The sensitivity of urban surface water flood modelling to the temporal structure of rainfall

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1. Motivation

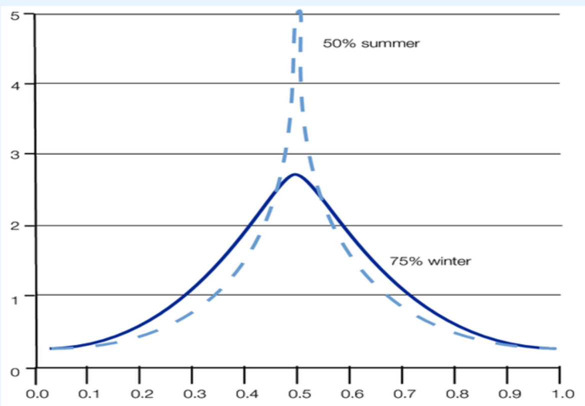
Surface water flooding poses a risk to people and properties. This risk can be evaluated using the design storm procedure in which an event-based flood model is used to simulate catchment response to a storm event with a defined return period. Accurate representation of this design storm is essential for robust flood estimation. There remains a knowledge gap around the sensitivity of models to the temporal structure of rainfall in the design storm.

A. Design storms: the conventional method

Defining a design storm requires:

- A design rainfall depth
- A design storm hyetograph (distributing this rainfall over time)

In the UK, the Flood Estimation Handbook (FEH) provides both (i) a depth-duration-frequency model which estimates the design rainfall depth using historical records for the catchment; and (ii) two design hyetographs, which are symmetrical with a singular peak in intensity.



The profiles were derived from analysis of 80 summer and 32 winter storms of 24 hour duration which occurred between 1961 and 1970.

2. Objectives

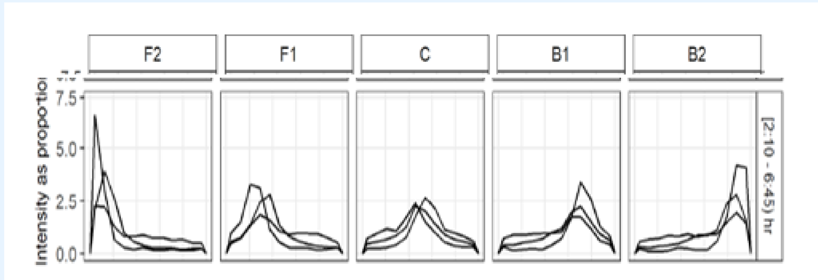
- To test urban hydraulic model sensitivity to the timing of the peak intensity in a single-peaked design storm (based on the FEH profile)
- To analyse the range in flooding outcomes resulting from physically realistic hyetographs, and to quantify how these outcomes differ from using a single-peaked design storm (based on the FEH profile)

3. Methods

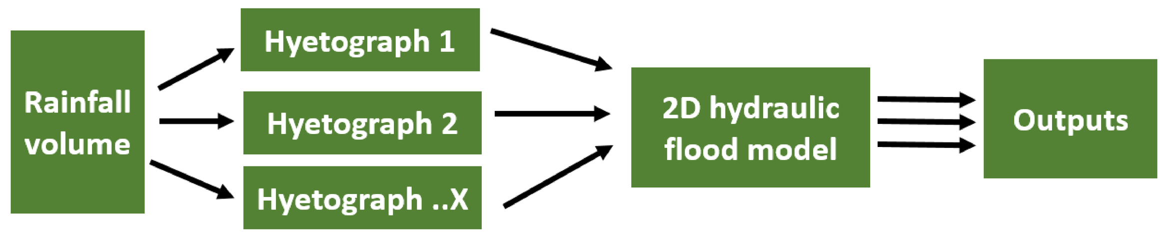
A 2d hydraulic rain-on-grid model is ran in Hec-Ras using the 2D unsteady diffusion wave equation set. The model is ran multiple times using rainfall inputs with a constant rainfall volume, but distributed over time using a variety of different rainfall profiles. All other model parameters are held constant. The total rainfall volume used is associated with a 6 hour, 100 year return period event in the test catchment.

B. Do real storms look like design storms?

A large set of UK extremes from sub-hourly to daily durations have been analysed previously and used to produce hyetographs describing the distribution of rainfall over events in different duration categories (Villalobos-Herrera, 2022). The fifteen hyetographs are split into five categories based on the timing of the peak in rainfall intensity (front loaded (F2 and F1), centred (C) or back loaded (B1 and B2)).



Implication that FEH hyetographs do not well represent real events. Particularly, only 1/4 of all storms are centrally peaked, and front loaded storms are the most common at short durations.

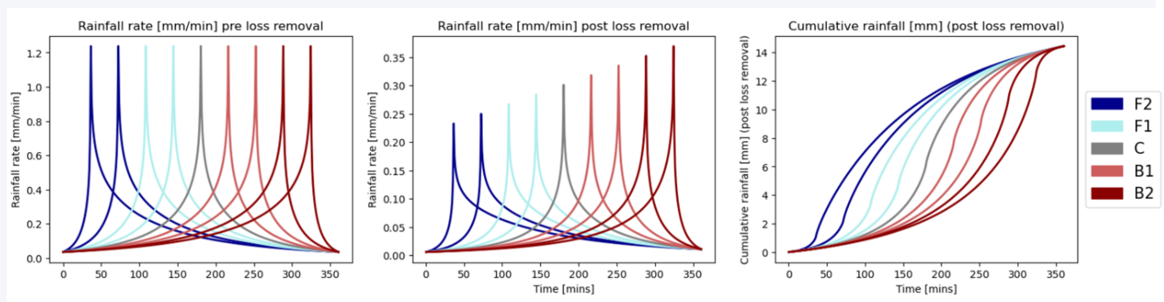


Deriving rainfall profiles

Two approaches are used to define design storms in this research.

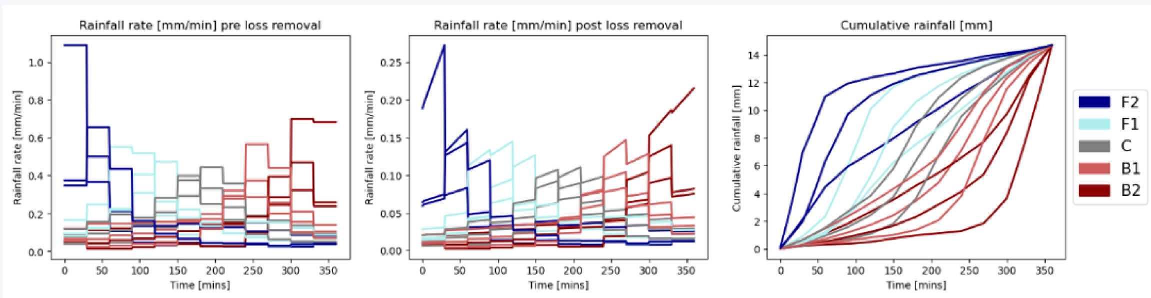
Idealised variations to the FEH design profile

The FEH profile (C), and versions in which the peak if shifted to produce front (F2/F1) or back loaded (B2/B1) profiles.



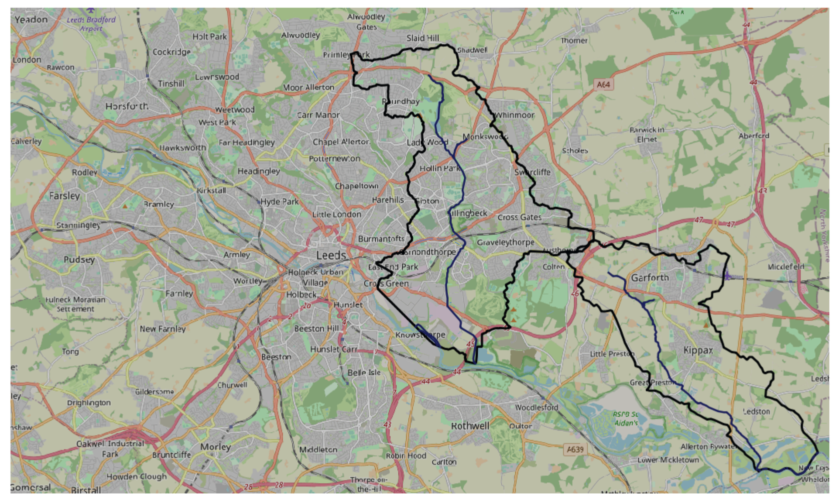
Profiles based on analysis of observed extremes

Fifteen dimensionless profiles from Villalobos-Herrera (2022)



The Hec-Ras model does not account for losses, so these are removed from the rainfall on a lumped basis before model input. Front loaded profiles display a greater reduction in peak intensity.

The test catchments are in the north and east of Leeds in northern England. They are comprised of a mixture of urban and rural land uses.

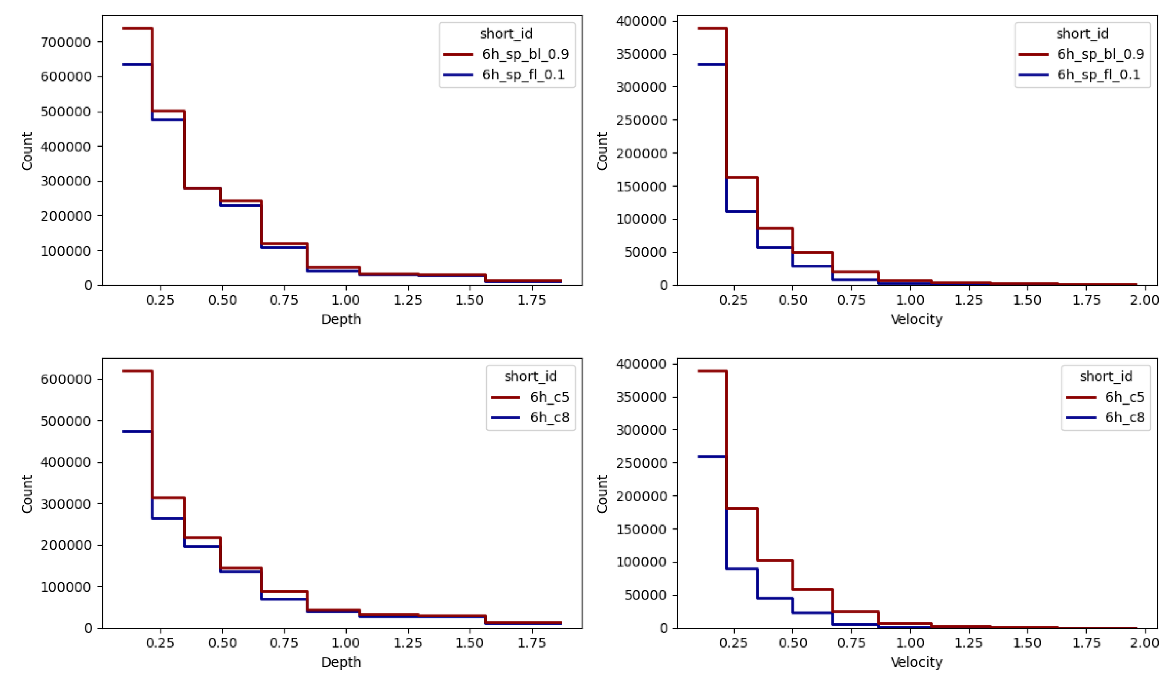


4. Results

Changes to the total flooded extent:

1. Idealised profiles: most **front loaded** profiles have **smallest flooded areas** (with a 9.7% increase from the lowest to highest values)
2. Observed profiles: less clear pattern; however, the most **back loaded** profile has **largest flooded area**. This area is 17.1% larger than **smallest flooded area** which arises with a **front loaded** profile
3. In areas where flooding is **most pertinent (e.g. urban areas)** the difference between the most front and back loaded profiles is **even more pronounced** (a 23.1% increase in area between C8 and C5)

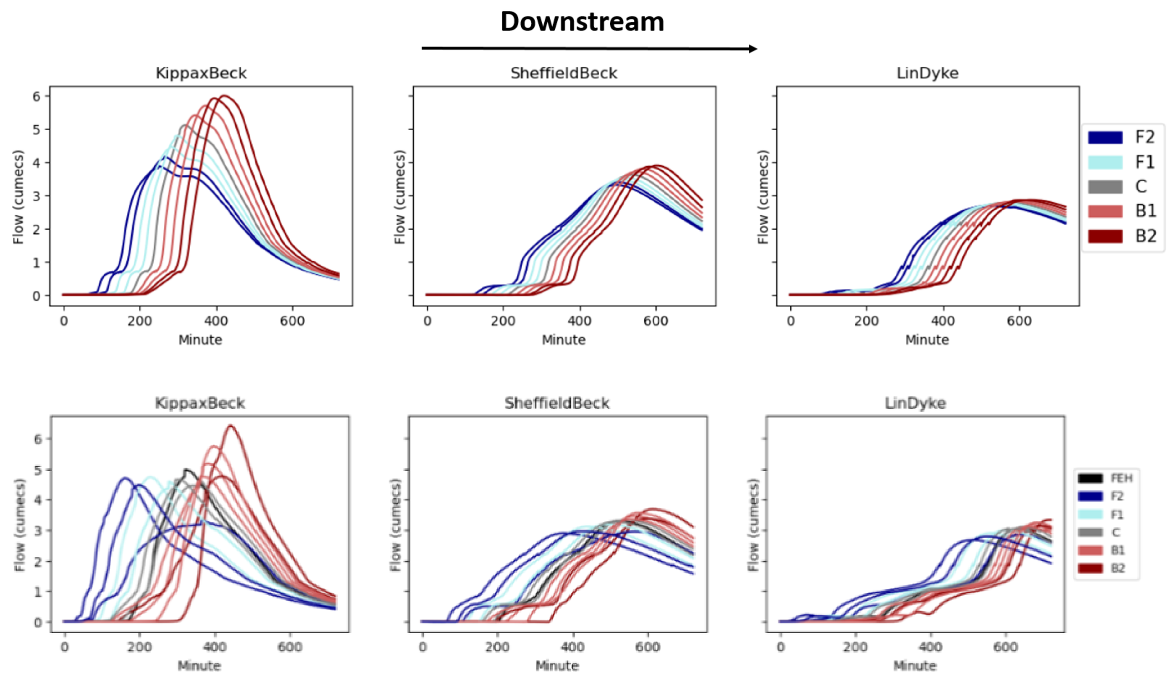
Changes to the severity of flooding:



Idealised and observed profiles: comparing the pair of scenarios with largest difference in flooded extent:

1. The additional flooded area in more back loaded profiles has a range of depths and velocities (e.g. it is *not* solely comprised of very shallow, slow moving water)

Changes to the timing of the flood peak:



1. Idealised profiles: flood peak **arrives later** and **peaks higher** in **back loaded** profiles. In most back loaded profile peak arrives 107 minutes later and peaks 15% higher than most front loaded profile.
2. Observed profiles: similar, but more noisy, trend

Conclusions

We demonstrate that for a **single peaked profile** (in the form of the FEH profile commonly used in the UK), the **positioning of the peak**, as well as its **magnitude**, influences the **extent, severity and timing** of flooding. Our work also considers profiles based on observed extremes. These **physically realistic profiles** generate **even greater differences**, implying that using a single idealised profile - instead of representing the variety of storm profiles found in reality - risks **under or overestimating the flood risk** associated with an event of a certain return period/volume.

Future work

- Explore generalisability of results to other catchments, and whether catchment characteristics influence temporal profile sensitivity
- Investigate the changes to temporal profiles anticipated to occur in future climates using the UKCP18 Local 2.2km projections.
- Consider how the impact of the profiles will change in future climates (e.g. with more intense summer time events, occurring in generally drier conditions)

References

Villalobos Herrera, R., Blenkinsop, S., Guerreiro, S.B., Fowler, H.J., 2022. The creation and climatology of a large independent rainfall event database for GB (in press)

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