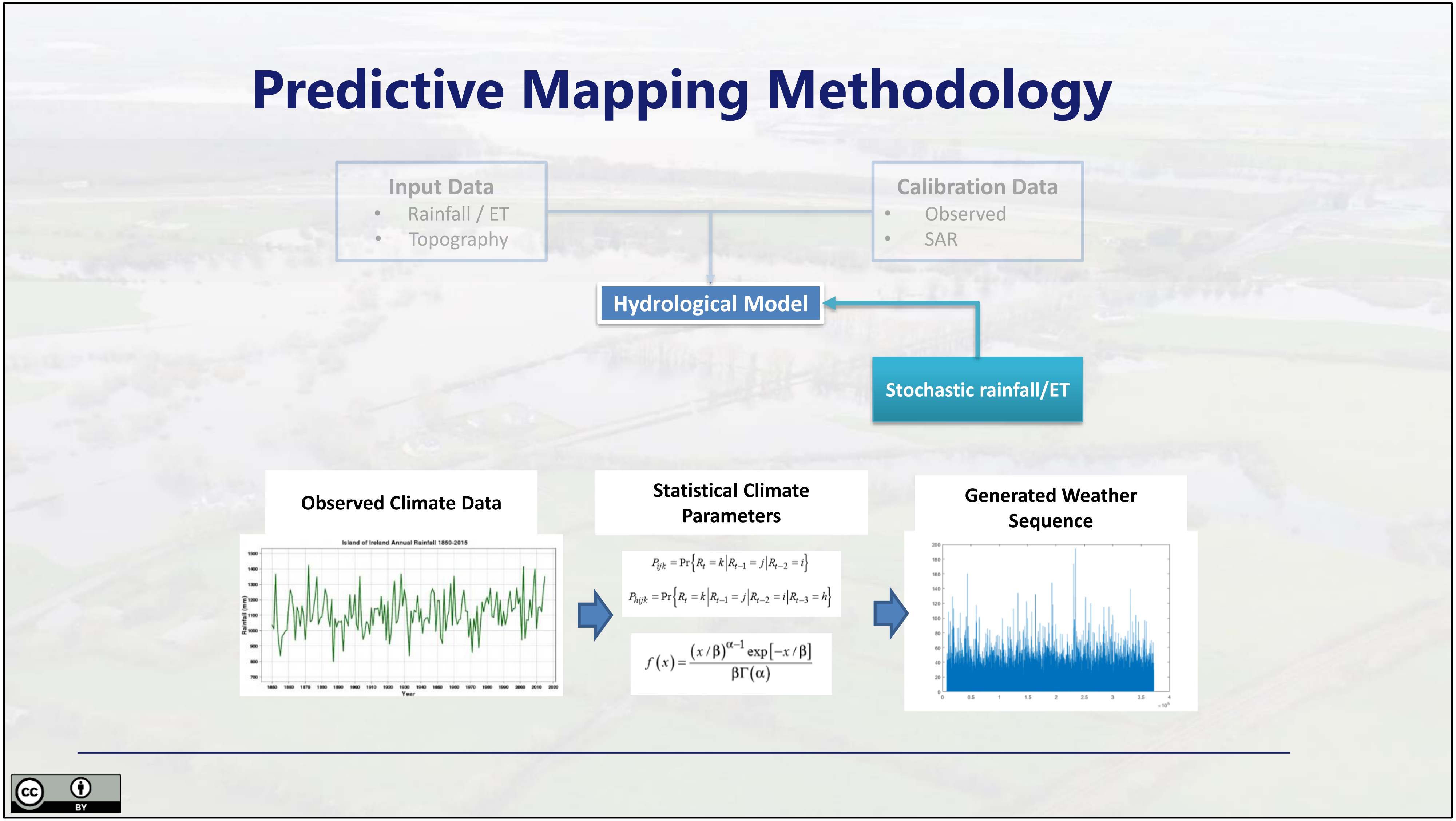
Examples of model results



Examples of model results



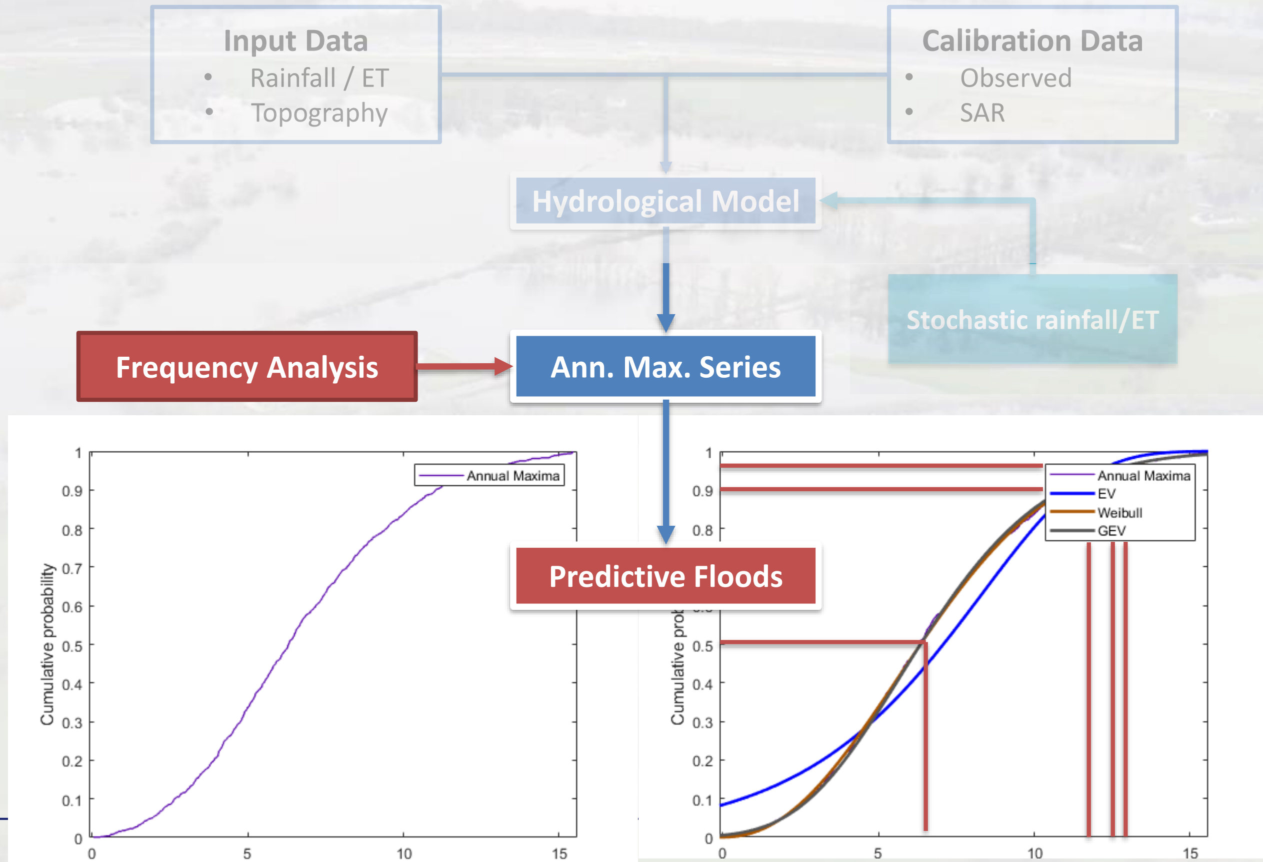
Examples of model results



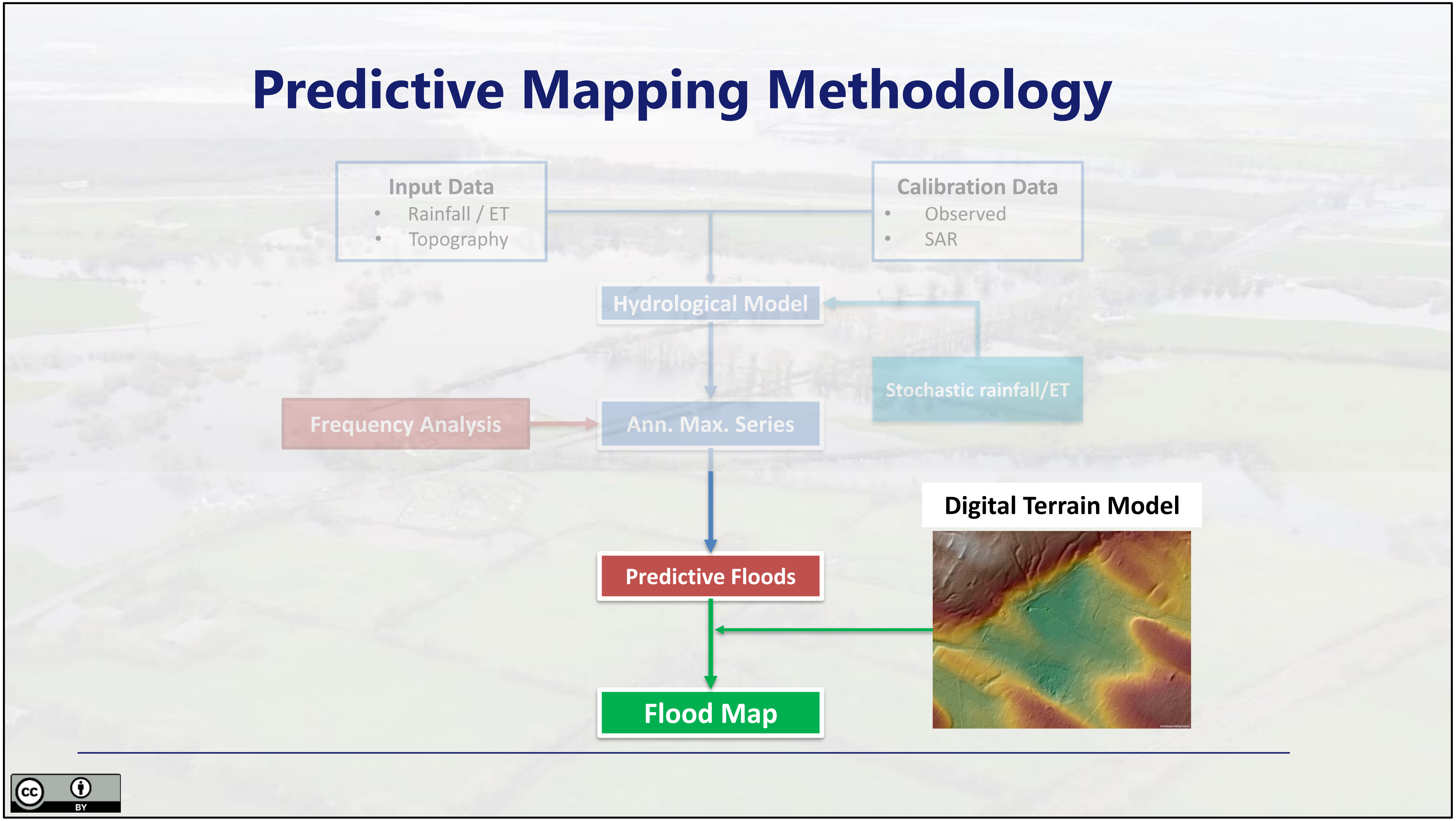
A stochastic weather generator calibrated on 70-year meteorological records was used to generate long-term synthetic rainfall data for each site.

These stochastic series, together with long-term average evapotranspiration, were used as input to the site models to produce long-term hydrological series from which annual maxima series were derived.

Predictive Mapping Methodology

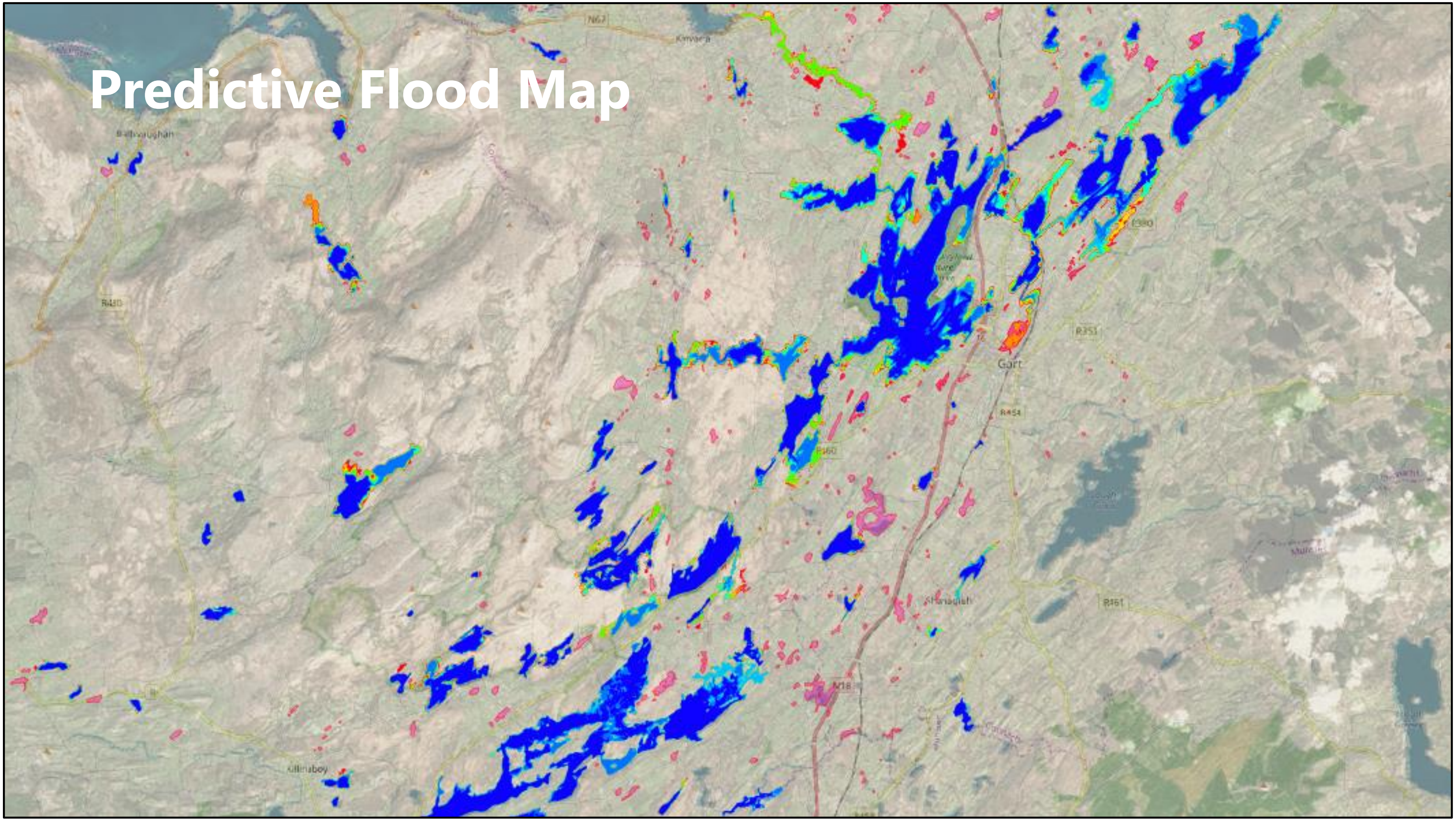


Thereafter, flood frequency analysis was used to estimate predictive flood levels for a range of Annual Exceedence Probabilities (AEP%)



Digital terrain models were then used to produce national predictive groundwater flood maps

Predictive Flood Map



Thank You

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