Tackling uncertainty in flood forecasting

Methods explained

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1. What is uncertainty in flood forecasting?
2. Why is understanding uncertainty of predictions important?
3. What are the available methods?
4. Selecting a suitable method
5. Minimising uncertainty, what source will you focus on?
6. Where are we going with uncertainty?
7. Communicating uncertainty
8. Discussion
What is uncertainty in flood forecasting?

Definition of uncertainty:
“Uncertainty results from the lack of knowledge or the inability to accurately measure or calculate an observed value, which can lead to differences between the modelled and its “true” value of a variable.” (Gouldby & Samuels, 2009).

Difference is predictive uncertainty quantifies the uncertainty of the prediction rather than validation uncertainty or model uncertainty, which are the ability of a model to reproduce reality.
Main sources of uncertainty

Input uncertainty
- Observations
- Meteorological forecasts

Initial conditions uncertainty
- Initial conditions
- Data assimilation

Modelling uncertainty
- Hydrological model
- Hydraulic model

Predicted variable

Model unable to fully represent processes
Model parameters
Why is uncertainty such an important topic?

1. More reliable forecast information
2. Greater wealth of forecast information
3. Extends forecast lead times

Probabilistic weather forecasts are becoming more common
Increase in computing power
Initiatives like Hydrologic Ensemble Prediction Experiment (HEPEx) are encouraging the uptake of uncertainty in hydrological predictions.

https://hepex.irstea.fr/
Uncertainty methods for flood forecasting
Uncertainty methods for flood forecasting

- **Ensemble methods**
  - Foster et al., 2018
  - Seo et al., 2018
  - Waller et al., 2018
  - Zarzar et al., 2018

- **Statistical methods**
  - Xu et al., 2017
  - Wani et al., 2017
  - Ocio et al., 2017
  - Benninga et al., 2017
  - Fan et al., 2016
  - Muthusamy et al., 2016
  - Klein et al., 2016
  - Thibault et al., 2016
  - Rodriguez-Rincon et al., 2015
  - Bourgin et al., 2015
  - Hemri et al., 2015
  - Dogulu et al., 2015
  - Lopez et al., 2014
  - Laiolo et al., 2014
  - Madadgar et al., 2014
  - Silvestro et al., 2014
  - Demirel et al., 2013
  - Todini, 2013
  - Hemri et al., 2013
  - Mendoza et al., 2012
  - Nester et al., 2012
  - Mendoza et al., 2012
  - Pianosi et al., 2012
  - Coccia et al., 2011
  - Zappa et al., 2011
  - Weerts et al., 2011

- **Combined methods**
  - Krzysztofowicz, 1999
  - Krzysztofowicz et al., 2001
  - Krzysztofowicz, 2002
  - Romanowicz et al., 2003
  - Krzysztofowicz et al., 2004
  - Pappenberger et al., 2005
  - Moradkhani et al., 2005
  - Duan et al., 2007
  - Vrugt et al., 2008
  - Todini, 2008
  - Reggiani et al., 2008
  - Hopson et al., 2009
  - Dietrich et al., 2009
  - Reggiani et al., 2009
  - Tiwari et al., 2010

Key:
- Red circle: Flood forecasting uncertainty methods
- Blue circle: Published outputs from different method types
- Timeline of publications: The colour of the publications refer to the method types.

*Full references of the publications are available in the supplementary material*
Uncertainty methods for flood forecasting

1. Ensemble forecasts (spaghetti plots)
   - Statistical analysis or comparison of the performance
   - Forecast with uncertainty bands
   - Forecast with confidence bounds/intervals

Key:
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Uncertainty methods for flood forecasting

1. Forecasts with probability bands
2. Post processed ensemble forecast

Ensemble methods
Statistical methods
Combined methods
Uncertainty methods for flood forecasting

**Ensembles**

“What is the likely spread of the forecast given the known lack of knowledge on the model structure, parameter and/or initial conditions of the catchment, river and/or atmosphere?”

**Statistical method**

“What is the probability of the forecasts being accurate, based on past performance?”

Van Steenbergen, Willems (2012)
### Uncertainty methods for flood forecasting

<table>
<thead>
<tr>
<th></th>
<th>Statistical methods</th>
<th>Ensembles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational</td>
<td>Most methods have low computational requirements and resources, however they will</td>
<td>Dependent on the size of the ensemble, however computational requirement and resources are likely to be higher than the statistical methods.</td>
</tr>
<tr>
<td>requirements,</td>
<td>require maintenance.</td>
<td></td>
</tr>
<tr>
<td>resources</td>
<td></td>
<td></td>
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<tr>
<td>Application to an</td>
<td>Can be added onto an existing flood forecasting chain as a post process.</td>
<td>Forecast system would need to be structured in a way that makes rerunning of models within of the forecasting system possible</td>
</tr>
<tr>
<td>existing system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed location or</td>
<td>Can only be applied to locations with gauged stream flow or level data</td>
<td>Can be generated for the whole model domain</td>
</tr>
<tr>
<td>whole domain</td>
<td></td>
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<tr>
<td>Sources of uncertainty</td>
<td>Captures the ‘total’ uncertainty</td>
<td>The uncertainty can be disaggregated per sources or targeted to a single source</td>
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</tbody>
</table>
“The essential question is not which model (method) is the more suitable for flood forecasting, but rather what type of information a decision maker needs and how they can proficiently use it to produce good and, possibly, more reliable decisions” (Todini, 2017).

System constraints

What are the applications of uncertainty?

Method type

- Ensemble
- Statistical
- Combined

Literature review
Minimise system restructuring

Limited computational power

Uncertainty for ungauged locations

NWP* ensembles required

Splitting up of uncertainty

Combined

Statistical Method

Ensemble Method

* NWP: Numerical Weather Predictions
Minimising uncertainty, what source will you focus on?

Where would you spend your budget?

Van Steenbergen, Willems (2015)
Where are we going with uncertainty?

1. Most systems will move to include some form of uncertainty in their forecast, from large ensembles to pragmatic statistical solutions and combinations of the two.
2. Using statistical methods to validate, adjust and reduce ensemble spread will become more mainstream and will help with the usability of the ensemble.
3. Using uncertainty as an analysis tool so that ensembles can be produced with prior knowledge of the sources of uncertainty in the system.
Communication – UK Flood forecasting centre

![Flood Risk Matrix](image)

- **Likelihood**:
  - High
  - Medium
  - Low
  - Very Low

- **Potential Impacts**:
  - Minimal
  - Minor
  - Significant
  - Severe

- **Overall Flood Risk**:
  - HIGH
  - MEDIUM
  - LOW
  - VERY LOW
Uncertainty information in every day life
1. Uncertainty can improve your forecast!
2. Uncertainty – where are you spending your budget?
3. Stay critical, not all uncertainty methods answer the question that is relevant to your situation.
4. Weather ensembles aren’t the whole picture!
5. More information, but what are we going to do with it?

