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CIVIL INFRASTRUCTURE

# Simulating Flood Hazard in Wye Valley during Storm Dennis using Hec-Ras

A 2D Hec-Ras flood model is established at the middle reach of the River Wye, from Ross-on-Wye to Monmouth, along the English-Wales border. The flow conditions during Strom Dennis, which occurred on 15-16 Feb 2020 are used to simulate the flood extents in the study area. The flood hazard rate, suggested by EA, is analysed to assess the risk level of flooding in the area. The results show the extensive flood extents at the study site. The flood hazard rate map shows that large part of Wye Valley is at high risk of flooding.

*Keywords:*
*River Wye, flooding dynamics, hazard rate, Hec-Ras, Wye Valley, Ross-on-Wye.*

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## INTRODUCTION

In recent years, the UK has been met with some of the most severe flooding since records began. For example, February 2020 was recorded as the highest peak flow[1], exceeding the previous record by a significant margin, with 3.5-4 times the average long-term flow. The recent records in 2021 and 2022 also suggested that the events previously considered as extreme, are now the new normal. Over the past decades, the River Wye catchment, particularly in the middle reach (from Hereford to Monmouth), has been subjected to frequent and severe flooding. The flood extents in Ross-on-Wye during Storm Dennis in Feb 2020 were devastating to the local community. This study is to use an advanced 2D flood model – Hec-Ras to simulate that flood event in the area between Ross-on-Wye and Monmouth, as shown in Fig. 1 under the storm conditions.

## MATERIALS AND METHODS

The River Wye (Welsh: Afon Gwy) is one of Britain's most scenic and un-spoilt rivers, flowing 157 miles (251 km) through Hay-on-Wye, Hereford and Ross-on-Wye and continues on through Symonds Yat, Monmouth and Tintern, and reaches Chepstow where it joins the Severn Estuary. It is the fifth longest river in the UK. The river changes from a spring at its source on Mount Plynlimon to a fast flowing upland stream to a wide meandering river towards the mouth of the river at Beachley, on the edge of the Forest of Dean.

In this study, the middle reach of the River Wye between Ross-on-Wye and Monmouth as shown in Fig.1 is selected as the study site.

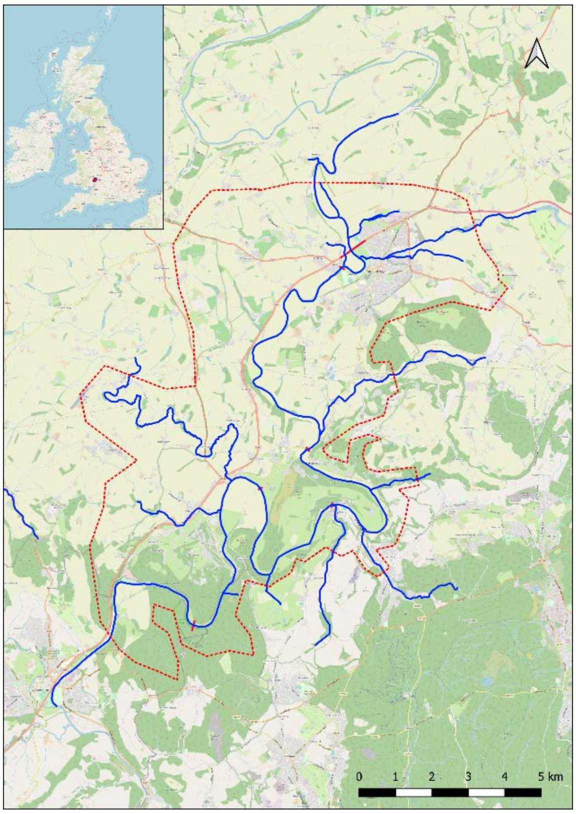


Fig. 1. Study site: Middle reach of River Wye (blue lines, including connecting waterways) and the 2D computational domain (dotted line).

To simulate the flood events, a 2D model based on the Hec-Ras software is created in the study area.

Hec-Ras is an open source software, primarily designed to aid channel flow analysis with an emphasis on floodplain determination, initially developed by the United States Army Corps of Engineers for use within the public sector, following its release to the public in 1995. It has the capability of modelling both one- and two-dimensional unsteady open channel flows, containing many continents particularly to understand and alleviate flooding[2]. It has been continually developed and updated, to include features such as dam break analysis[3] and flood analysis[4], and widely used in industry and for research. In this study, the version (6.3.1) of the software released in 2022, is used.

To set up the computer model for the study site, lidar data with resolution of 2 m by 2 m, obtained from EA, are used as the bathymetry, as shown in Fig. 2.

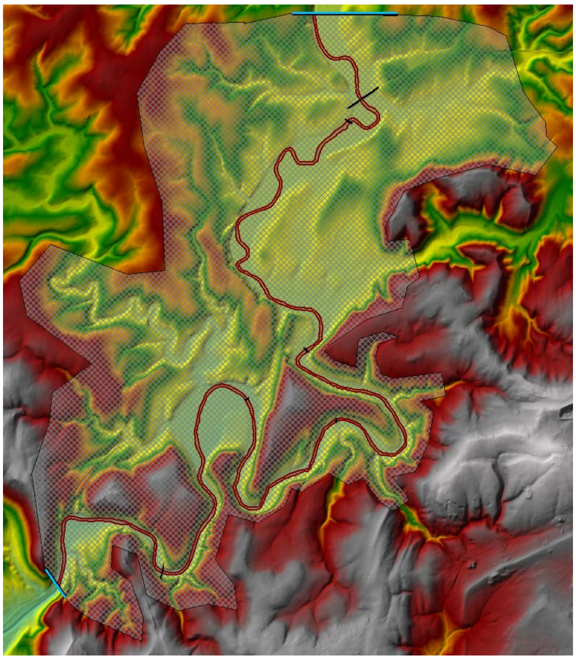

Fig. 2. Terrain of the study site derived from 2m Lidar data (EA) with computational mesh, bridges and upstream and downstream boundaries.

Within the study site, there are 6 bridges across the River Wye, including 2 foot bridges (Fig. 2), which are fully implemented in the model. Fig. 3 shows the implementation of the longest, Bristow Bridge, along the A40 and Huntsham Bridge off B4229 in the model. A number of break lines are defined in the domain, such as that for A40, to achieve a better quality of the computational mesh. The mesh contains in total 35,193 cells, with the largest cell being 5,560 $m^2$ and smallest cell being 306 $m^2$.

The flow boundary condition is set at the upstream boundary, using the daily measurements from the National River Flow Archive (nrfa.ceh.ac.uk). Since there is no measuring station at the upstream boundary (near Bristow Bridge), a combination of the daily flows at Belmont (NRFA Station ID: 55002), Lugwardine (55003), Yarkhill (55018) and Three-Elms (55032) is assumed to contribute to the total flow discharge in River Wye into the study site. Fig. 4 shows the hydrograph used at the upstream boundary for the period of Storm Dennis (20220212 00:00 UTC-20220220 00:00UTC). Normal water depth is adopted for the downstream boundary.

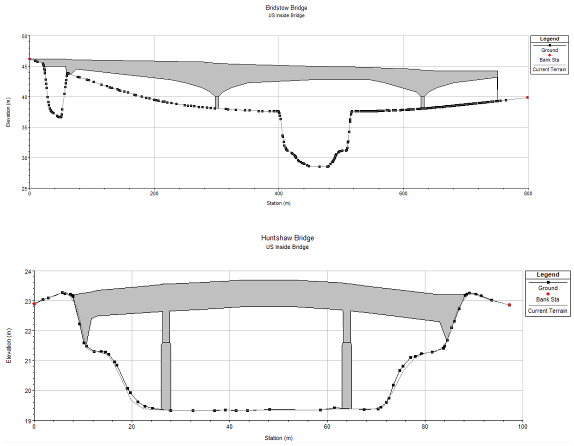


Fig. 3. 2D and Storage Area (SA) connections for bridges: (a) Bristow Bridge (top) and (b) Huntsham Bridge (bottom).

Uniform Manning's coefficient (n) of 0.035 is used in the model simulations. The time step is set to 5 mins and output interval is set 15 mins.

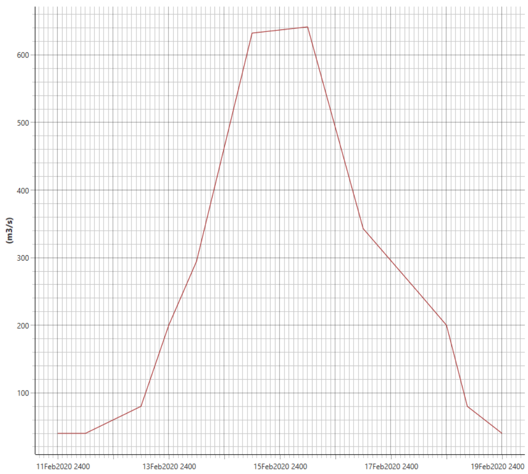


Fig. 4. Hydrograph for the upstream boundary for Storm Dennis (8 days from 20220212 00:00UTC).

## RESULTS

The duration of the computation is set to 192 hrs (8 days), with a leading period of 36 hrs at the averaged discharge to establish initial flow conditions in the domain. Fig. 5(a) shows the maximum water depth at the study site. During Storm Dennis, the water depth in the upstream section (near Ross-on-Wye) is found to be around 5 m in the river, and 3 m in the flood plain. Almost all flood plain is flooded during the storm. In the downstream end of the domain, the water depth is found to be deeper, in a range of 8-10 m. The areas around Huntsham Farm and Saint Dubricius Church are severely flooded. The highest water level at Huntsham Bridge from the model is 23.09 mAOD, which exceeds the low dock level and overtops part of the bridge, as shown in Fig. 6.

The maximum flow velocity, as shown in Fig 5(b), is generally lower than 1 m/s, due to the river over flowing. However, the velocity in the downstream channel can exceed 3.0 m/s.

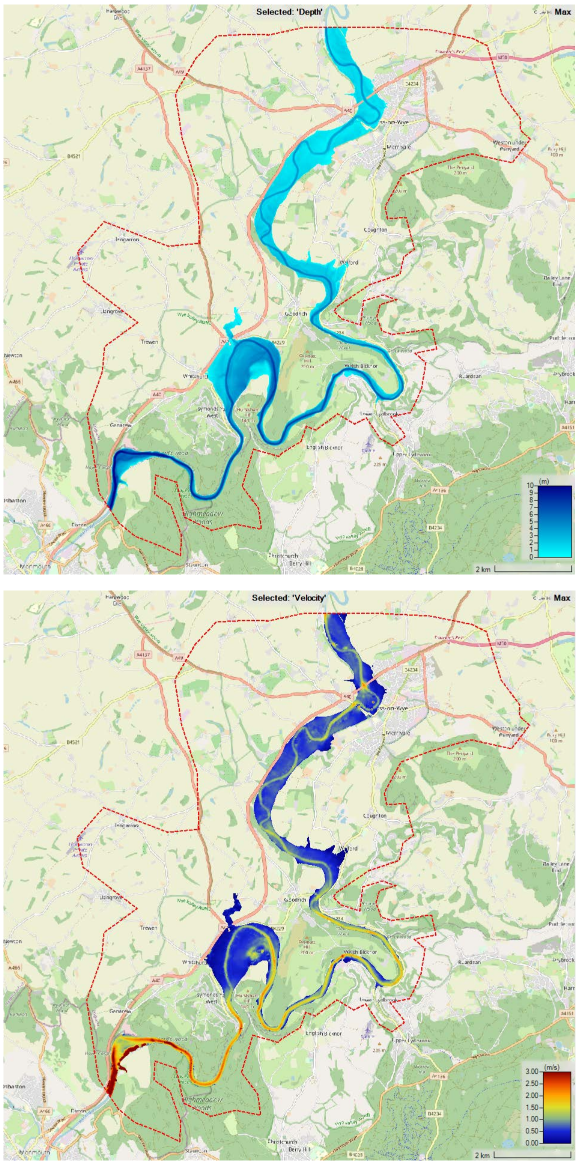


Fig. 5. (Top) max water depth (m) and (bottom) max velocity (m/s) during Storm Dennis

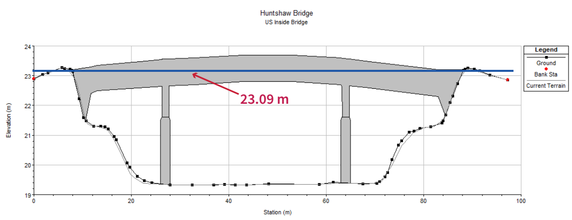


Fig. 6. The highest water level at Huntshaw Bridge from the model (23.09 mAOD).

In order to study the flood dynamics[5], the Flood Hazard Rate (FHR) suggested by the EA is used in this study as:

$$FHR = d(v + 0.5) + F_{Deb} \quad (1)$$

where, $d$ is water depth (m); $v$ is velocity (m/s); and $F_{Deb}$ is a debris coefficient varying from 0~1 depending on local conditions. The flood hazard can be generally categorised into 4 groups, based on the FHR values as listed in Table 1.

| FHR | Level | Description |
|---|---|---|
| <0.75 | L | Flood zone with shallow flowing water or deep standing water |
| 0.75 – 1.25 | M | Moderate Danger for some (i.e. children). *Danger: Flood zone with deep or fast flowing water.* |
| 1.25 - 2.50 | H | Significant Danger for most people. D*anger: flood zone with deep fast flowing water.* |
| >2.50 | E | Extreme Danger for everyone. *Extreme danger: flood zone with deep fast flowing water.* |

Table 1. Classifications of Flood Hazard Risk

A FHR layer is created within HEC-RAS taking the time series of water depth and velocity from the model with a user script based on Eq. 1 during the event. The effect of the debris coefficient has been discounted ie. $F_{deb} = 0.0$ across the area as the required details, (e.g. soil structure, flora density and presence of paving/ subsurface drainage) are unknown. As a result of this, the inclusion of an $F_{deb}$ coefficient would likely be fictitious thereby reduce the accuracy of results.

## DISCUSSION

Fig. 7(a) shows the FHR before the peak river discharge (20200215 00:00) and Fig. 7(b) shows the FHR at the maximum river discharge (20200216 00:00). The results indicate that before the peak flow discharge, where the inflow is at ~500 $m^3/s$, representing a typical flood event, the FHR ranges predominately from low to moderate, with a small area being high as shown in Fig. 7(a). However, as shown Fig. 7(b), it is clear that the FHR increases considerably at the peak river discharge (~640 $m^3/s$), which represents a severe flood event in the area. The FHR in the majority of the study site is at high risk level, whilst the area of moderate risk is noticeably reduced.

To further examine the details of the flood risk level locally, two areas, as indicated in Fig, 7(b) as "A" and "B", are selected. Area A is centred in the surrounding area of Ross-on-Wye, a historically flood prone area, while Area B is centred in Wye valley.

For Area A, as shown in Fig. 8(a), it is clear that most of the area is at high risk of flooding, but most residential areas are at low risk or safe due to the relative high ground, but access to these areas is restricted, as Wilton Bridge is likely to be flooded. In Area B, Fig. 8(b) shows a high risk level of flooding in most of the area. The Huntsham farm land near St Dubricius Church is inundated, but the residential area along the west bank near the church is at low risk.

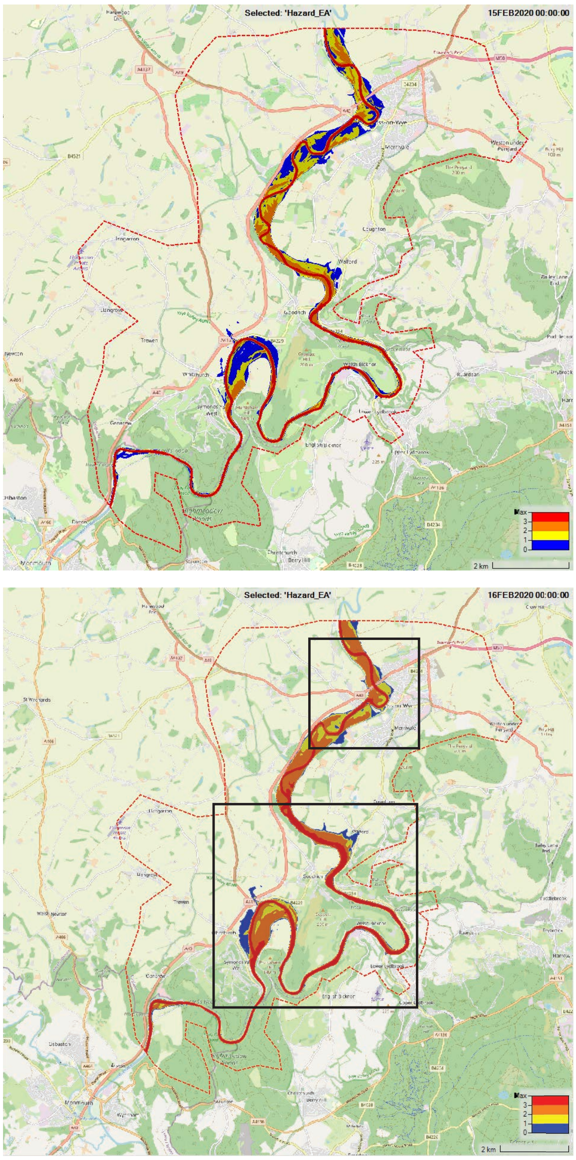


Fig. 7. FHR during Storm Dennis: (a) before peak discharge (top); (b) at the peak discharge (bottom).

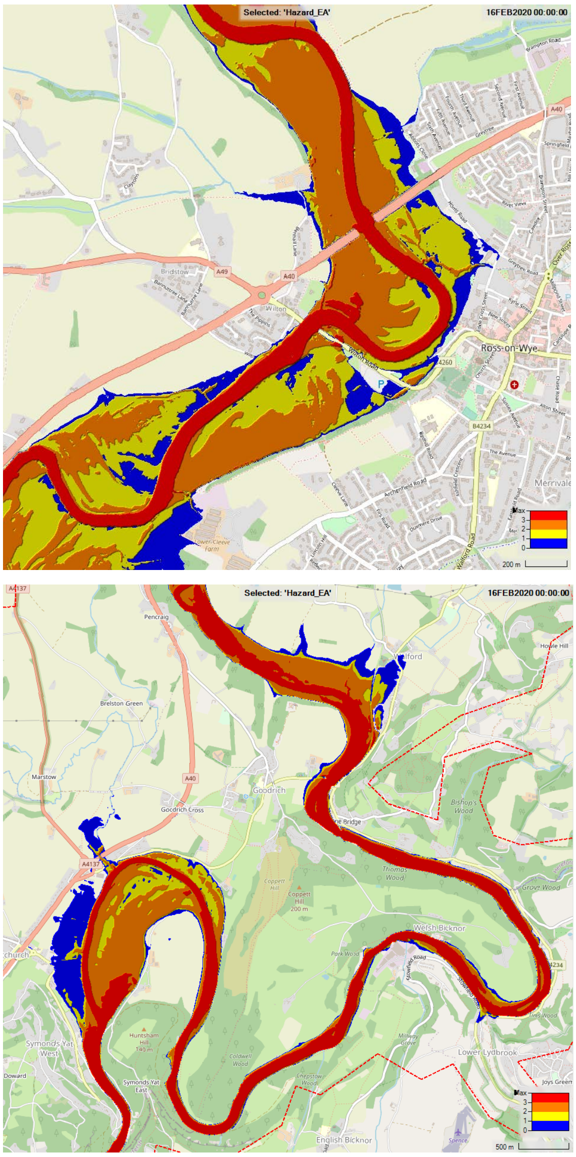


Fig. 8. FHR during Storm Dennis at the peak discharge in: (a) Area A; (b) Area B (see Fig. 7(b)).

## CONCLUSIONS

A 2D Hec-Ras flood model is established at the middle reach of River Wye from Ross-on-Wye to Monmouth along the English-Wales border. The flow conditions during Strom Dennis occurred on 15-16 Feb 2020 are used to simulate the flood extents at the study site. The FHR as suggested by EA is analysed to assess the risk level of flooding in the study site.

The results indicate that under the severe flow conditions such as those during Storm Dennis, a large area close to the river course and flood plain at the study site is inundated. Bridges and highways are likely to be flooded. The FHR which combines the water depth and flow velocity indicates that the most area at the study site is at high risk from flooding. This is particularly severe in the Wye Valley, where the vast agricultural lands could be affected.

***Conflicts of interest***
*The authors declare no conflict of interest.*

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