HEREFORDSHIRE EVENT MAGNITUDE ANALYSIS TECHNICAL NOTE

DATE:	18 December 2020	**CONFIDENTIALITY:**	Restricted
SUBJECT:	Herefordshire Event Magnitude Analysis for October 2019 and February 2020		
PROJECT:	Herefordshire Section 19 Investigations	**AUTHOR:**	Isabelle Farley
CHECKED:	Claire Storer	**APPROVED:**	Joanna Goodwin

BACKGROUND

Herefordshire suffered severe flooding events in October 2019 and February 2020, with several flooding incidents passing the 'significant event' threshold as set out within the Herefordshire Local Flood Risk Management Strategy. As such and in accordance with the Flood and Water Management Act 2010, these events require investigation under Section 19 of the Act. The purpose of this technical note is to determine the approximate event magnitude of these two events and inform the Section 19 investigations.

The October 2019 event comprised a succession of heavy rainfall events that fell across England and Wales, and towards the end of the month led to flooding across Herefordshire. This was followed by a series of heavy successive rainfall events in February 2020 that led to record breaking flows and significant flooding across Herefordshire. The three named storms, Ciara, Dennis and Jorge, along with other rainfall in the month resulted in the new UK maximum for February monthly rainfall total since records started in 1862[1].

The rainfall for the nine months leading up to the end of February 2020 resulted in saturated catchments and enhanced flood risk. The Soil Moisture Deficits for the UK were near-zero for five consecutive months from October 2019 to February 2020[2]. The consequence of the Soil Moisture Deficits being near zero is that river flows were very responsive to the rainfall, resulting in some peak flow records being established across the UK.

Approach

Two approaches have been used: assessment of rarity of the event rainfall and frequency assessment of recorded river flows.

In order to assess the equivalent 'event magnitude' of the rainfall which resulted in property flooding across Herefordshire, the Flood Estimation Handbook (FEH) webservice Event Rarity calculator was used. This compares recorded rainfall with design rainfall estimates obtained from the FEH13 depth duration frequency (DDF) model. With an input of duration of rainfall and depth recorded, the Event Rarity Calculator can assess the Annual Exceedance Probability (AEP) of the rainfall, which is the likelihood of the rainfall of this depth falling in that timeframe within the year. For example, a rainfall event with an AEP of 1% means

[1] MetOffice, 2020, February 2020 Climate Summary, https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/summaries/uk_monthly_climate_summary_202002.pdf

[2] Sefton et al., 2020, NERC (CEH) 2019, 2020, Hydrological Summary for the United Kingdom: February 2020, http://nora.nerc.ac.uk/id/eprint/527499

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that the rainfall of this depth or greater would have a 1% chance of occurring in any given year, and is also known as the '1 in 100' year event.

Rainfall across England is recorded in a series of rain gauges, operated by the Environment Agency (EA). Rainfall depths are measured and recorded in 15 minute or hourly intervals. Rainfall measurements were obtained at 4 locations in Herefordshire: Yarkill to the east of Hereford, Vowchurch to the west of Hereford, Titley Mill by Kington and Broomy Hill in Hereford itself. The rain gauges were selected as they cover the county of Herefordshire and were provided by the EA[3].

The limitations of this approach for assessing the event rainfall rarity when looking at fluvial flooding is that the rain gauges record the rainfall in one given location which may not be where the highest rainfall totals fell, nor do they measure rainfall across the whole catchment. The flooding that occurred in Herefordshire in 2019 and 2020 was predominantly fluvial flooding from watercourses of varying catchment areas. The catchment of the Wye by Hereford is over 1900km^2, with the headwaters of the catchment in the Cambrian Mountains, whereas the rain gauges assessed are located only within Herefordshire.

River flows around the country are recorded by a series of level and flow gauges operated by the EA. These report the peak flows recorded over a 15-minute or 1 hour interval. To assess the equivalent event magnitude of the flows that were recorded at 5 flow gauges in Herefordshire, the gauged sites were used for a range of analyses. The rarity of the recorded peak flows at river gauges was assessed using flood frequency analysis for the five sites in accordance with the FEH statistical methodology using the latest NRFA Hiflows dataset. Enhanced single site (where a greater weight is placed on the site record) and pooled estimates were obtained. The inclusion of the latest flood events can also introduce bias to the assessment, so a check was completed excluding the 2020 peak flows from the sites.

The five gauges across Herefordshire obtained for this study from the EA are the following: River Wye at Belmont, River Teme at Tenbury, River Arrow at Titley Mill, River Lugg at Byton and River Lugg at Butts Bridge[4]. These gauges are located across Herefordshire and measure catchments of varying sizes.

October 2019 Event Analysis

The month of October 2019 was a very wet and cool month across the UK with a succession of frontal systems pushed by an anomalously southern jet stream[5]. The 25th and 26th of October saw flooding events to numerous properties across Herefordshire.

[3] Environment Agency Hydrometry Data, 11/11/2020, enquiries_westmids@environment-agency.gov.uk
[4] Environment Agency Hydrometry Data, 11/11/2020, enquiries_westmids@environment-agency.gov.uk
[5] Parry et al., 2020, NERC (CEH) 2020, Briefing note: Severity of the February 2020 floods –preliminary analysis, https://nrfa.ceh.ac.uk/sites/default/files/Briefing_Note_V6.pdf

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Data from four rain gauges across Herefordshire were recorded and analysed for the October 2019 flood event. The data for four rain gauges were compared to design estimates for a kilometre grid square in Central Hereford at 350000, 240000. Some variation in design rainfall across the county is expected due to differences in topography etc, however at this scale this is unlikely to significantly impact on the findings.

Figure 1 shows the location of the rain gauge and flow gauge locations across Herefordshire used in the October 2019 event analysis. These are largely across the central area of Herefordshire.

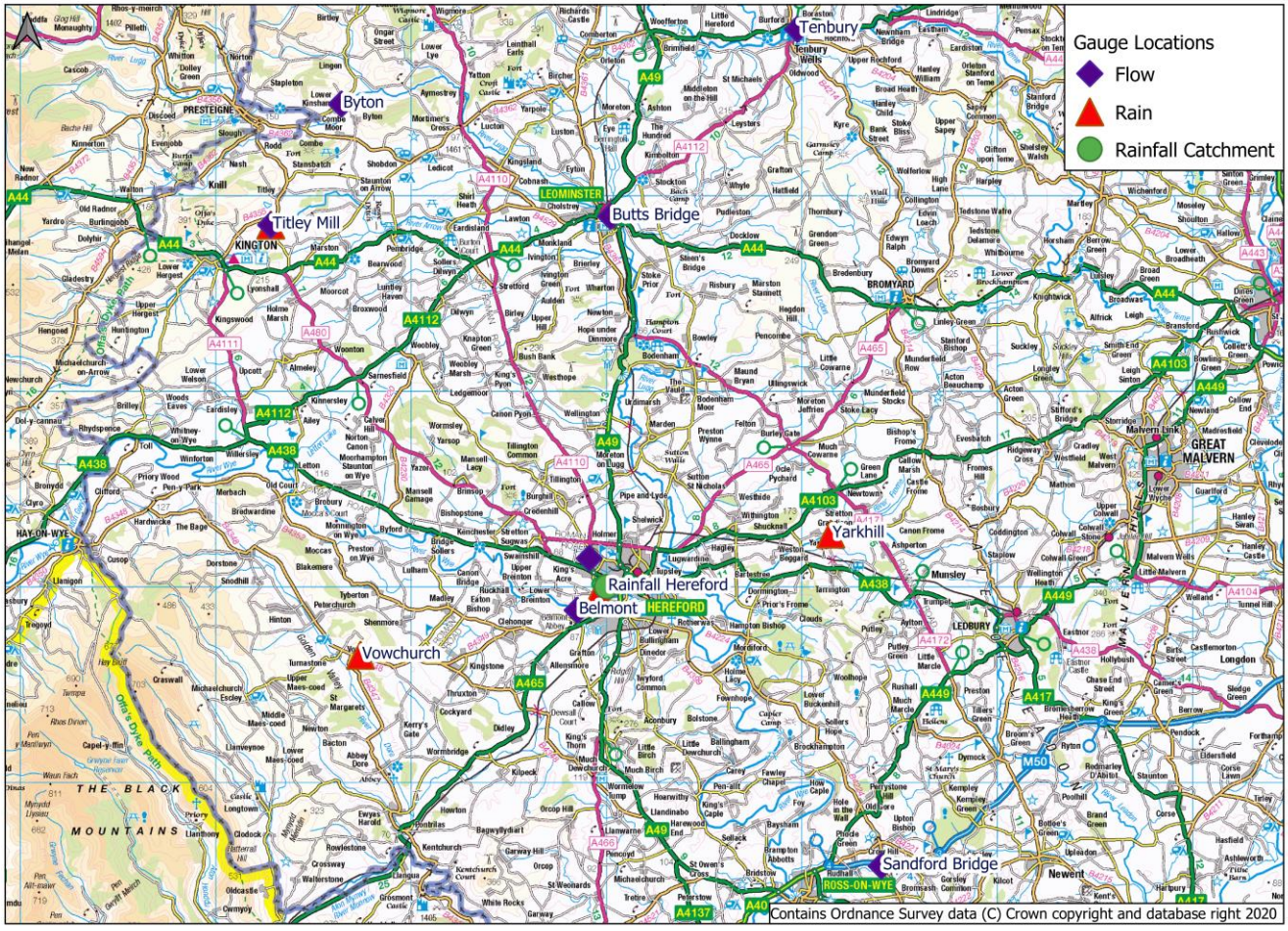

Figure 1: Rain and flow gauge map for the October 2019 analysis

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OCTOBER 2019 RAINFALL ANALYSIS

In the figure below, the flows have been plotted for the Wye gauge in Belmont and the Teme gauge at Tenbury, with rainfalls from the Vowchurch and the Yarkhill rain gauges to illustrate the rainfall and flows over the month of October 2019.

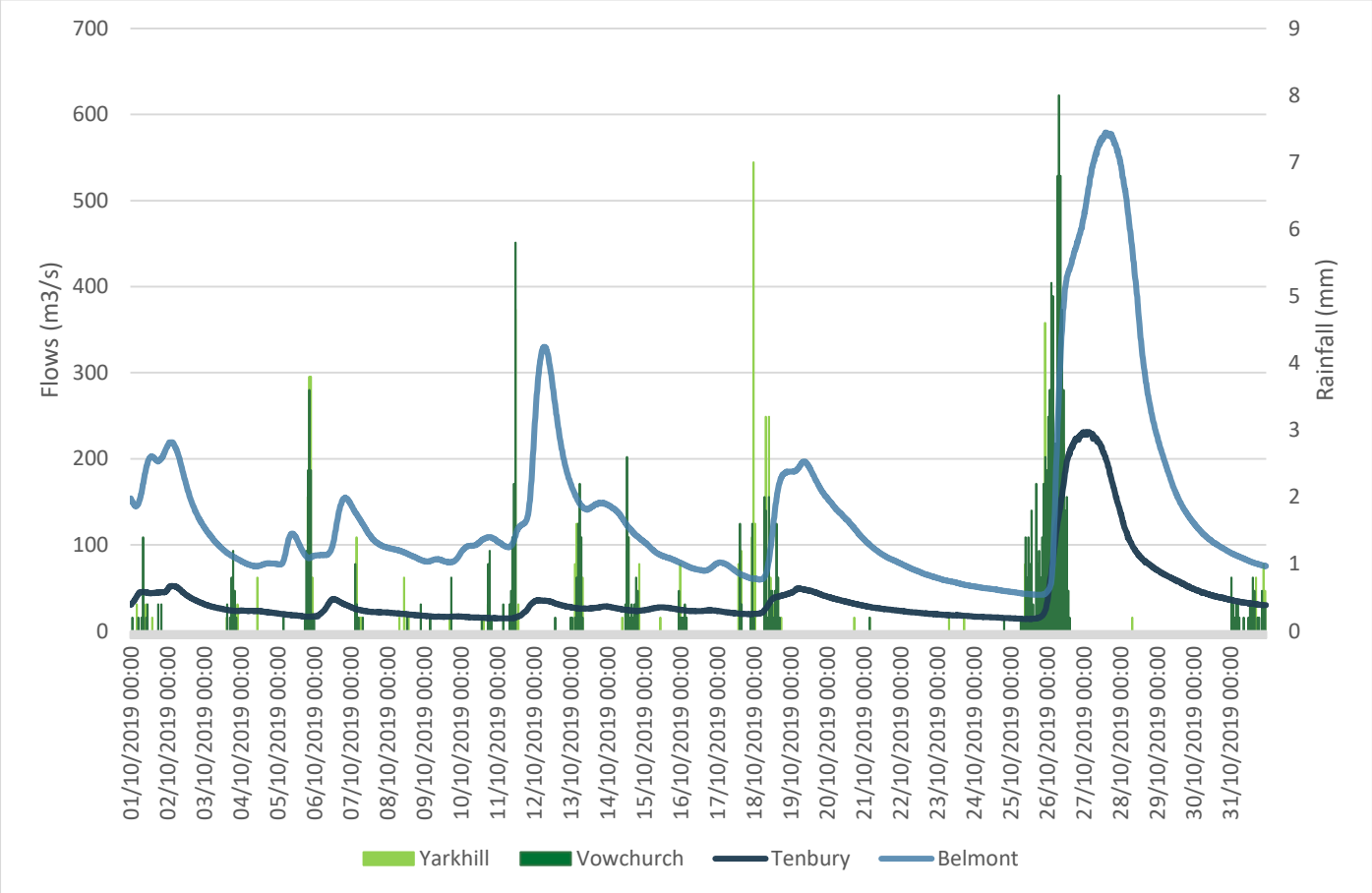

Figure 2: Flows and hourly rainfall totals for October 2019

The plot shows frequent rainfall events keeping flows high across the first half of October before an intensive rainfall event starting on the 25th October which resulted in the peak flows for both the Teme at Tenbury and the Wye at Belmont. Table 1 summarises the total depth of rainfall measured at each assessed rain gauge.

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Table 1: October 2019 event rainfall analysis[6]

Rain gauge name	Easting	Northing	Start time	End time	Total depth (mm)	Duration (hours)	Event magnitude (1 in x years)
Yarkhill	361475	242699	25/10/2019 21:30	26/10/2019 14:15	52.2	16.75	16
			25/10/2019 22:45	26/10/2019 11:45	49.4	13	15
Titley Mill	332820	258506	25/10/2019 09:00	26/10/2019 14:00	56.4	29	13
			26/10/2019 01:00	26/10/2019 12:00	33.0	11	3
Vowchurch	337408	236501	25/10/2019 09:00	26/10/2019 14:00	77.6	29.0	87
			25/10/2019 18:45	26/10/2019 14:30	68.0	20.25	55
Broomy Hill	349596	239665	25/10/2019 09:00	26/10/2019 14:00	67.4	29.0	37
			25/10/2019 22:45	26/10/2019 11:45	55.0	13.0	26

The rainfall analysis shows a range of possible return periods for the individual gauges. The Titley Mill rain gauge shows the lowest return period of an equivalent 1 in 13 year event from the rainfall depth and duration recorded, and the Vowchurch rain gauge shows the highest return period of an equivalent 1 in 90 year event from the rainfall depth and duration recorded. The event rainfall may not reflect the flood rainfall due to prior rainfall events resulting in saturated catchments.

The Met Office climate summary for October 2019 noted that the 25th and 26th October were both very wet days with a gauge in the Brecon Beacons in Powys recording 101mm on the 25th October[7]. In England the highest gauge total for the day of 25th October was in Derbyshire with 67.2mm of rain.

[6] Environment Agency Hydrometry Data, 11/11/2020, enquiries_westmids@environment-agency.gov.uk
[7] Source: Met Office Climate Summary October 2019 https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/summaries/uk_monthly_climate_summary_201910.pdf

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OCTOBER 2019 RIVER FLOWS ANALYSIS

Flows around the country are recorded by a series of level and flow gauges operated by the EA. These report the peak flows recorded over a 15-minute or 1 hour interval. The rarity of the recorded peak flows at river gauges was assessed using flood frequency analysis the five flow gauges across Herefordshire. To assess the equivalent event magnitude of the flows that were recorded at the 5 flow gauges in Herefordshire, the gauged sites were used for an enhanced single site, pooled analysis and pooled analysis excluding the 2020 event in WINFAP using the latest NRFA Hiflows dataset.

Table 2 below shows the flow gauges and recorded flows measured in October 2019 associated with the flooding across Herefordshire.

Table 2: October 2019 river flow gauge analysis[8]

River gauge name	River	Catchment area (km2)	Date and time of peak	Recorded peak flow (m^3/s)	Event magnitude (1 in x years)	Best estimate event magnitude range
Tenbury	Teme	1134.4	26/10/2019 23:45	231	10-20	10-20
Belmont	Wye	1895.9	27/10/2019 14:30	579	20-30	25-30
Titley Mill	Arrow	126.4	26/10/2019 16:00	47.7	10-20	10-20
Byton	Lugg	203.3	27/10/2019 03:30	65.1	30-75	30-50
Butts Bridge	Lugg	371.0	27/10/2019 11:30	67	5-10	5-10

The flows recorded for the October 2019 event show that the equivalent event magnitude varies a lot per watercourse, but on average the analysis indicates the event to have been equivalent to a 1 in 20-30 year event across Herefordshire.

The Enhanced Single Site analysis places a higher importance on the gauge itself therefore has been used for the best estimate range where this differs from the pooled range. The Lugg gauge at Byton shows a wide range in the event magnitude and a lower range in the best estimate and this is because the rating curve for the Byton slightly overestimates the flows based on the measured stage, which pushes the estimated return period up. For the Byton, the best estimate is therefore based on a combination of the pooled and single site analysis. The peak flow estimates are fairly consistent across the county along with the rainfall. This suggests the high intensity rainfall of approximate return period estimate of 1 in 20 year

[8] Environment Agency Hydrometry Data, 11/11/2020, enquiries_westmids@environment-agency.gov.uk

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following a wet month in the autumn could result in events like that seen in October 2019, which have an approximate flow return period frequency of 1 in 20 year across the assessed gauges.

February 2020 Event Analysis

In February 2020, a succession of rainfall events swept across the west and south-west of the UK resulting in high rainfall totals. Three of these rainfall events which affected the UK were Storm Ciara on the 9th February, Storm Dennis on the 15th February and Storm Jorge on the 28th February. A red warning for rain was issued in South Wales by the Met Office. Across the Brecon Beacons, rainfall totals were of 100 to 150mm of rain in two days from Storm Dennis. In some localised areas of Gloucestershire and Herefordshire over 200% of the average February whole-month rainfall fell from the 8th to the 16th February as a result of Storms Ciara and Dennis[9] shown in the figure below. The multiple storm events in February lead to numerous properties affected by flooding in Herefordshire.

[9] Source: Met Office Climate Summary February 2020, https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/summaries/uk_monthly_climate_summary_202002.pdf

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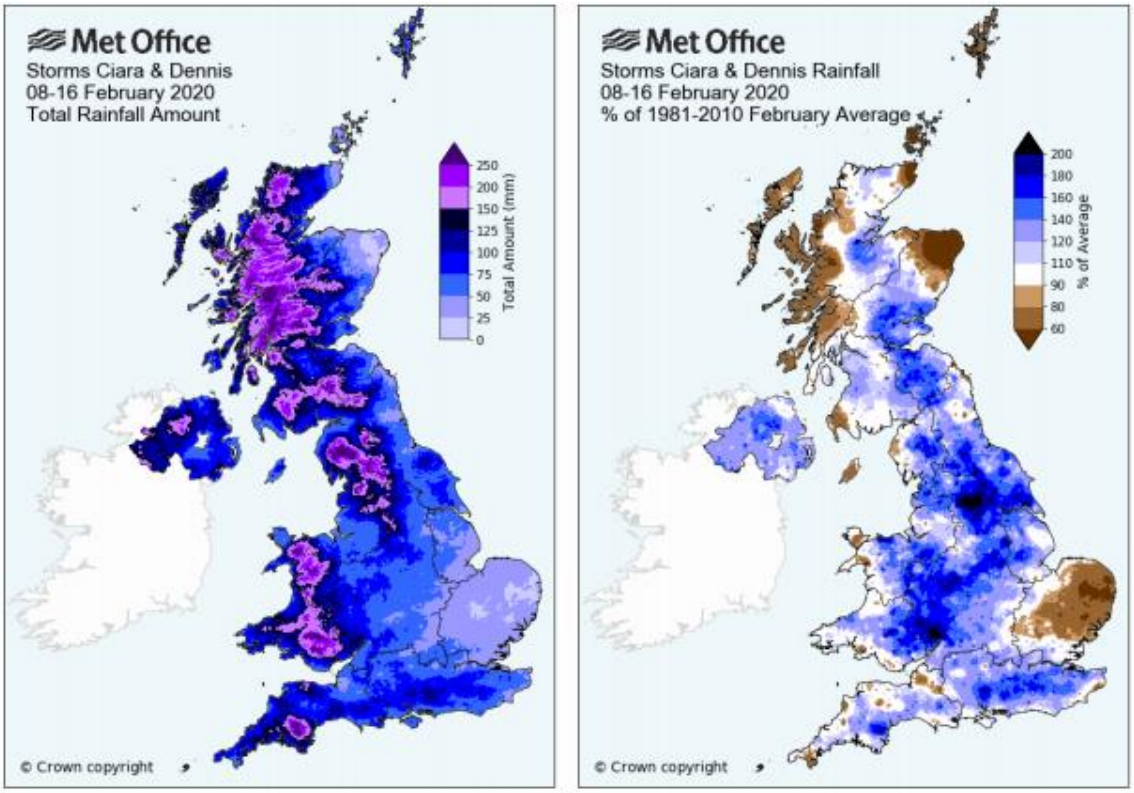

Figure 3: Rainfall total from 8th to 16th February which includes Storms Ciara and Storm Dennis[10]

Figure 4 shows the location of the rain gauges and flow gauges across Herefordshire used in the February 2020 event analysis.

Some of the rivers in Herefordshire rise in the west along the Welsh mountains, including the Wye, the Arrow and the Lugg. In addition to the gauges assessed for October 2019, three rain gauges in Wales closest to Herefordshire were also assessed for Storm Ciara and Storm Dennis which led to the February 2020 floods. These three rain gauges[11] were assessed for a different rainfall catchment which is located along the A465 close to the border at grid reference 333000, 222000.

[10] Source: Met Office Storm Dennis, 2020, https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/interesting/2020/2020_03_storm_dennis.pdf

[11] NRW, Rivers levels, rainfall and sea data, https://rivers-and-seas.naturalresources.wales/Station/1073?parameterType=2 accessed on 02/12/2020 for Stations 1073, 1076, 1066

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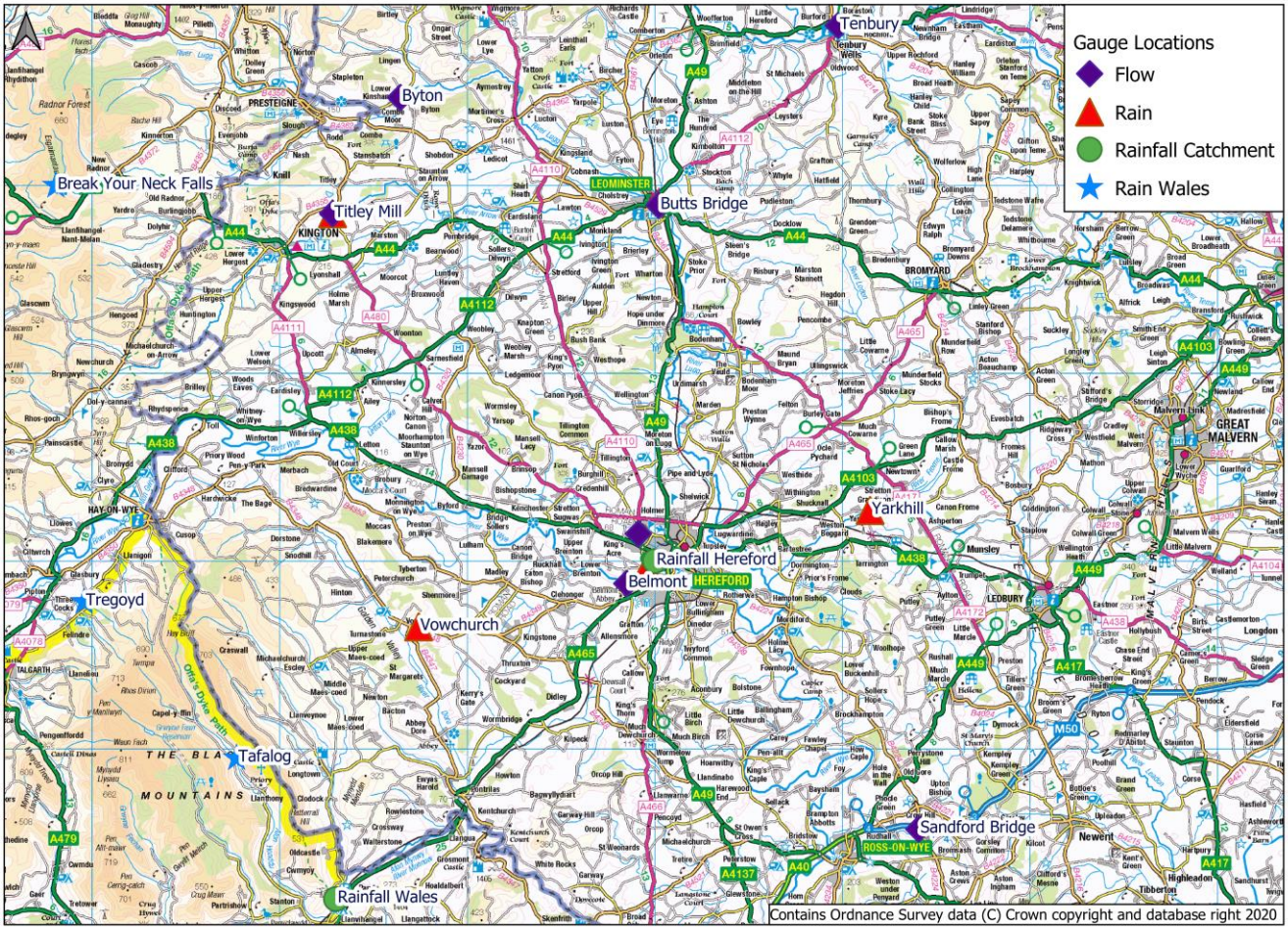

Figure 4: Rain and flow gauge map for the February 2020 analysis

FEBRUARY 2020 RAINFALL ANALYSIS

In the figure below, the flows have been plotted for the Wye gauge in Belmont and the Teme gauge at Tenbury, with rainfalls from the Vowchurch and the Yarkhill rain gauges to illustrate the rainfall and flows over the month of February 2020.

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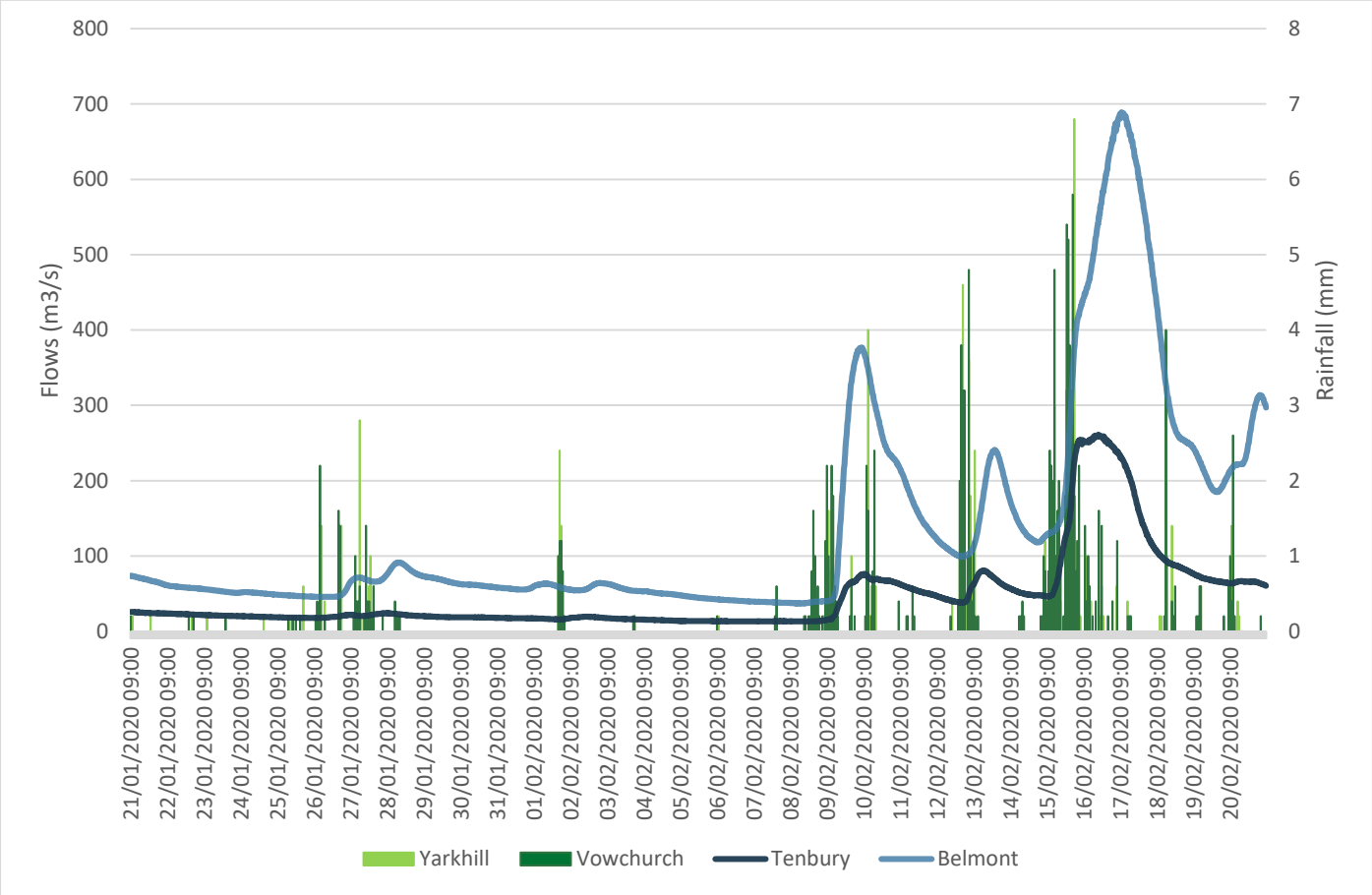

Figure 5: Flows and hourly rainfall totals from 21 January to 20 February 2020

The plot shows rainfall events starting on the 8th February (Storm Ciara) and the 12th February which cause a peak in flows at the two gauges. The largest rainfall totals are shown on the 15th and 16th which result in a spike in the peak flows at both gauges on the 16th and 17th.

The rainfall totals shown in the table below for the events in February 2020 include the durations for each rain gauge during Storm Dennis. The rainfall totals from Storm Ciara were not high enough to be classified using this methodology as it was continuous steady rainfall rather than heavy rainfall.

Table 3: February 2020 event rainfall analysis – Herefordshire rain gauges

Rain gauge name	Easting	Northing	Start time	End time	Total depth (mm)	Duration (hours)	Event magnitude (1 in x years)
Yarkhill	361475	242699	15/02/2020 07:00	16/02/2020 07:15	37.0	24.25	2
Titley Mill	332820	258506	15/02/2020 07:00	16/02/2020 14:00	51.6	31.0	7
Vowchurch	337408	236501	15/02/2020 07:00	16/02/2020 06:30	51.2	23.5	10
Broomy Hill	349596	239665	15/02/2020 07:15	16/02/2020 06:45	38.6	23.5	3

The three rain gauges in Table 4 were compared to the Rainfall Wales rainfall catchment shown in Figure 4.

Table 4: February 2020 rainfall analysis – Wales rain gauges

Rain Gauge Name	Easting	Northing	Start Time	End Time	Total depth (mm)	Duration (hours)	Event magnitude (1 in x years)
Tafalog	327703	229502	15/02/2020 04:30	16/02/2020 06:30	67.8	26	8
Tregoyd	319570	237830	15/02/2020 07:00	16/02/2020 06:30	44.4	23.5	2
Break Your Neck Falls	318070	26000	15/02/2020 06:30	16/02/2020 06:30	55.4	24	3

The two tables above show that the peak rainfall totals are not very high for Storm Dennis. The two highest are for the Vowchurch and Tafalog rain gauges. The rainfall from the 8th to the 16th February was also analysed to check the rainfall totals encompassing Storm Ciara and Storm Dennis. The Event Rarity calculator is designed for shorter duration events, but showed that the totals over the 8 days for the

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Vowchurch and Tafalog gauges had a return period frequency of 14 and 19 years respectively. Winter storms tend to be consistently wet over a longer duration as shown in the plot in Figure 5 which may explain why the return periods identified in the tables above do not show very high return periods.

FEBRUARY 2020 RIVER FLOWS ANALYSIS

The table below summarises the flow gauge records for the February 2020 flooding events across Herefordshire. The peak flows were all recorded during Storm Dennis with the earliest peak flows being measured in the smaller river catchments.

Table 5: February 2020 river flow gauge analysis

River gauge name	River	Catchment area (km2)	Date and time of peak	Recorded peak flow (m^3/s)	Event magnitude (1 in x years)	Best estimate event magnitude range
Tenbury	Teme	1134.4	16/02/2020 18:45	261	30-50	30-50
Belmont	Wye	1895.9	17/02/2020 10:00	689	75-300	100-150
Titley Mill	Arrow	126.4	16/02/2020 05:00	53.1	30-50	30-50
Byton	Lugg	203.3	16/02/2020 17:00	103	200-600	200-300
Butts Bridge	Lugg	371.0	17/02/2020 04:00	90.8	20-50	30-50

At three of the gauges, the flows show a return period of 30-50 years and were in this range for all three methodologies of enhanced single site, pooled analysis and an analysis excluding the 2020 records. The enhanced single site analysis places a greater weight on the site record and the pooled analysis creates a representative growth curve based on similar catchments. The analysis excluding 2020 is to ensure no bias is introduced into the analysis because the 2020 flows are the highest ever recorded flows in some catchments.

The wide ranges shown in the Lugg at Byton and the Wye at Belmont are as a result of the three different analysis methods within WINFAP. The Wye at Belmont shows a 75-300 year return period; the lower estimate comes from including the 2020 records in the pooling group and the higher estimate comes from an enhanced single site analysis. For the Lugg at Byton, the lower estimate is from the enhanced single site analysis showing a 100 year return period and the two pooled methodologies showing a 300-600 return period. The flow record for the Lugg at Byton has very few high gaugings and the rating at the gauge does not account for any non-modular conditions at the weir nor any out of bank flow and the rating curve slightly

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overestimates flows based on the measured stage. This will result in the reported flow being over-estimated for the measured levels at the gauge.

Conclusions

On the 25th and 26th October 2019, the property flooding across Herefordshire was as a result of intense rainfall following a wet month which affected the antecedent conditions across the county. The calculated return period of the rainfall events is between a 13 and 87 year return period frequency (AEPs of 7.7% to 1.1%). This resulted in a fluvial (river) flooding event with a return period frequency of a 5 to 50 year (AEPs of 20% to 2%) depending on the river. The rain gauges are located within Herefordshire and only record the data at a given time at that exact location and do not take into account any other factors, whereas the flow gauges within the rivers are as a result of the rainfall hitting the catchment and entering the river which is entirely dependent on antecedent conditions. A very high intensity rainfall event may not actually result in any fluvial flooding if the antecedent conditions in the catchment allow for the landscape to absorb the water. The October 2019 flooding event occurred when river levels were fairly high after a few weeks of wet weather and, combined with a storm with intensive rainfall, river flows increased rapidly.

In February 2020, a succession of storms (principally Storm Ciara and Storm Dennis) followed a very wet winter and resulted in high river flows across the county which resulted in a large number of properties flooding. The calculated return period of the rainfall events is between a 2 and 19 year return period frequency (AEPs of 50% to 5.3%). When combined with very wet antecedent conditions and therefore very responsive catchments, this resulted in serious fluvial (river) flooding with a return period frequency of a 1 in 30 to 300 year event (AEPs of 3.3% to 0.3%) depending on the river. The rainfall totals recorded across the UK in February 2020 were particularly high in Wales and Gloucestershire and Herefordshire as shown in Figure 3 which therefore resulted in the high return period events. Both the Wye and the Lugg rise in a similar area by the Welsh Border so it is possible high rainfall totals in this specific area predominantly affected flows in those catchments. The February 2020 flooding event occurred after semi continuous rainfall from the 8th February to the 17th February. This resulted in very wet antecedent conditions which when combined with heavy rainfall resulted in the highest ever recorded peak flows on the River Wye.