Dinas Powys S19 Data Analysis

Final Report

August 2021

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Revision History

Revision Ref/Date	Amendments	Issued to
S3-P01 / March 2021	Draft Report	Clive Moon
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Contract

This report describes work commissioned by Vale of Glamorgan Council, by a letter dated 19th January 2021. Vale of Glamorgan Council's representative for the contract was Clive Moon. Jenni Essex of JBA Consulting carried out this work.

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Purpose

This document has been prepared as a Final Report for Vale of Glamorgan Council. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBA Consulting has no liability regarding the use of this report except to Vale of Glamorgan Council.

Acknowledgements

JBA text

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Abbreviations

AEP	annual exceedance probability
AMAX	annual maximum
FEH	Flood Estimation Handbook
FWMA	Flood and Water Management Act (2010)
GL	Generalised Logistic
LLFA	Lead Local Flood Authority
LMED	median annual maximum level
LTA	long-term average
NRFA	National River Flow Archive
NRW	Natural Resources Wales
POT	peaks over threshold
QMED	median annual maximum flood
S19	Section 19 (report)

SMD	soil moisture deficit
STW	sewage treatment works
TBR	tipping bucket raingauge
VoGC	Vale of Glamorgan Council

1 Scope & objectives

In December 2020 flooding occurred in the Cadoxton River catchment, Vale of Glamorgan, South Wales. This was predominantly in the village of Dinas Powys, but also along Sully Moors Road and Cold Brook, a tributary of Cadoxton River. A flood reconnaissance study[1] for the event, undertaken by JBA Consulting for Natural Resources Wales (NRW), documented widespread flooding.

As Lead Local Flood Authority (LLFA), Vale of Glamorgan Council (VoGC) has a duty to prepare and publish reports of significant flood incidents, as detailed within Section 19 (S19) of the Flood and Water Management Act 2010 (FWMA). As part of the preparation of a S19 report for the 23rd December 2020 flood incident, VoGC commissioned JBA Consulting to compile an account and analysis of the meteorological and hydrological event data. This analysis will support understanding and communication of the flood event and provide an estimate of the event frequency. VoGC also requested assessment of data for an earlier flood event which occurred on 28th February 2020 (Storm 'Jorge').

The key tasks for this study were:

- Collect and collate hydrometric datasets and any other relevant data / information.
- Review, quality check and analyse all data, extracting and visualising key parameters such as storm duration, time-to-peak, flood peak travel time, and maximum and total values.
- Examine Natural Resources Wales (NRW) ratings for Dinas Powys and Sully Moors Road level gauges and determine if flow series, in which there is reasonable confidence, can be derived. Comparison of the existing ratings, and results derived from them, with those derived from hydraulic modelling as part of a study commissioned by NRW to review and update the ratings (running in parallel with this study).
- Estimate event frequency from level, flow (where possible) and rainfall data, to provide a probable range in which the events lie.
- Document the findings of the assessment, including discussion and comparison of the hydro-meteorological conditions for the two events, and results of the frequency analysis.

This report is divided into the following sections:

Element	Report section
Scope and objectives	1
Available data	2
Flood event characteristics & catchment response	3
Flood statistics & frequency analysis	4
Summary & conclusions	5

[1] JBA Consulting. March 2021. Dinas Powys Flood Reconnaissance. EZN-JBAU-XX-XXTN-Z-0001-S3-P02-Dinas_Powys_Flood_Extent.pdf

2 Available data

2.1 Hydrometric gauge data

Gauge name	Gauge type	Record length supplied	Source of data
Dinas Powys FWS	Level	15/10/2013-25/01/2021	NRW (15-minute resolution)
Sully Moors Road	Level	30/08/2007-25/01/2021	
Cog Moors STW TBR	TBR*	03/12/1999-24/01/2021	
St Richard School	Level	13/01/2020-11/01/2021	VoGC (15-minute resolution)
Coldbrook Road East Inlet	Level	14/01/2020-12/01/2021	
Meadow Vale	Level	14/01/2020-12/01/2021	
Brookfields Screen	Level	14/01/2020-12/01/2021	
Price Avenue	Level	15/01/2020-12/01/2021	
Maple Close Inlet	Level	18/01/2020-12/01/2021	
Dyfan Road POS Outlet	Level	14/01/2020-12/01/2021	
Redberth Close Culvert Inlet	Level	14/01/2020-12/01/2021	
Merthyr Dyfan Road Culvert	Level	14/01/2020-12/01/2021	
Coldbrook Weather Station	TBR	13/01/2020-10/01/2021	
St Fagans	TBR	10/02/2020-10/02/2021	NRW 'River levels, rainfall and sea data' website https://rivers-and-seas.naturalresources.wales/
Rhiwbina Res	TBR		
Rhiwsaeson STW	TBR		
Llantwit Major	TBR		
Cowbridge STW	TBR		

* Tipping bucket raingauge

2.2 Other data / information

Details	Source
Interim Rating Report. January 2021. Cadoxton River at Dinas Powys	NRW
Interim Rating Review Report. January 2021. Cadoxton River at Sully Moors Road	
Spot gaugings for Dinas Powys (03/12/2015-14/03/2019) and Sully Moors Road (05/03/2001-14/03/2019) gauges	
Analysis spreadsheet to derive median annual maximum level (LMED)	
Barry Port tide curves for December 2020 and February 2020 flood events	JBA Consulting Coastal Team

3 Flood event characteristics & catchment response

3.1 Catchment description

Cadoxton River drains a relatively small catchment (<40km^2) which outfalls to the sea to the south of Barry Docks. Wrinstone Brook, rising near Wenvoe, and Bullcroft Brook, rising to the south of Caerau (west Cardiff), join at Michaelston-le-Pit to become Cadoxton River. This flows in a generally southerly direction to, and through, the village of Dinas Powys. East Brook (2.4km^2) joins Cadoxton River from the east within Dinas Powys, downstream of Murchfield Community Centre near the eastern end of St Cadoc's Avenue.

Downstream of Dinas Powys, Cadoxton River passes through Cog Moors / Pymbylu Moors. It is joined by Cold Brook (9km^2) from the west just upstream of the urban area of Palmerston and Cadoxton, and by Sully Brook (8km^2) from the east just downstream of the B4267 Sully Moors Road. The moors are drained by a complex system of channels. There are no significant reservoirs / lakes within the catchment except Cosmeston Lakes in the upper catchment of Sully Brook.

The catchment is predominantly underlain by Triassic Rocks comprised of mudstone, siltstone, and sandstone. There are smaller areas of Dinantian Rocks (limestone with subordinate sandstone and argillaceous rocks), and Lias Group (mudstone, siltstone, limestone, and sandstone). Superficial deposits of alluvium (clay, silt, and sand) are found along, and in the areas adjacent to, the watercourses.

Soils are predominantly loamy and clayey with impeded drainage, with freely draining soils in smaller areas to the north and south of the catchment. At the upper extent of Sully Brook and to the north of Barry there are slowly permeable seasonally wet loamy and clayey soils. Across the moors and through the docks area there are loamy and clayey floodplain soils with naturally high groundwater.

Upstream of the moors and through the urban area of Barry the catchment topography is relatively steep. However, the moors and the area downstream of Sully Moors Road to the docks is low-lying and flat. The lower catchment downstream of Sully Moors Road is highly urbanised. Upstream of this the catchment is more rural, although Dinas Powys and Wenvoe account for a relatively large proportion of the catchment area.

Based on these physical characteristics, it may be expected that there will be a fast response to rainfall upstream of the moors and in the western part of the lower catchment, with peak flows exceeding the channel capacity most likely to cause flooding. Surface water runoff may also be a flooding mechanism in these areas. Across the moors and downstream of Sully Moors Road, flood volumes may be more important as the river response will be slower and surface water ponding may be an important flooding mechanism.

Figure 3-1 shows the Cadoxton River catchment boundary, the watercourses, and the hydrometric gauges located within the catchment. Note: The TBRs detailed in Section 2.1 which are not located within the catchment boundary (St Fagans, Rhiwbina Res, Rhiwsaeson STW, Llantwit Major, and Cowbridge STW) are not shown on the map.

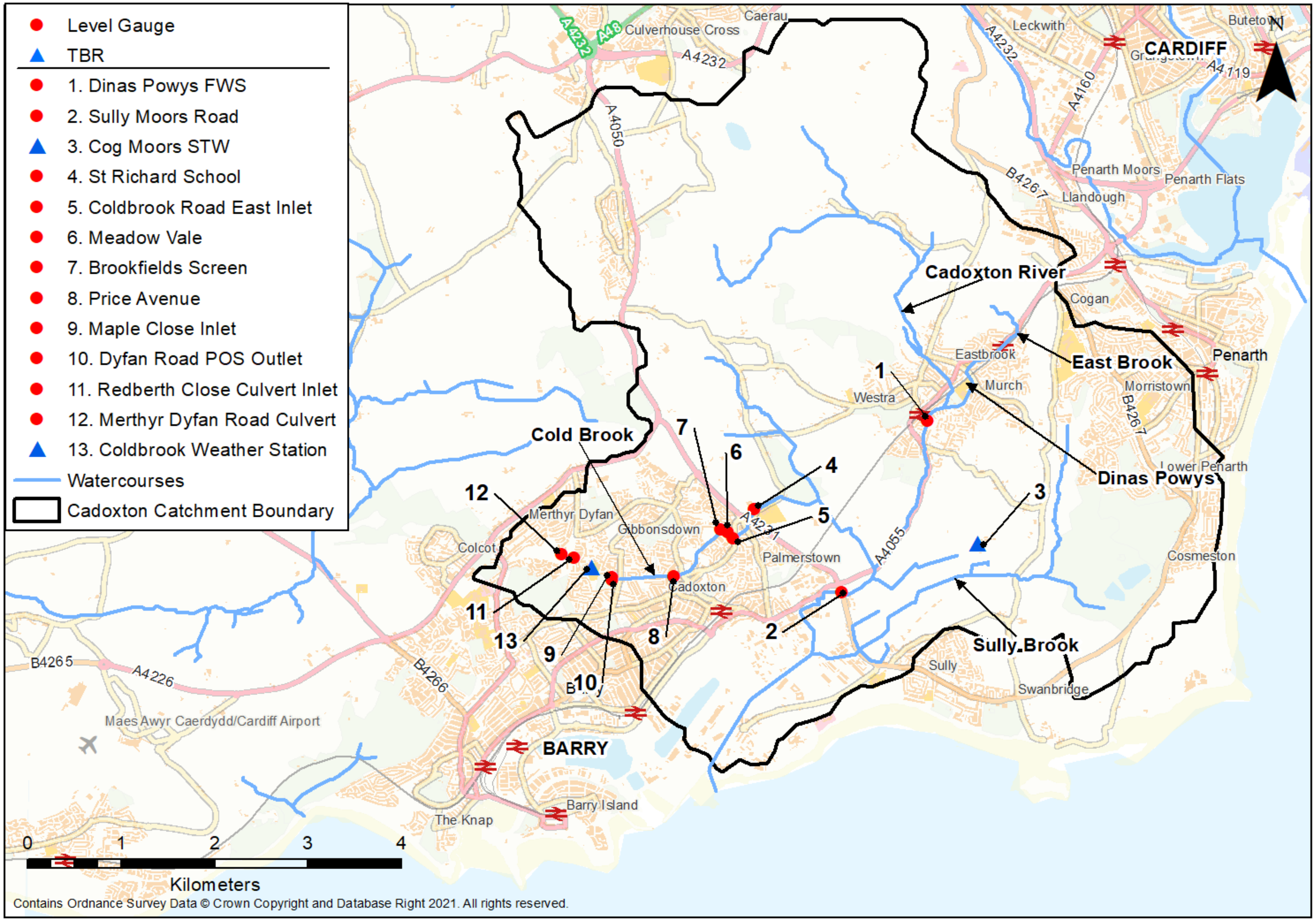

Figure 3-1: Catchment map & hydrometric gauges

3.2 Hydrological context for flood events

The UK Centre for Ecology and Hydrology produces monthly hydrological summaries for the UK. These have been used to provide a wider context to the floods which occurred in Dinas Powys in December and February 2020.

3.2.1 December 2020[2]

December 2020 was an unsettled and very wet month, at the end of the third wettest year (after 2000 and 2012) for the UK in a series from 1910. Rainfall was above average across most of the UK. River flows generally far exceeded December averages across England and Wales, notably so in South Wales. Soil moisture deficits (SMD) were near-zero across the whole of the UK, the wettest soils for late December at a national scale since 2012 and comparable with 2000.

December featured a series of cyclonic systems, with successive spells of unsettled weather generating rainfall over saturated ground. Surface water flooding causing significant disruption was a recurrent characteristic of the month. However, the only 'named' storm during the month was 'Bella' which occurred over the 26th and 27th of the month.

Overall, December rainfall was substantially above average (139% of the long-term average (LTA) for the UK). Rainfall exceeded 150% of the average across a broad swathe of Wales, eastern Scotland, and central, eastern, and north-eastern England. Rainfall for 2020 overall (January to December) was above average across most of the UK, particularly so across western regions.

At the start of December river flows were generally below average, but with catchments close to saturation flows quickly responded to the succession of weather systems. These maintained high flows throughout December in catchments across England and Wales, only receding towards the end of the month. Mean river flows for December were substantially above average across most of England and Wales. Mean river flows over 2020 (January to December) were exceptionally high in Wales. Annual mean outflows from England and Wales in 2020 were the third highest in a series from 1961, only surpassed by the significant flooding of 2000 and 2012.

3.2.2 February 2020[3]

February 2020 was a remarkable month in hydrological terms, with three named storms ('Ciara', 'Dennis' and 'Jorge') and record-breaking river flows bringing widespread, protracted and severe flooding. The greatest rainfall anomalies (more than 350% of LTA) were over upland areas of northern and central England and in Wales, and for the UK it was the fourth wettest month on record (in a series from 1910). New peak flow, daily mean and monthly mean maxima were established on numerous rivers in England, Wales, Northern Ireland, and southern Scotland. Over 3,000 properties were flooded, with northern England, the West Midlands, and South Wales the worst affected areas.

Storm 'Ciara' arrived on the 8th / 9th bringing strong winds and heavy rain. On 15th / 16th, Storm 'Dennis' brought widespread heavy rain, especially over high ground (148mm at Maerdy, Mid-Glamorgan). Subsequent rain and snow traversed the UK and culminated in Storm 'Jorge' on 28th / 29th with rainfall in South Wales again among the highest (120mm at Treherbert, Mid-Glamorgan). With the UK receiving 240% of the LTA monthly rainfall, it was the wettest February in a series from 1910. Most regions received more than twice their average February rainfall.

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[2] Parry, S., Chitson, T., Turner, S., Lewis, M. and Clemas, S. 2021. Hydrological Summary for the United Kingdom: December 2020. Wallingford, UK, UK Centre for Ecology & Hydrology.
[3] Sefton, C., Matthews, B., Lewis, M. and Clemas, S. 2020. Hydrological Summary for the United Kingdom: February 2020. Wallingford, UK, UK Centre for Ecology & Hydrology.

River flows initially receded before successive peaks caused by bands of heavy rain, predominantly those associated with the named storms. On 9th / 10th new daily flow maxima were set on many rivers in southern Scotland and northern England. From 15th-17th, flows rose again sharply, with widespread new daily maxima, and peak flows exceeded the highest recorded on the Cynon and Wye (in records from 1961 and 1908, respectively). By the 16th there was significant property flooding from the Teme, Severn, Wye and Taff, and the daily outflow from England and Wales marginally exceeded the maximum established in October 2000. Flows remained high particularly in northern England and the west of the UK.

Mean February river flows were notably or exceptionally high across most of the UK. Average flows over October to February were the highest on record for this period for many rivers in a band from Yorkshire across the Midlands to South Wales.

3.3 23rd December 2020 flood event

3.3.1 Cadoxton River catchment

Figure 3-2 shows the stage hydrographs for Dinas Powys and Sully Moors Road level gauges, and the rainfall hyetograph for Cog Moors STW TBR, for the month of December 2020. This provides an understanding of the conditions preceding the flood event on 23rd December. The figure shows that levels were reasonably low at the start of the month, 0.14m at Dinas Powys and 0.32m at Sully Moors Road.

A series of storm events occurred throughout the month, initially with a small response at the level gauges and with level only slightly elevated after the rainfall compared to the pre-event level. As the month continued the peak levels started to become larger, with base level continuing to build after each storm.

By 23rd December, the base level at Dinas Powys was around 0.32m and 0.74m at Sully Moors Road, about 0.2m and 0.4m, respectively, higher than at the start of the month. NRW confirmed that the SMD for the week ending 22nd December 2020 was 0mm, i.e. the soils were saturated prior to the rainfall on 23rd December.

Figure 3-3 provides the stage hydrographs and rainfall data for the 23rd December 2020 event. This shows that there was an initial short and intense burst of rainfall between 09:00 and 10:00. Cog Moors STW TBR recorded 8.2mm of rainfall in this hour. The river starts to respond at both gauge locations as soon as the rainfall commences, albeit less notably at Sully Moors Road. There was no rainfall for a further 1.5hr, followed by 1mm over 30 minutes between 11:30 and 12:00, with levels continuing to rise at both gauges over this period.

The main burst of rainfall started at 12:45 and continued until 18:00, with 47.8mm of rainfall falling over this 5.25hr period, giving an average intensity of 9.1mm/hr. The maximum hourly intensity over the period was 14.4mm/hr between 14:00 and 15:00. The rainfall intensity was >10mm/hr between 13:15 and 15:30 and between 15:45 and 17:00.

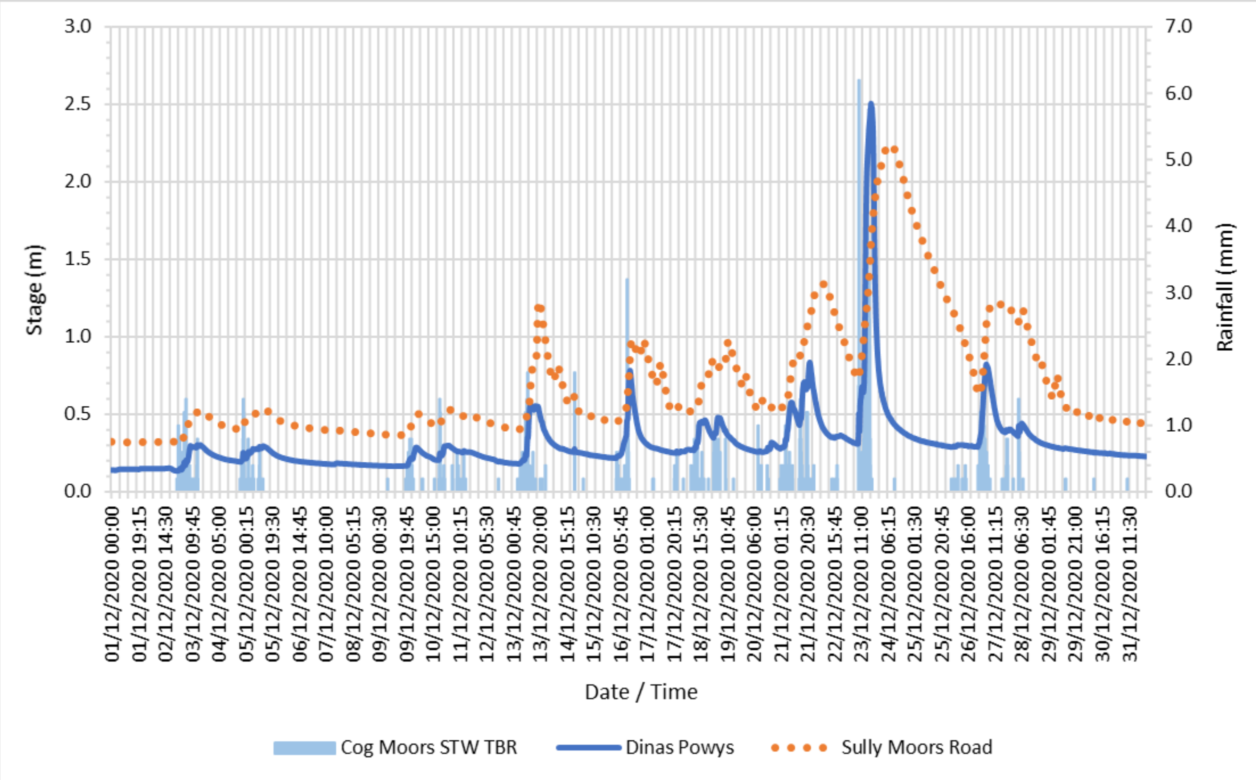

Figure 3-2: Cadoxton River stage hydrographs & rainfall hyetograph - December 2020

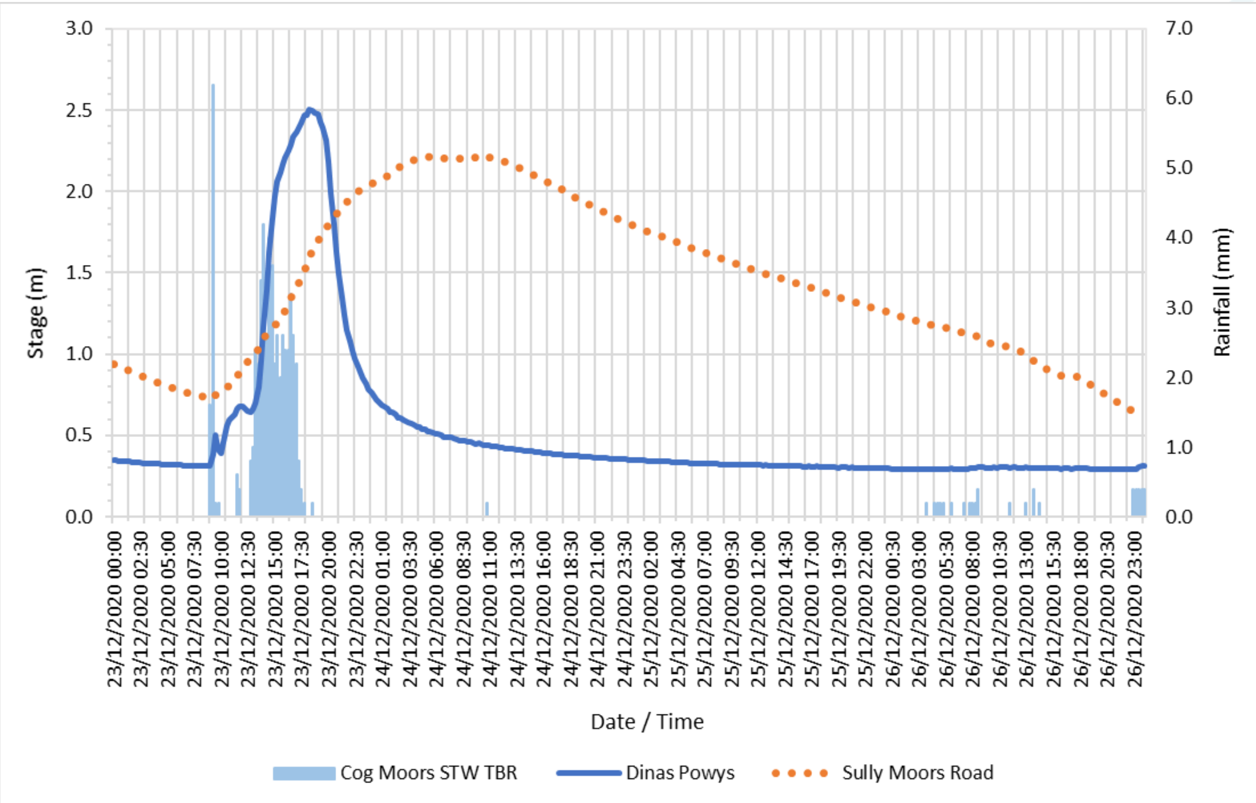

Figure 3-3: Cadoxton River stage hydrographs & rainfall hyetograph - 23rd December 2020 event

Rainfall totals at other local raingauges were also assessed for the 23rd December 2020 event (detailed in Table 3-1). Note: Rain falls at slightly different times at the gauges, hence the period and duration vary for each.

This indicates that the Cog Moors STW TBR total for the event is substantially larger than at the other gauges. Online historical rainfall radar images[4], although difficult to assess due to the resolution, do not indicate that there was a localised storm over Cog Moors. This may suggest that rainfall at Cog Moors is overestimated for this event. However, information provided by NRW indicates that there is confidence in the Cog Moors data:

- The gauge was visited by NRW Hydrometry & Telemetry staff on 31st December 2020, hence data up to this date has been quality checked.
- The primary TBR was within 2% of the check gauge total (since the previous visit on 9th November 2020) and the secondary TBR was within 8% of that figure, i.e. both TBRs were suggesting good data.
- 15-minute data for 23rd and 24th December for the primary and secondary TBRs, which record independently, is generally consistent, with any differences being 0.2mm and only signifying a slight difference in the 'time of tip'. This provides confidence in the data for the event.
- There has been some building work at the STW, but this is not known to have influenced the gauge site.

Table 3-1: 23rd December 2020 event rainfall totals

Raingauge	Period	Duration (hr)	Rainfall depth (mm)
Cog Moors STW TBR	23/12/2020 12:45 - 23/12/2020 18:00	5.25	47.8
	23/12/2020 09:00 - 23/12/2020 18:45	9.75	57.2
Coldbrook Weather Station	23/12/2020 12:30 - 23/12/2020 17:45	5.25	29.0
	23/12/2020 08:45 - 23/12/2020 18:30	9.75	37.0
St Fagans TBR	23/12/2020 11:30 - 23/12/2020 17:30	6.00	30.8
	23/12/2020 09:00 - 23/12/2020 18:45	9.75	43.6
Rhiwbina Reservoir TBR	23/12/2020 11:30 - 23/12/2020 17:30	6.00	27.6
	23/12/2020 09:15 - 23/12/2020 19:00	9.75	44.4
Rhiwsaeson STW TBR	23/12/2020 11:00 - 23/12/2020 18:00	7.00	28.2
	23/12/2020 09:15 - 23/12/2020 19:15	10.00	37.4
Llantwit Major TBR	23/12/2020 09:45 - 23/12/2020 18:15	8.50	32.6
Cowbridge TBR	23/12/2020 11:15 - 23/12/2020 18:00	6.75	28.8
	23/12/2020 09:15 - 23/12/2020 18:30	9.25	35.2

Cadoxton River responded immediately to the main burst of rainfall, most clearly seen at the Dinas Powys gauge where the peak level (2.506m) was reached at 18:15, just under 6hr after the main rainfall burst commenced, a rise of well over 2m in this time. The centroid of the rainfall occurred at around 15:00, giving a lag between rainfall centroid and peak level of just over 3hr. The initial recession after the peak was rapid, although base level did not return to the pre-event level until after midday on 25th December.

At Sully Moors Road the response to the rainfall was much slower, with the peak level (2.218m) occurring on 24th December at 05:45. This is 11.5hr after the peak at Dinas Powys, 17hr after the start of the main rainfall burst, and with a lag of nearly 15hr between

[4] https://www.meteoradar.co.uk/historie?startdatum=12-23-2020%2009:00:00&aantal=360&stap=0#

the rainfall centroid and the peak level. This will be due to the flat nature of the catchment downstream of Dinas Powys. The peak level was sustained, with only a slight decrease in level, for approximately 5hr. The recession after the peak is seen to be even slower than the rise to peak, with the pre-event base level not reached again until the evening of the 26th December. A slightly steeper recession is seen from about 11:30 on the 26th.

The Sully Moors Road level data has also been plotted against the tide curve at Barry Port, see Figure 3-4, to understand what influence the state of the tide might have had on peak levels at Sully Moors Road. Note: Level (mAOD) has been plotted for Sully Moors Road in this figure for consistency with the tide curve data. It can be seen from the plot that the peak level at Sully Moors Road occurs within a trough of the tide curve, indicating that the tide did not adversely impact levels at the gauge location.

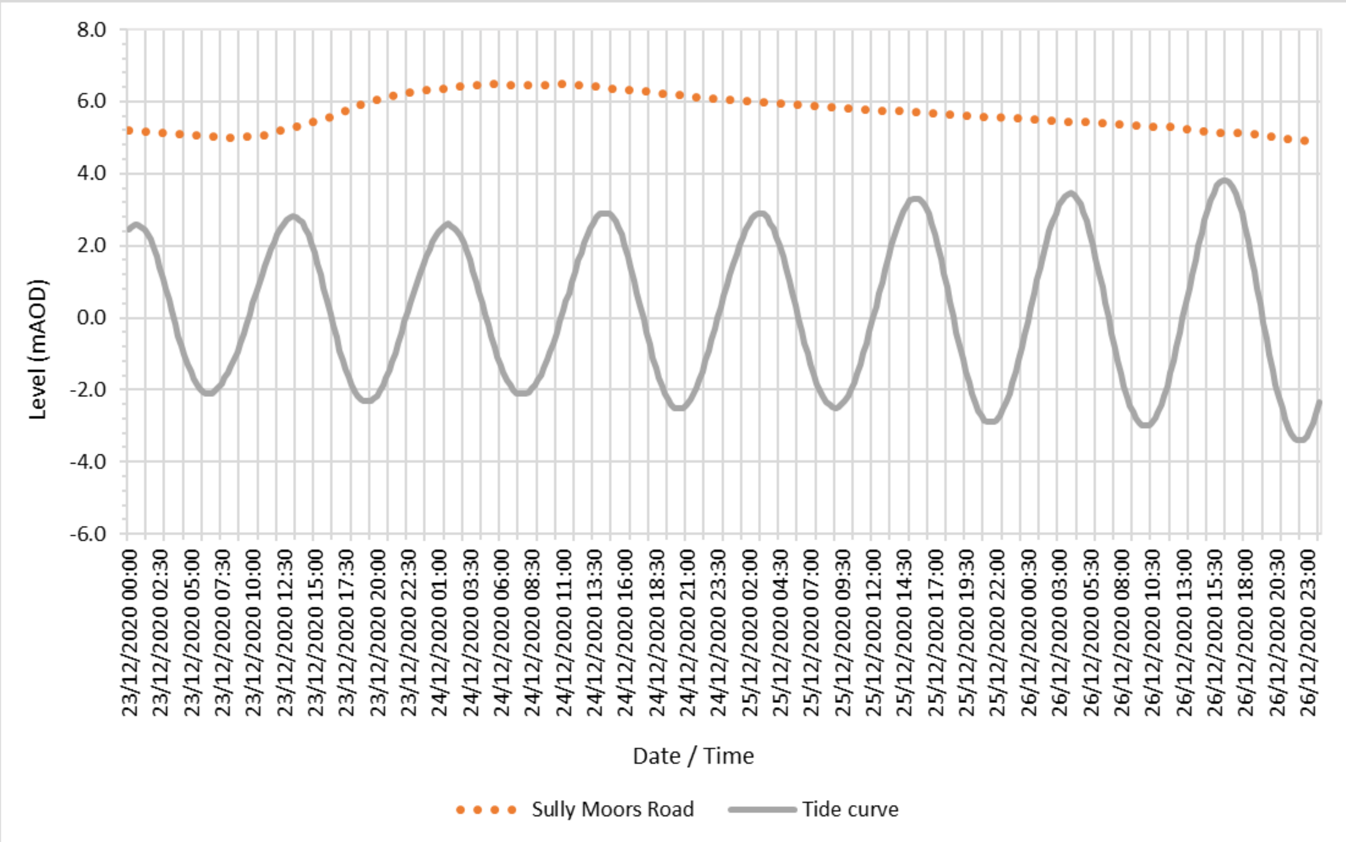

Figure 3-4: Sully Moors Road stage hydrograph & Barry Port tide curve - 23rd December 2020 event

The flood reconnaissance study identified that, during the 23rd December 2020 flood event, water came out of bank from Cadoxton River and East Brook at several locations, causing flood water to flow overland along roads and into properties. There were also reports of drains backing-up around Cardiff Road and Greenfield Avenue contributing to the volume of water in the area. Figure 3-5 shows the estimated flood extent in Dinas Powys.

In summary, the flood event on 23rd December 2020 was a response to a short and intense storm event, with Cadoxton River responding quickly to the rainfall, especially in Dinas Powys. Prior to the 23rd there had been a succession of storm events, resulting in a saturated catchment and elevated river levels. As a result of this there would have been little capacity for storage within the catchment and substantial runoff to the watercourse. An intense storm event also causes problems for the surface water sewer network, which is unable to cope with a large volume of water over a short period of time. High levels in the river, plus drains discharging to the watercourse and surcharging, is likely to have led to conditions liable to lead to flooding. A rough calculation of volume for the Dinas Powys gauge, using the NRW rating (see further discussion in Section 4), and the rainfall from Cog Moors STW TBR, indicates that the percentage runoff from the catchment was in the order of 70% for the event.

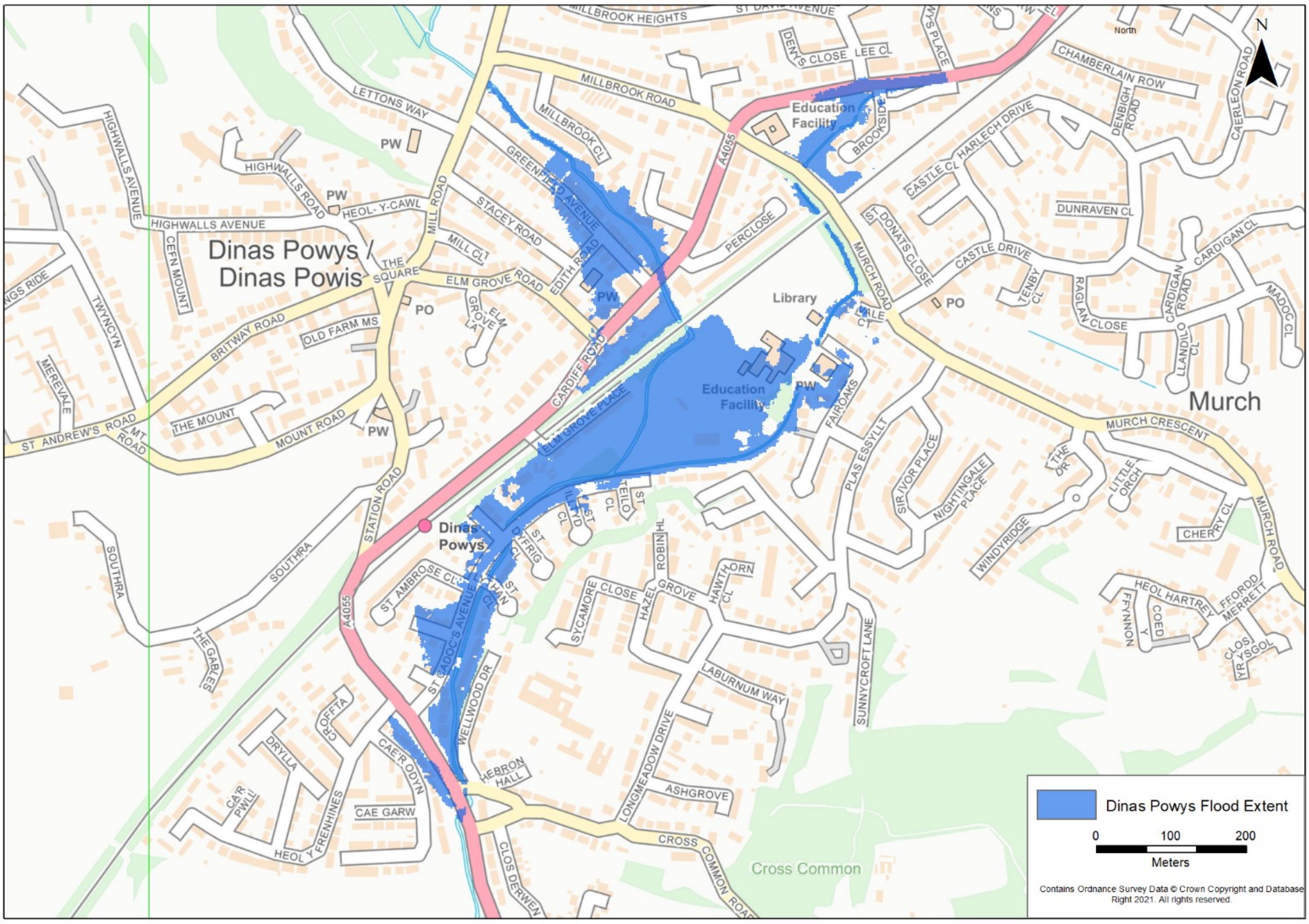

Figure 3-5: 23rd December 2020 estimated flood event outline (Dinas Powys)

3.3.2 Cold Brook catchment

Data was provided by VoGC for a series of level gauges along Cold Brook and for a Council maintained TBR in the catchment. Many of the level gauges are at culvert inlets, outlets, and screens, and will be subject to hydraulic influences from these structures. However, the data is useful to provide an understanding of the response of Cold Brook to the storm event.

Figure 3-6 shows the stage hydrographs for all Cold Brook level gauges and the Coldbrook Weather Station for the 23rd December 2020 event. The level gauges in the legend are from downstream to upstream, i.e. St Richard School is the most downstream gauge and Merthyr Dyfan Road Culvert is the most upstream gauge.

A response can be seen to the first burst of rainfall; this appears to be more significant at these gauges than at Dinas Powys or Sully Moors Road. There is a very quick initial response to the main burst of rainfall, although the peak level comes several hours after this. Table 3-2 details the peak level at each gauge and the date / time that the peak was reached. The gauges in the upper part of the catchment peak between about 15:00 and 15:30; in the lower part of the catchment the peak occurs 1.5hr-2.0hr later.

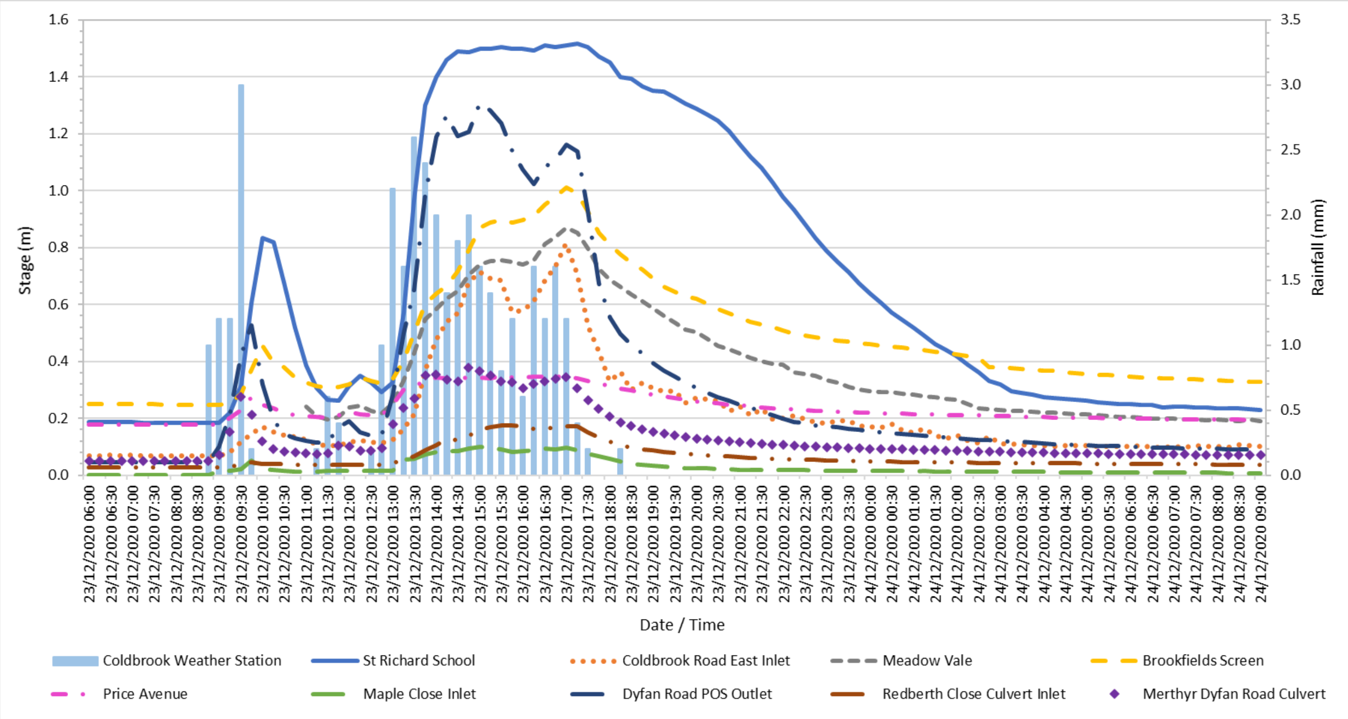

Figure 3-6: Cold Brook gauge stage hydrographs & rainfall hyetograph - 23rd December 2020 event

Table 3-2: 23rd December 2020 event Cold Brook gauge peak levels / times

Gauge	Peak stage (m)	Date / time of peak
St Richard School	1.517	23/12/2020 17:15
Coldbrook Road East Inlet	0.815	23/12/2020 17:00
Meadow Vale	0.870	23/12/2020 17:00
Brookfields Screen	1.012	23/12/2020 17:00
Price Avenue	0.348	23/12/2020 15:30
Maple Close Inlet	0.098	23/12/2020 15:00
Dyfan Road POS Outlet	1.309	23/12/2020 15:00
Redberth Close Culvert Inlet	0.176	23/12/2020 15:30
Merthyr Dyfan Road Culvert	0.379	23/12/2020 14:45

3.4 28th February 2020 flood event

3.4.1 Cadoxton River catchment

Stage hydrographs for Dinas Powys and Sully Moors Road level gauges, and the rainfall hyetograph for Cog Moors STW TBR, for February and the first half of March 2020 are provided in Figure 3-7, to show conditions preceding and following the flood event on 28th February. The figure shows that levels were reasonably low at the start of the month, 0.16m at Dinas Powys and 0.36m at Sully Moors Road, similar to but slightly higher than for December 2020.

As seen for December 2020, a series of storm events occurred throughout the month. However, although there were peak levels as large, or larger than, those for December 2020, the base level does not appear to have risen to the same degree before 28th February as it did for 23rd December. By 28th February, the base level at Dinas Powys was around 0.20m and 0.47m at Sully Moors Road, about 0.04m and 0.10m, respectively, higher than at the start of the month. This is much less substantial than the increase in base level prior to the 23rd December 2020 event. SMD for the weeks ending 25th February 2020 and 29th February 2020 was 0mm, so the catchment was saturated as it was for 23rd December.

The data for Sully Moors Road is missing between 28th February 2020 18:30 and 2nd March 2020 14:15 due to an outstation fault. A later event on 10th March 2020 has a peak of 1.79m at Sully Moors Road. The peak at Dinas Powys for 10th March is substantially lower than that for 28th February. Therefore, it would seem reasonable to assume that the 28th February peak at Sully Moors Road is likely to have been somewhat larger than 1.8m.

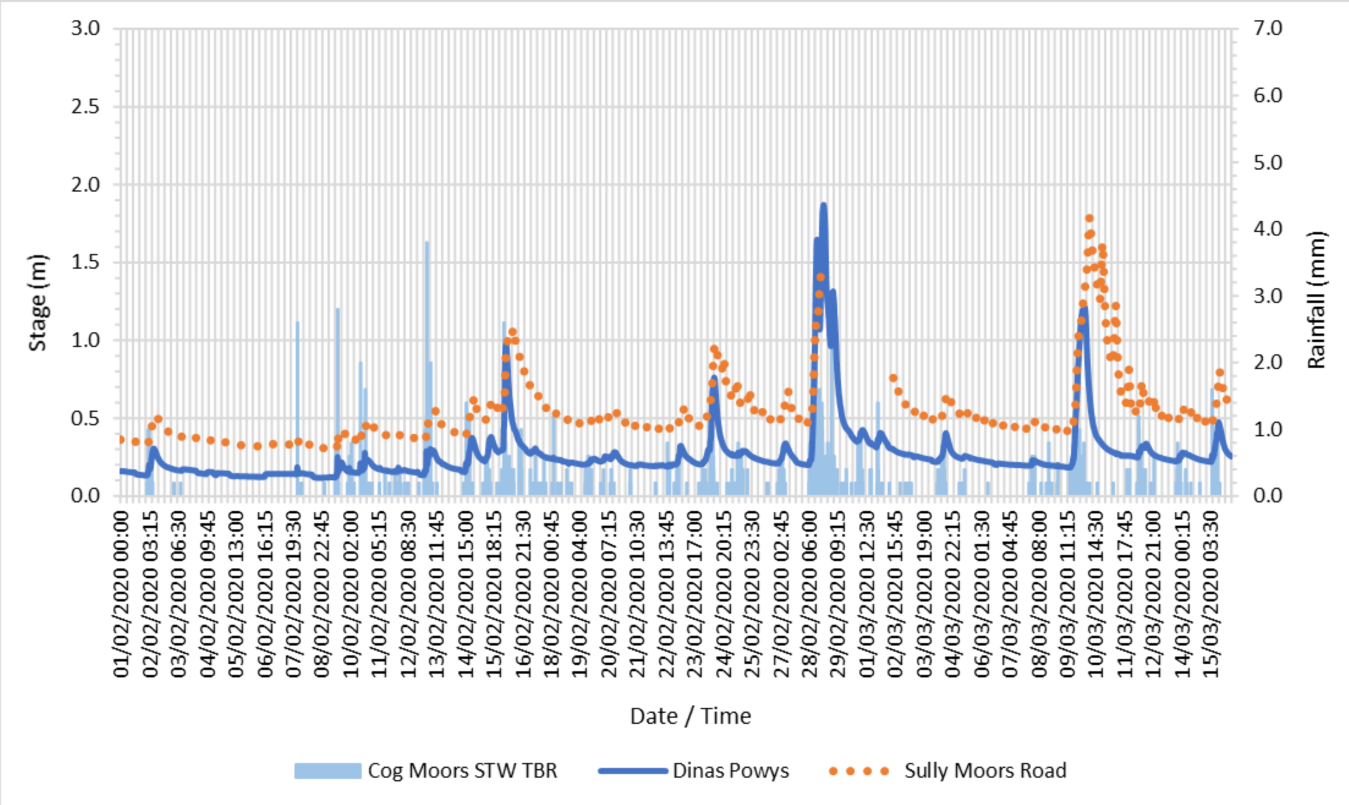

Figure 3-7: Cadoxton River stage hydrograph & rainfall hyetograph - February & March 2020

Figure 3-8 provides the stage hydrographs and rainfall data for the 28th February 2020 event. This shows that there were three main bursts of rainfall, with some additional rainfall between the second and third bursts. The first burst of rainfall was from 05:45 to 13:00 on the 28th, with 26.2mm of rain falling in the 7.25hr period; this gives an average intensity of 3.6mm/hr. The maximum hourly intensity over the period was 7.4mm/hr between 12:00 and 13:00.

The second burst of rainfall was longer, between 15:00 and 00:15 on the 29th (a period of 9.25hr), and with two 15-minute intervals where no rainfall was recorded. A total of 21.0mm of rain fell during this burst, giving an average intensity of 2.3mm/hr; the maximum hourly intensity over the period was 4.6mm/hr between 16:45 and 17:45, 17:30 and 18:30, and 17:45 and 18:45.

Between 00:15 and 03:00 there were brief intervals of rainfall. The third burst of rainfall was the shortest, between 03:00 and 05:15 on the 29th (2.25hr), with a total rainfall depth of 7.0mm, giving an average intensity of 3.1mm/hr. Over this period the maximum hourly intensity of 4.8mm/hr occurred between 03:15 and 04:15.

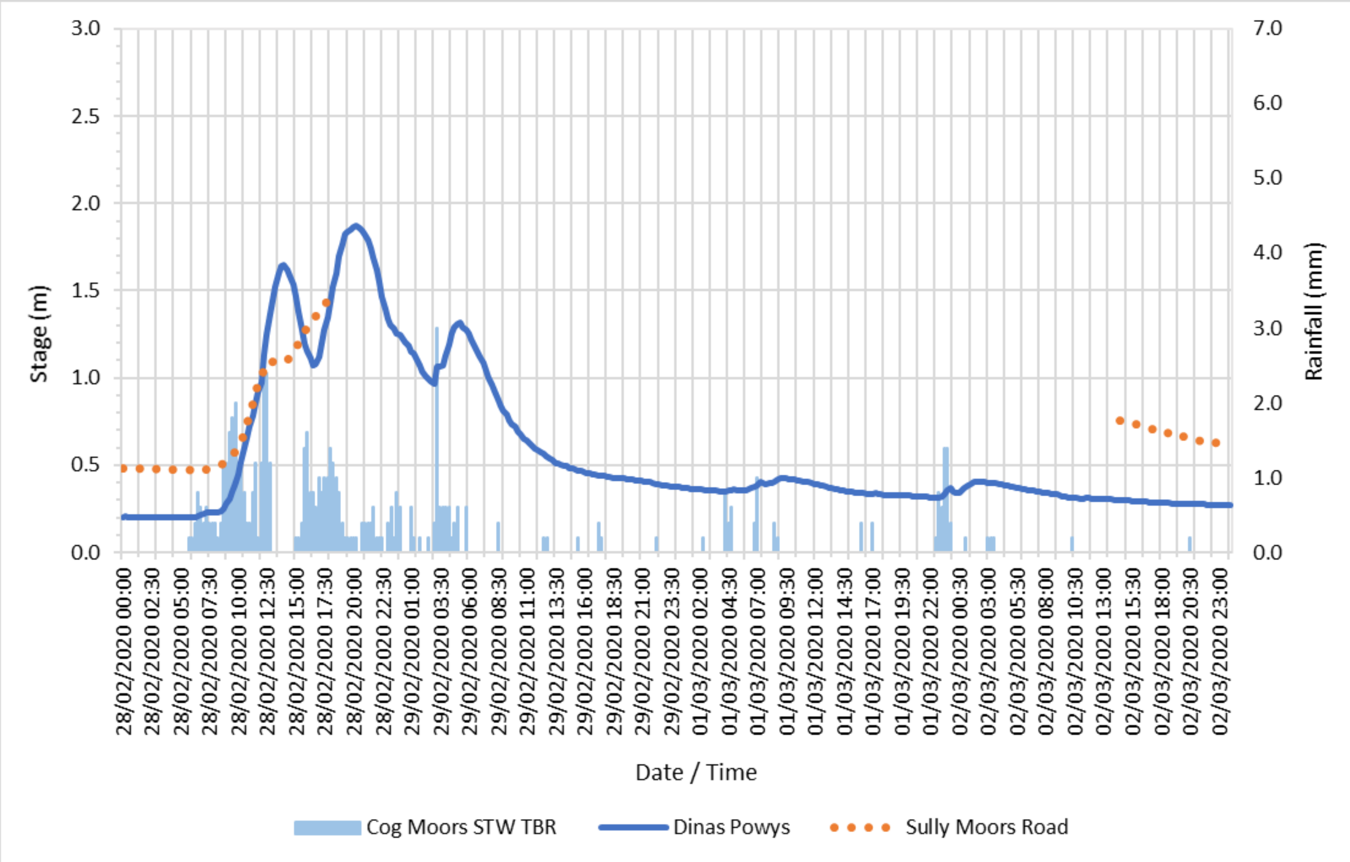

Figure 3-8: Cadoxton River stage hydrographs & rainfall hyetograph - 28th February 2020 event

Table 3-3: 28th February 2020 event rainfall totals

Raingauge	Period	Duration (hr)	Rainfall depth (mm)
Cog Moors STW TBR	28/02/2020 05:45 - 28/02/2020 13:00	7.25	26.2
	28/02/2020 05:45 - 29/02/2020 06:00	24.25	56.0
Coldbrook Weather Station	28/02/2020 05:30 - 28/02/2020 13:00	7.50	23.4
	28/02/2020 05:30 - 29/02/2020 05:45	24.25	51.4
St Fagans TBR	28/02/2020 05:15 - 28/02/2020 13:15	8.00	26.8
	28/02/2020 05:15 - 29/02/2020 06:00	24.75	71.2
Rhiwbina Reservoir TBR	28/02/2020 06:00 - 28/02/2020 14:15	8.25	29.4
	28/02/2020 06:00 - 29/02/2020 06:00	24.00	78.2
Rhiwsaeson STW TBR	28/02/2020 06:00 - 28/02/2020 13:30	7.50	29.2
	28/02/2020 06:00 - 29/02/2020 06:00	24.00	71.4
Llantwit Major TBR	28/02/2020 05:15 - 28/02/2020 12:45	7.50	26.2
	28/02/2020 05:15 - 29/02/2020 05:45	24.50	47.2
Cowbridge TBR	28/02/2020 05:15 - 28/02/2020 13:00	7.75	31.8
	28/02/2020 05:15 - 29/02/2020 05:45	24.50	62.6

Rainfall totals for the other local raingauges for the 28th February 2020 event are detailed in Table 3-3. Totals are provided for the first rainfall burst and for the full length of the rainfall event. The values are reasonably consistent at all gauges for the first, and largest, burst of rainfall. Cog Moors STW TBR, Coldbrook Weather Station and Llantwit Major TBR also have reasonably consistent totals for the whole event. However, totals at the other gauges are 10%-40% higher than at Cog Moors STW.

For the February 2020 event there are three distinct peaks in the level records in response to the separate bursts of rainfall. There was initially little response to the rainfall, with a notable increase in level occurring only after the first 3hr of rain and when the rainfall intensity started to increase. Following this the rising limb of the hydrograph for both gauges took a very similar trajectory. However, the Sully Moors Road hydrograph plateaus after the initial burst of rain ceases and starts rising again before the second burst of rainfall commences. The plateau is likely to be related to the reduction in rainfall intensity around 11:00, with the subsequent increase in level related to the more intense rainfall from 12:00. However, this is difficult to confirm due to the missing data for the rest of the event.

The peak level at the Dinas Powys gauge following the first burst of rainfall was 1.647m (at 14:00), occurring just over 8hr after rainfall commenced, a rise of about 1.5m in this time. A notable decrease in level occurred following the end of the first burst of rainfall, although the river level remains high prior to the second burst of rainfall commencing. There is a lag of about 2hr between the start of the second burst of rainfall and the river responding. The second peak is the largest of the three (1.870m at 20:15), despite the rainfall total being smaller and the intensity less than for the first burst of rain, due to the elevated level prior to the rainfall. Whilst the rainfall continues the river level begins to fall, due to the smaller rainfall amounts and lower intensity. The decline lessens when another burst of slightly greater intensity rainfall begins at 23:15. There was an immediate response to the third burst of rainfall, but the short period of rainfall leads to a much smaller peak level of 1.315m (at 05:15). The recession is relatively gentle, and the pre-event level is not reached again until the middle of 6th March. The centroid of the rainfall event occurs at around 16:00, giving a lag between rainfall centroid and peak level of about 4hr.

For this event there is little benefit in providing a plot of the Sully Moors Road river level data and the tide curve, due to the missing data over the event at the former.

In summary, the flood event on 28th February 2020 was a response to a prolonged and low intensity series of rainfall events. River response to the rainfall was initially slow but became more rapid as rainfall intensity increased. The separate bursts of rainfall led to three distinct river level peaks, with the second of these being the largest. Although there was a succession of storm events prior to the 28th, the river level was only moderately elevated prior to the event compared to the level at the start of the month. However, the SMD value indicates that the catchment was saturated prior to the event. Flow volume estimates from the Dinas Powys NRW rating, and the rainfall volume from the Cog Moors STW TBR, indicates that the percentage runoff from the catchment was in the order of 100% for the event. It is believed that no internal property flooding occurred during the 28th February 2020 flood event, although some flooding of gardens was experienced.

3.4.2 Cold Brook catchment

The Cold Brook catchment gauge data was plotted for the 28th February 2020 event (Figure 3-9). This shows a similar river response to that of Cadoxton River at Dinas Powys, with the three separate rainfall bursts and river level peaks clearly seen. There is an initial slow response to the rainfall, although this is slightly more notable than for Cadoxton River at Dinas Powys. However, for the Cold Brook catchment gauges, the first river level peak is the largest at all gauges, rather than the second peak as at Dinas Powys. Table 3-4 details the peak level at each gauge and the date / time that the peak was reached. For this event, the peak is reached at all gauges within 30 minutes of each other, with most gauges peaking at 12:45.

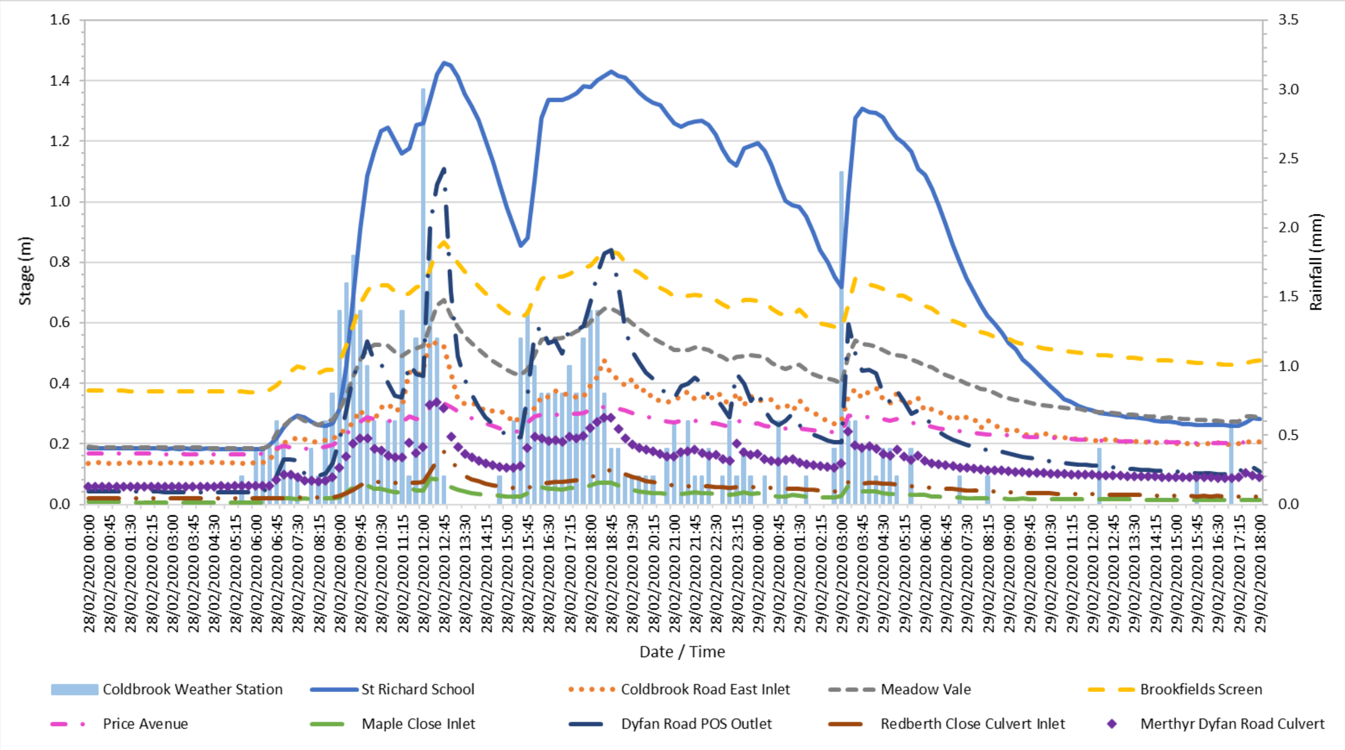

Figure 3-9: Cold Brook gauge stage hydrographs & rainfall hyetograph - 28th February 2020 event

Table 3-4: 28th February 2020 event Cold Brook gauge peak levels / times

Gauge	Peak stage (m)	Date / time of peak
St Richard School	1.458	28/02/2020 12:45
Coldbrook Road East Inlet	0.539	28/02/2020 12:15
Meadow Vale	0.675	28/02/2020 12:45
Brookfields Screen	0.866	28/02/2020 12:45
Price Avenue	0.334	28/02/2020 12:30
Maple Close Inlet	0.085	28/02/2020 12:15
Dyfan Road POS Outlet	1.109	28/02/2020 12:45
Redberth Close Culvert Inlet	0.174	28/02/2020 12:45
Merthyr Dyfan Road Culvert	0.337	28/02/2020 12:30

4 Flood statistics & frequency analysis

Flood peak data was generated and analysed for the Dinas Powys and Sully Moors Road river level gauges, for the purpose of putting the 23rd December 2020 and 28th February 2020 flood events in context with the rest of the gauge record and to enable frequency analysis to be undertaken. This section first discusses some general points regarding flood frequency analysis, followed by a detailed assessment of first the Dinas Powys gauge, and then the Sully Moors Road gauge. It concludes with a summary of the likely frequency of the December and February 2020 flood events. Rainfall frequency estimates are also provided for these events to give context.

4.1 Overview of flood frequency estimation

Flood frequency estimation is normally carried out on a flow peak series. An estimate of the index flood, QMED (median annual maximum flood), is made which is multiplied by growth factors from an estimated growth curve, to generate the flood frequency curve. QMED has an annual exceedance probability (AEP) of 50% (2yr return period).

Where gauge data is available at the site of interest, QMED can be estimated from annual maximum (AMAX) or peaks over threshold (POT) data. The AMAX series contains the largest observed flow in each water year[5]. The POT series contains all peak flows that are greater than a given threshold, generally set to give an average of three to five events per year. For gauges with a record length of less than 14 years, it is recommended that the POT series is used to estimate QMED. A simple method for estimating QMED from POT data is provided in the Flood Estimation Handbook (FEH).

Climatic variability can result in flood-rich or flood-poor periods. When estimating QMED it is important to consider if such a period distorts the estimate from the gauge data. An adjustment for climatic variation is recommended if the record is shorter than 14 years.

An estimate of the growth curve can be made using single-site analysis, using data only from the gauge site of interest, or pooled analysis, which 'pools' data from hydrologically similar sites, providing more data and enabling more reliable estimates of the growth curve for rarer floods to be made. Single-site analysis is appropriate when there is a reliable and long record at the gauge site and when the design event of interest is no longer than the record length.

When undertaking frequency analysis, if the frequency of a specific flood event needs to be determined, consideration must be given to whether to include or exclude that event from the analysis. It is most common to estimate the frequency of a flood in its immediate aftermath. This risks introducing a bias; the study is only being carried out because a large flood has occurred. Including the flood event is relevant to moving forward, for example, to assess what new flood management scheme, or what updating of the flood risk map, might be required. Excluding the event would be proper in any dispute that sought to make or defend an accusation of negligence concerning the flood of interest.

Where flow data is not available, level data may be used in frequency analysis to generate indicative design event level estimates. LMED (median annual maximum level) becomes the index value. The growth curve can only be estimated using single-site analysis for level data; pooled analysis is restricted to flow data only. Regarding climatic variation adjustment, the method provided in the FEH is only for flow, not level, data and there is no known procedure for applying a climatic variation adjustment to level data. It is unlikely to be appropriate to apply an adjustment calculated on flows to river levels. Rating curves are non-linear, so the proportional change in flow will generally be different to the proportional change in level.

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[5] A UK water year starts on 1st October and finishes on 30th September, this is used to avoid splitting the principal river flood season (winter) between two years.

4.2 Dinas Powys gauge – level data analysis

The Dinas Powys level gauge record is short, starting on 15th October 2013, giving seven complete water years of record. It has been assumed that water year 2013 is complete, missing only two weeks at the start, and the peak level date for this year matching the Ely at St Fagans gauge which has a complete water year. Water year 2020 is only 30% complete, however, it is thought likely that the December 2020 event will remain the largest event for this water year.

AMAX and POT series were derived from the 15-minute data. Table 4-1 shows the AMAX series for Dinas Powys along with the percentage complete for each water year and the rank of each AMAX event within the series. In the date / time column blue text indicates a winter event and green text indicates a summer event. Peak levels predominantly occur in the winter, although there are a few summer peaks. The POT series is provided in Table 4-2; a threshold of 0.95m was applied to derive the series.

The AMAX table shows that the 23rd December 2020 event is AMAX1 (i.e. the largest peak in the dataset) and the 28th February 2020 is AMAX2. The December 2020 level is 0.64m larger than February 2020, however there is only 0.01m difference between the level for February 2020 and the next highest peak (AMAX3, October 2013). The POT table indicates that there are no peak events within the rest of the 2020 water year that are larger than February 2020 level, i.e. it may have been possible for other events in water year 2020 to be smaller than 2.506m but larger than 1.870m.

From these flood peak series an estimate of LMED was made. This was carried out using both the AMAX and the POT series', and with the 23rd December 2020 event included and excluded, as a sensitivity test to determine the impact of the event on the results. Due to the short record length for the gauge and the size of the December 2020 event compared to the others in the record, use of the different methods and inclusion / exclusion of December 2020 has a significant impact on the results.

A single-site analysis was undertaken to provide level estimates for a range of design events, using the Generalised Logistic (GL) distribution. There is limited confidence in the results due to the short record. Note: The analysis can only be carried out using the AMAX series, although the POT LMED value can be substituted and the growth curve from the AMAX data applied to these estimates. The results are shown in Table 4-3; red text indicates the results in which there is less confidence due to the record length. Yellow highlighting shows the design events between which the December 2020 event falls (2.506m) and blue highlighting shows the design events between which the February 2020 event falls (1.870m).

Excluding the December 2020 event from the analysis gives results which suggest that the event has an AEP <0.1% (>1,000yr return period), this does not seem reasonable. Including the event in the analysis gives an AEP of between 10% and 3.33% (10yr to 30yr return period), which seems more realistic. Single-site results excluding the December 2020 event were not considered further.

Table 4-1: Dinas Powys level AMAX series

Water year	Date / time	Stage (m)	% available	Rank
2013	28/10/2013 06:15	1.860	96	3
2014	22/02/2015 18:15	1.142	100	8
2015	09/03/2016 04:30	1.157	100	7
2016	21/11/2016 16:00	1.553	100	5
2017	10/12/2017 11:15	1.753	100	4
2018	29/09/2019 00:15	1.407	100	6
2019	28/02/2020 20:15	1.870	100	2
2020	23/12/2020 18:15	2.506	32	1

Table 4-2: Dinas Powys level POT series

Date / time	Stage (m)
28/10/2013 06:15	1.860
22/02/2015 18:15	1.142
04/01/2016 19:30	1.014
22/01/2016 10:15	1.009
09/03/2016 04:30	1.157
20/11/2016 03:45	1.099
21/11/2016 16:00	1.553
10/12/2017 11:15	1.753
21/01/2018 17:15	1.232
10/03/2018 03:30	1.322
02/04/2018 02:45	1.084
07/12/2018 08:00	1.039
14/03/2019 08:30	0.990
29/09/2019 00:15	1.407
02/11/2019 17:30	1.216
14/11/2019 12:45	0.999
16/02/2020 06:30	0.981
28/02/2020 14:00	1.647
28/02/2020 20:15	1.870
10/03/2020 04:30	1.213
28/08/2020 03:00	1.088
23/12/2020 18:15	2.506

Table 4-3: Dinas Powys level frequency analysis results

Method / data	Level (m) for given AEP (%) event									
	50	20	10	5	3.33	2	1.33	1	0.5	0.1
AM inc.	1.653	2.057	2.336	2.626	2.805	3.044	3.245	3.395	3.783	4.855
AM exc.	1.553	1.791	1.916	2.023	2.080	2.148	2.199	2.233	2.313	2.477
POT inc.	1.545	1.923	2.184	2.454	2.622	2.845	3.033	3.173	3.536	4.538
POT exc.	1.402	1.617	1.730	1.827	1.878	1.939	1.985	2.017	2.089	2.237

AM inc. = LMED AMAX including December 2020 event; AM exc. = LMED AMAX excluding December 2020 event

POT inc. = LMED POT including December 2020 event; POT exc. = LMED POT excluding December 2020 event

4.3 Dinas Powys gauge – flow data analysis

4.3.1 Gauge ratings

Although level data can be useful where flow data is not available, the latter is of more value when undertaking frequency analysis and estimation of the frequency of a specific flood event. NRW has produced an interim rating for the Dinas Powys gauge, which is detailed in an Interim Rating Report[6]. This report identifies that:

- The aim of the rating review was to investigate the suitability of using a regression-based rating for derivation of flow at Dinas Powys.
- The aim of the investigation was not to create an approved stage-discharge rating, or to change the site to flow measurement. The results may, however, be used to help inform future endeavours.
- Over the period of record ten gaugings have been taken using a variety of measuring technologies. This is below the British Standard recommendation of 15 gaugings for each limb of a regression-based rating. The gaugings range from 0.135m to 0.768m stage, therefore careful consideration should be given to using the rating to derive flow outside this range.
- The rating investigation does not account for the results of any survey at site, or the availability of any cross-section data or modelled ratings already available.
- Based on the above points, and the available gaugings, a single limb regression was deemed to be the most appropriate method of flow determination. Flows are calculated by a shifted power law.

The rating equation is: $Q = 6.1384(h-0.069682)^{1.4539}$

The lower limit and upper limit are set to the lowest and highest gauging stages.

Conclusions drawn from the rating review were:

- The rating is a good fit to the data and can be considered a good model for the data within the range for which it has been derived.
- There are too few gaugings to carry out a fully suitable regression analysis to derive a new rating.
- The gaugings only cover a period of four years and will not account for any potential changes in channel or hydraulic properties outside this range.

[6] Natural Resources Wales. January 2021. Interim Rating Report. Cadoxton River at Dinas Powys.

Recommendations from the rating review were:

- The new rating should **not** be used for flow calculation at this time. However, it could be used to inform a high flow model, or other high flow investigations.
- Further gaugings are required to meet the minimum number of 15 gaugings to carry out a full regression analysis.
- A full assessment of the site is required to determine if it is appropriate to use as a flow site. If it is, endeavours should be made to:
    - Continue to gauge throughout the operating stage range, with consideration for application of this data regarding future high / low flow use.
    - Carry out a thorough cross-section survey to help identify key components, including the cease-to-flow stage and potential change points.

NRW commissioned JBA Consulting to develop a modelled rating for the Dinas Powys gauge site using the existing NRW hydraulic model of Cadoxton River. This assessed the sensitivity of the modelled rating to various parameters including roughness coefficient, culvert parameterisation in the model, and culvert blockage. Using a hydraulic model in this way is a common approach to validating and improving confidence in a rating, particularly at flows higher than have previously been gauged. This rating review work has found the NRW rating to align well with the modelled stage-discharge relationship and to display little sensitivity to the model parameters. This provides additional confidence in the NRW rating to estimate flow during significant flood events.

Figure 4-1 shows the interim NRW rating, the modelled stage-discharge pairs, and the gaugings. It should be noted that the modelled stage-discharge pairs are for both the rising and falling limb of the hydrograph. The plot shows that there is a very close match between the interim NRW rating and the modelled rating up to about 2.5m stage, with a good fit to the available gaugings. The modelled rating sits slightly above the interim NRW rating above about 0.9m stage, giving a slightly lower flow for a given stage. Between around 2.6m and 2.7m there is a shift in the modelled rating and evidence of hysteresis, leading to a larger difference to the interim NRW rating. It is not clear at this stage what this hysteresis is related to. Initial investigation as part of the rating review study has indicated that it does not appear to be due to downstream bridges. However, by around 3.1m to 3.2m, the modelled rating appears to converge with the interim NRW rating again.

The difference between the derived flows for the 23rd December 2020 event from both ratings is about 4%, with the flow from the interim NRW rating being larger than that from the modelled rating. This gives confidence that the interim NRW rating is reasonable and can be used, with caution, to derive indicative flows for the purposes of frequency analysis for the current study, bearing in mind the limitations of rating verification due to the small number and low stage range of the gaugings. It should also be noted that the rating review study is ongoing and that results may change, although this is unlikely to significantly change those used in this analysis.

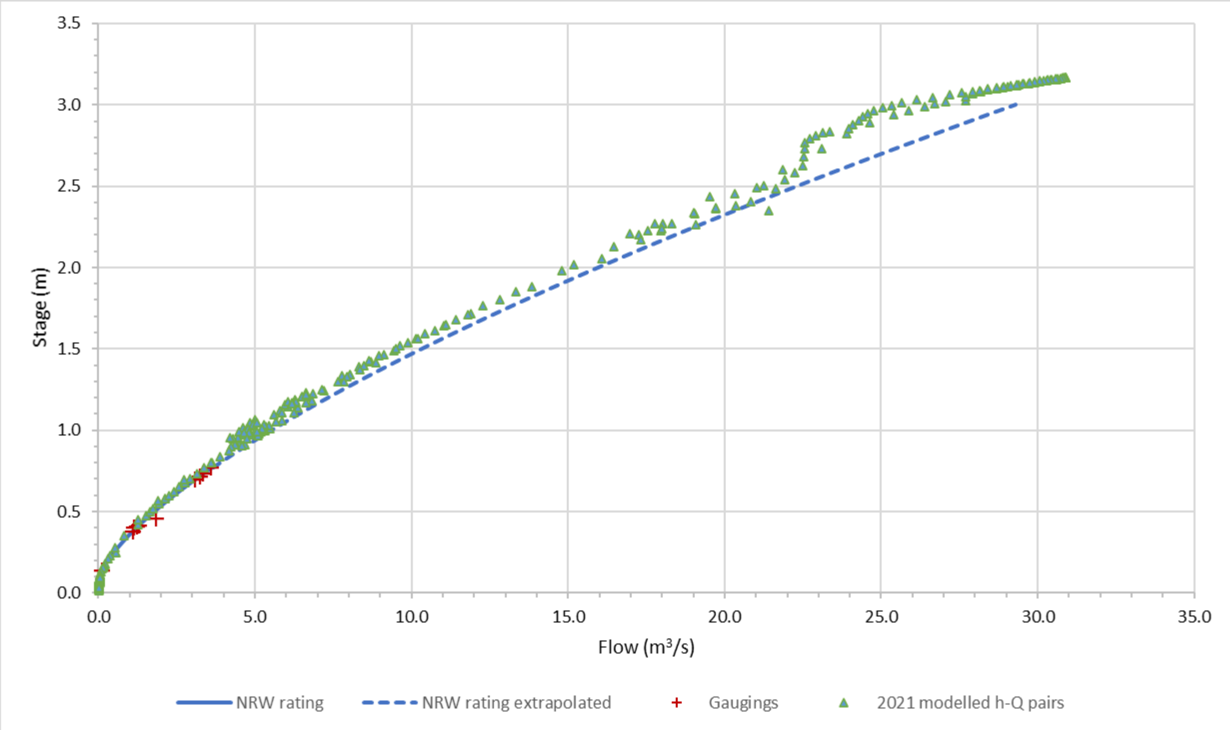

Figure 4-1: Dinas Powys NRW interim & modelled ratings

4.3.2 Flow frequency analysis

Several approaches for estimation of QMED and the growth curve were used to generate flow estimates at Dinas Powys for a range of design events. It should be noted that the 15-minute stage series was not converted to flow for this analysis, instead the interim NRW rating was only applied to the stage AMAX series and the peak level events used to derive the POT estimate. The QMED estimates ($QMED_{AM}$ and $QMED_{POT}$) were derived from this data with the December 2020 event included and excluded. A climatic variation adjustment was considered, and the calculations carried out using the POT data and station 57009 Ely at St Fagans as a donor. The FEH states that:

- Ideally a donor site should show strong correlation; a donor site should not be used if negative correlation occurs.
- If no suitable donor can be found, then no adjustment is made to QMED.

In this case there are only six years of overlapping record for the two gauges (with the St Fagans data taken from the National River Flow Archive (NRFA)). A negative correlation was found between the gauges and the decision was made not to apply a climatic adjustment.

In addition to estimating QMED from the gauge data, it was also estimated from catchment descriptors ($QMED_{CD}$), using the QMED regression equation, for comparison. Donor stations were considered for adjusting the $QMED_{CD}$ estimate, however the closest donors led to little change in the estimate.

Single-site analysis and pooled analysis were undertaken to derive growth curves, both using the GL distribution. The default pooling group from the WINFAP-FEH v4 software was briefly reviewed; no changes were made. NRFA peak flows dataset v9 was used in the analysis. Design peak flow estimates were also derived using the ReFH2 method for comparison; these were generated using catchment descriptors only.

The results from all approaches applied are detailed in Table 4-4. As noted for the level data results, red text indicates results in which there is less confidence from the single-site analysis, yellow highlighting shows the design events between which the December 2020 event falls (22.4m^3/s) and blue highlighting shows the design events between which the February 2020 event falls (14.4m^3/s).

Single-site analysis results excluding the December 2020 event were not considered further as they generated an event AEP estimate of <0.1% (>1,000yr return period, which is not realistic. There is a consistent frequency estimate from the results using the Dinas Powys gauge data of 10% - 3.33% AEP (10yr -30yr return period) for the December 2020 event, with most estimates being between 10% and 5% AEP. For the February 2020 event the frequency estimate is 50% - 10% AEP (2yr – 10yr return period), with most estimates being between 50% and 20% AEP. Although there is some uncertainty regarding the rating, and the record length is short, the estimates are consistent with the level data results and the single-site estimates are consistent with the pooled analysis results. This gives more confidence that the event frequency estimates are reasonable.

The results generated from the $QMED_{CD}$ estimate and the ReFH2 method suggest that the December and February 2020 events are much rarer than indicated by the results using QMED derived from the Dinas Powys gauge data. The 50% AEP event (QMED) estimate is much larger from the gauge data than from catchment descriptors or ReFH2. The same pooled growth curve is applied to the $QMED_{CD}$ estimate as is applied to the $QMED_{AM}$ and $QMED_{POT}$ estimates, and the ReFH2 growth curve is similar to the single-site curve. Therefore, it is the estimate of the QMED / 50% AEP event that is creating the differences between the approaches.

Although the gauge record is short, it is expected that a reasonable estimate of LMED will be generated by the data. The modelled rating generates QMED estimates that are slightly smaller than those from the interim NRW rating, however these are still much larger than from catchment descriptors and the 50% AEP event estimate from the ReFH2 method. It would therefore appear that catchment descriptor estimates substantially underestimate the 50% AEP event flow.

Results from the hydrological assessment completed in November 2015 to provide inflows for the existing NRW hydraulic model, are also provided in Table 4-4 for reference. These are for a location (CADX03) which is about 200m-250m downstream of the gauge; flows will be comparable between the locations for this purpose. The design peak flow estimates were derived using ReFH1. A factor of 1.23 was applied to these flows as part of the 2015 study, following consultation with NRW, to generate more realistic predictions of flooding in Dinas Powys. The flows for CADX03 in the table have the factor applied to give the final values used to derive the model inflows. The 50% AEP event estimate for CADX03 falls between the $QMED_{CD}$ and ReFH2 estimates, and the estimates from the gauge data. The growth curve for CADX03 is shallower than the pooled, single-site and ReFH2 growth curves, leading to frequency estimates for the December and February 2020 events which are similar to those for the $QMED_{CD}$ results.

The conclusion of this analysis is that catchment river gauge data indicates that design peak flow estimates based on catchment descriptors are likely to be too small. As the gauge record length increases there will be more confidence in the results obtained from this. This will be further strengthened if high flow gaugings can be collected to verify the gauge rating. The results in which there is currently most confidence is $QMED_{POT}$ (including the December 2020 event), and the growth curve derived from pooled analysis (shown by bold text in the table). This gives the following frequency estimates for the events:

- December 2020: **10% - 5% AEP**, potentially closer to 5% AEP.
- February 2020: **50% - 20% AEP**, potentially closer to 20% AEP.

Table 4-4: Dinas Powys flow frequency analysis results

Method / data	Flow (m^3/s) for given AEP (%) event									
	50	20	10	5	3.33	2	1.33	1	0.5	0.1
$QMED_{POT}$ inc. - P	**10.8**	**15.3**	**18.8**	**22.8**	**25.4**	**29.1**	**32.3**	**34.9**	**41.8**	**63.4**
$QMED_{POT}$ exc. - P	9.8	13.9	17.1	20.7	23.1	26.5	29.4	31.7	38.0	57.7
$QMED_{POT}$ inc. - SS	10.8	15.0	18.1	21.5	23.6	26.6	29.1	31.1	36.3	51.7
$QMED_{POT}$ exc. - SS	9.8	12.1	13.4	14.5	15.1	15.8	16.3	16.7	17.5	19.4
$QMED_{AM}$ inc. - P	12.0	17.0	20.9	25.3	28.2	32.3	35.9	38.7	46.3	70.3
$QMED_{AM}$ exc. - P	10.9	15.4	19.0	23.0	25.6	29.3	32.6	35.1	42.1	63.9
$QMED_{AM}$ inc. - SS	12.0	16.6	20.1	23.8	26.2	29.5	32.3	34.5	40.2	57.3
$QMED_{AM}$ exc. - SS	10.9	13.4	14.8	16.0	16.7	17.5	18.1	18.5	19.4	21.5
$QMED_{CD}$ - P	6.3	8.9	10.9	13.2	14.8	16.9	18.8	20.2	24.2	36.8
ReFH2	5.3	7.0	8.3	9.8	10.8	12.1	13.4	14.4	17.4	26.6
CADX03	8.3	11.0	13.0	N/A	16.4	18.3	20.0	21.4	25.1	37.8

$QMED_{POT}$ = QMED from POT data; $QMED_{AM}$ = QMED from AMAX data; $QMED_{CD}$ = QMED from catchment descriptors

SS = single-site analysis; P = pooled analysis

Inc. = including the December 2020 event; Exc. = excluding the December 2020 event

4.4 Sully Moors Road gauge – level data analysis

The Sully Moors Road level gauge record is longer than that for the Dinas Powys gauge, starting on 30th August 2007, giving 13 complete water years of record. However, some of these water years have missing data throughout the year. AMAX event dates were compared to those for the Ely at St Fagans gauge. Where dates were different, but no data was missing at Sully Moors Road for the AMAX date at St Fagans, it was assumed that the peak level event is captured at Sully Moors Road and that differences between the gauges are due to localised rainfall events. Water year 2020 is only 30% complete, however, it is thought likely that the December 2020 event will remain the largest event for this water year.

AMAX and POT series were derived from the 15-minute data. Table 4-5 shows the AMAX series for Sully Moors Road along with the percentage complete for each water year and the rank of each AMAX event within the series. In the date / time column blue text indicates a winter event and green text indicates a summer event. Peak levels predominantly occur in the winter. About 30% of the AMAX peak level events occur in the summer but the largest events tend to occur in the winter. The POT series is provided in Table 4-6; a threshold of 1.2m was applied to derive the series.

Table 4-5 shows that the 23rd December 2020 event is AMAX1. Data at the peak of the 28th February 2020 event is missing therefore the AMAX event for water year 2019 is given as 10th March 2020. Note: The percentage data available for water year 2019 is shown at 100% in the table, this is due to only a small amount of data missing around 28th February, given to one decimal place the percentage complete value is 99.5%.

Table 4-5: Sully Moors Road level AMAX series

Water year	Date / Time	Stage (m)	% available	Rank
2006	24/09/2007 06:00	0.435	9%	15
2007	06/09/2008 06:45	1.647	100%	6
2008	07/06/2009 08:00	1.258	100%	13
2009	27/11/2009 15:45	1.295	100%	12
2010	14/01/2011 04:00	1.208	100%	14
2011	01/05/2012 15:15	1.571	100%	7
2012	23/12/2012 06:00	1.936	100%	2
2013	28/10/2013 19:30	1.500	70%	8
2014	22/02/2015 23:15	1.445	92%	9
2015	05/01/2016 00:45	1.367	100%	10
2016	22/11/2016 01:15	1.809	100%	3
2017	02/04/2018 09:45	1.699	93%	5
2018	07/12/2018 20:30	1.365	100%	11
2019	10/03/2020 09:00	1.790	100%	4
2020	24/12/2020 05:45	2.218	32%	1

Table 4-6: Sully Moors Road level POT series

Date / Time	Stage (m)
08/12/2007 19:15	1.324
15/01/2008 21:15	1.297
06/09/2008 06:45	1.647
07/06/2009 08:00	1.258
27/11/2009 15:45	1.295
14/01/2011 04:00	1.208
01/05/2012 15:15	1.571
03/05/2012 08:15	1.228
21/11/2012 17:00	1.238
25/11/2012 06:00	1.709
20/12/2012 13:15	1.460
23/12/2012 06:00	1.936
27/01/2013 08:15	1.518
30/01/2013 10:00	1.636
28/10/2013 19:30	1.500
05/11/2013 09:45	1.255
18/01/2014 22:00	1.262
22/02/2015 23:15	1.445
05/01/2016 00:45	1.367
10/01/2016 20:30	1.214
09/02/2016 08:45	1.364

09/03/2016 08:45	1.220
22/11/2016 01:15	1.809
10/12/2017 17:15	1.469
21/01/2018 23:00	1.657
10/03/2018 09:15	1.410
02/04/2018 09:45	1.699
07/12/2018 20:30	1.365
29/09/2019 09:30	1.349
11/10/2019 19:00	1.222
03/11/2019 01:00	1.396
14/11/2019 21:30	1.210
10/03/2020 09:00	1.790
13/12/2020 19:45	1.235
22/12/2020 08:15	1.342
24/12/2020 10:15	2.218
27/12/2020 12:30	1.221
20/01/2021 13:15	1.235

From these flood peak series an estimate of LMED was made. This was carried out using both the AMAX and the POT series', and with the 23rd December 2020 event included and excluded, as a sensitivity test to determine the impact of the event on the results. Due to the relatively short record length for the gauge and the size of the December 2020 event compared to the others in the record, use of the different methods and inclusion / exclusion of December 2020 has a significant impact on the results.

A single-site analysis was undertaken to provide level estimates for a range of design events, using the GL distribution. There is limited confidence in the results due to the short record. Note: The analysis can only be carried out using the AMAX series, although the POT LMED value can be substituted and the growth curve from the AMAX data applied to these estimates. The results are shown in Table 4-7; red text indicates the results in which there is less confidence due to the record length. Yellow highlighting shows the design events between which the December 2020 event falls (2.218m).

Excluding the December 2020 event from the analysis gives results which suggest that the event has an AEP between 1.33% and 1% (75yr-100yr return period). Although this is not entirely unrealistic, it is thought more appropriate to use the results which include the December 2020 event in the analysis. This gives an AEP of between 20% and 3.33% (20yr to 30yr return period), which seems more realistic and is consistent with the Dinas Powys gauge results. Single-site results excluding the December 2020 event were not considered further.

Table 4-7: Sully Moors Road level frequency analysis results

Method / data	Level (m) for given AEP (%) event									
	50	20	10	5	3.33	2	1.33	1	0.5	0.1
AM inc.	1.536	1.786	1.963	2.149	2.265	2.422	2.556	2.656	2.918	3.657
AM exc.	1.500	1.700	1.828	1.955	2.030	2.127	2.207	2.265	2.410	2.781
POT inc.	1.528	1.777	1.953	2.138	2.254	2.410	2.543	2.643	2.903	3.639
POT exc.	1.503	1.704	1.832	1.959	2.035	2.132	2.212	2.270	2.415	2.787

AM inc. = LMED AMAX including December 2020 event; AM exc. = LMED AMAX excluding December 2020 event

POT inc. = LMED POT including December 2020 event; POT exc. = LMED POT excluding December 2020 event

4.5 Sully Moors Road gauge – flow data analysis

4.6 Gauge ratings

The Interim Rating Report[7] for the Sully Moors Road gauge contains similar conclusions and recommendations to the Dinas Powys report. A rating with two limbs was derived for the Sully Moors Road gauge. There are 80 gaugings available from 5th March 2001 to 14th March 2019, with a stage range of 0.198m to 1.102m. There is a large amount of scatter in the gaugings, which is noted to be common for sites with no formal control section and which do not undergo the rigorous maintenance schedule of a formal flow measuring site. It is stated that a more stringent review of the available gaugings may help to reduce the scatter, and consideration could be given to further change points.

As part of the NRW commission to develop a modelled rating for the Dinas Powys level gauge, a request was also made to consider development of a modelled rating for the Sully Moors Road level gauge. The stage-discharge pairs were extracted from the existing hydraulic model and plotted. This showed significant hysteresis (different flow for the same level on the rising and falling limb). The hysteresis is likely to be caused by the gradual ponding of floodwater across the Sully Moors area which, in turn, affects the stage-discharge relationship. The stage recorded at the gauge effectively becomes a function of the flood volume and not the instantaneous flow. This is further complicated by the tidal influence at the outfall of Cadoxton River, which causes flows and levels to backup, as visible in the gauge record.

Due to these factors, it is not possible to obtain a unique relationship between stage and flow at this site during high flows, as evidenced by the model results and the scatter in the gaugings. As such, no further work was undertaken to derive a rating for the Sully Moors Road gauge, and it was decided that it would not be appropriate to use the interim NRW rating for use in frequency analysis.

4.7 Rainfall frequency

The frequency of the storm events for 23rd December and 28th February 2020 can be assessed using information on the rainfall depth and duration, and the depth-duration-frequency model provided on the FEH Web Service. It should be noted that rainfall rarity is often not the same as flood rarity. The inference of flood rarity from rainfall data is seldom accurate, as treating rainfall rarity as a measure of flood rarity neglects the complex scenarios leading to flood formation. The assessment may overestimate flood rarity, especially when applied to mixed geology or mixed land use catchments. On typically impermeable catchments, which are heavily urbanised or steep, or a combination of both, it may be possible to infer something more useful about flood rarity from rainfall data. This is because any heavy rainfall event produces a flood and because other processes (such as

[7] Natural Resources Wales. January 2021. Interim Rating Report. Cadoxton River at Sully Moors Road.

snowmelt and groundwater) are too slow to be relevant. However, assessing the rainfall rarity may provide further understanding of the severity of the event and the potential of the catchment to respond.

Table 4-8 and Table 4-9 provide frequency estimates for the periods previously detailed in Table 3-1 and Table 3-3. The frequency is provided in both AEP and return period for ease of reference and interpretation.

The 23rd December 2020 storm event frequency estimates in Table 4-8 show that Cog Moors STW TBR indicates a frequency of about 5% AEP (20yr return period). However, the other raingauges suggest a frequency of about 70%-20% AEP (1.5yr-5.0yr return period). As discussed previously, NRW has confirmed that the Cog Moors STW TBR data is good and there is no reason to suspect that the rainfall totals were overestimated. This might suggest that there was a localised storm over the Cog Moors areas. Detailed rainfall radar data was not assessed for this study, but rainfall radar images available from the Internet do not suggest that this was the case. It is therefore unclear why the Cog Moors STW TBR rainfall totals and frequency estimates differ so substantially to the other raingauges.

Table 4-8: Rainfall frequency estimates - December 2020 event

Raingauge	Period	AEP (%)	Return period (yr)
Cog Moors STW TBR	23/12/2020 12:45 - 23/12/2020 18:00	5	22
	23/12/2020 09:00 - 23/12/2020 18:45	4	23
Coldbrook Weather Station	23/12/2020 12:30 - 23/12/2020 17:45	35	2.9
	23/12/2020 08:45 - 23/12/2020 18:30	30	3.3
St Fagans TBR	23/12/2020 11:30 - 23/12/2020 17:30	36	2.8
	23/12/2020 09:00 - 23/12/2020 18:45	18	5.6
Rhiwbina Reservoir TBR	23/12/2020 11:30 - 23/12/2020 17:30	62	1.6
	23/12/2020 09:15 - 23/12/2020 19:00	27	3.8
Rhiwsaeson STW TBR	23/12/2020 11:00 - 23/12/2020 18:00	68	1.5
	23/12/2020 09:15 - 23/12/2020 19:15	51	2.0
Llantwit Major TBR	23/12/2020 09:45 - 23/12/2020 18:15	40	2.5
Cowbridge TBR	23/12/2020 11:15 - 23/12/2020 18:00	48	2.1
	23/12/2020 09:15 - 23/12/2020 18:30	36	2.8

The frequency estimate for the 28th February 2020 event is more consistent across the raingauges, with the largest estimate having an AEP of around 6% (about 15yr return period). However, the estimates for the raingauges within the Cadoxton River catchment (Cog Moors STW TBR and Coldbrook Weather Station) suggest that the event had an AEP of about 20%-15% (about 5yr-7yr return period). Estimates for the individual bursts of rainfall have an AEP which is somewhat more frequent than this, little over 1yr return period in some cases.

Table 4-9: Rainfall frequency estimates - February 2020 event

Raingauge	Period	AEP (%)	Return period (yr)
Cog Moors STW TBR	28/02/2020 05:45 - 28/02/2020 13:00	59	1.7
	28/02/2020 05:45 - 29/02/2020 06:00	14	7.1
Coldbrook Weather Station	28/02/2020 05:30 - 28/02/2020 13:00	75	1.3
	28/02/2020 05:30 - 29/02/2020 05:45	22	4.5
St Fagans TBR	28/02/2020 05:15 - 28/02/2020 13:15	67	1.5
	28/02/2020 05:15 - 29/02/2020 06:00	6	17
Rhiwbina Reservoir TBR	28/02/2020 06:00 - 28/02/2020 14:15	72	1.4
	28/02/2020 06:00 - 29/02/2020 06:00	6	16
Rhiwsaeson STW TBR	28/02/2020 06:00 - 28/02/2020 13:30	68	1.5
	28/02/2020 06:00 - 29/02/2020 06:00	11	9.5
Llantwit Major TBR	28/02/2020 05:15 - 28/02/2020 12:45	61	1.6
	28/02/2020 05:15 - 29/02/2020 05:45	33	3.0
Cowbridge TBR	28/02/2020 05:15 - 28/02/2020 13:00	41	2.4
	28/02/2020 05:15 - 29/02/2020 05:45	10	9.9

The rainfall rarity generally suggests that these were frequent rainfall events. When catchments are saturated prior to rainfall events it may be expected that the flood rarity will be more severe than the rainfall rarity, i.e. a small rainfall event can lead to significant runoff as there is little or no infiltration to the ground. However, in this case, the Cog Moors STW TBR suggests that the rainfall rarity is similar to the flood rarity for both events. The other raingauges indicate a more frequent event than that estimated from the flood frequency analysis for the December 2020 event, but for the February 2020 event the rainfall and flood rarity is similar.

5 Summary & conclusions

VoGC commissioned JBA Consulting to compile an account and analysis of the Cadoxton River catchment meteorological and hydrological data for flood events which occurred in Dinas Powys on 23rd December 2020 and 28th February 2020. Key points from the assessment are:

- Although the total rainfall depth recorded at Cog Moors STW TBR was similar for both events – 57.2mm for 23rd December and 56.0mm for 28th February – the December 2020 event led to extensive flooding resulting in internal flooding of many properties in Dinas Powys, whereas it is believed that no internal property flooding occurred during the February 2020 event.
- The catchment was saturated prior to both events (SMD=0).
- The main difference between the events is that the rainfall for December 2020 occurred over a much shorter time (9.75hr) than for February 2020 (24.25hr). In addition to this, 47.8mm of the December 2020 event total fell within a 5.25hr period, giving a maximum hourly intensity of 14.4mm/hr. This is likely to have led to surface water sewer drainage issues, with the volume of water received over a short period causing surcharging of the sewers, combined with high water levels in the river. In contrast, the rainfall for the February 2020 event was in three separate bursts, leading to three distinct peaks in the river level, with a maximum hourly intensity of 7.4mm/hr (during the first burst). The longer duration over which the rain fell would have enabled the channel and sewers to better cope with the volume of water.
- The base level in Cadoxton River prior to the 23rd December 2020 event was about 0.1m higher at the Dinas Powys river gauge than it was prior to the 28th February 2020 event.
- During the 23rd December event the river level rose by over 2m in 6hr, with the lag between the rainfall centroid and the peak level being just over 3hr. The first hydrograph peak at the Dinas Powys gauge for the 28th February event occurred just over 8hr after the rainfall commenced, rising by about 1.5m in this time. The second hydrograph peak was the largest, but there was only a rise of just under 0.4m in 5.5hr after the second burst of rainfall commenced, with the river level dropping somewhat between rainfall bursts.
- In summary, the December 2020 flood event was the result of a short and intense rainfall event whereas the February 2020 flood event was the response to a prolonged and low intensity series of rainfall events.
- Frequency analysis undertaken on the Dinas Powys level gauge data, and flow data derived using an as yet unverified rating at high flows, indicates that the 23rd December 2020 event has an estimated AEP of 10%-5% (10yr-20yr return period), with the 5% AEP estimate thought to be more likely. The 28th February 2020 event has an estimated AEP of 50%-20% (2yr-5yr return period), with the 20% AEP estimate thought to be more likely. There is substantial uncertainty in these estimates due to the short gauge record length and the unverified rating, but confidence is increased by the different approaches used generating similar frequency estimates for the events. Analysis of the Sully Moors Road level gauge data also generated similar frequency estimates for the December 2020 event.
- A 5% AEP event estimate for the December 2020 event might be considered too frequent, given the impact of the flooding, however the best available data has been used to generate these estimates. Until further data or information becomes available these will remain the best estimates of the event frequency.

- Design peak flow estimates generated using methods based on catchment descriptors are substantially smaller than those derived using the catchment gauge data. These give an AEP for the December 2020 event of between 1% and 0.1% (100yr-1,000yr return period), and an AEP of 5%-1% (20yr-100yr return period) for the February 2020 event. It therefore appears that the catchment descriptor results are likely to be underestimated, keeping in mind the caveats on the gauge data.
- It is recommended that the frequency estimates are revisited:
  - As the gauge record length increases.
  - When any further large events occur.
  - When high flow spot gaugings have been collected and used to verify / amend the Dinas Powys rating.

Table 5-1 summarises the key information for the two events. River gauge information is only provided for the Dinas Powys gauge as this is at the key site of interest. Rainfall information is for the Cog Moors STW TBR as this is the most representative raingauge for the catchment and is maintained and calibrated by NRW.

Table 5-1: Key information for December & February 2020 flood events

Parameter	23rd December 2020	28th February 2020
Max. value & date of max.	23/12/2020 18:15 – 2.506m / 22.4m^3/s	28/02/2020 20:15 – 1.870m / 14.4m^3/s
Pre-event level	0.32m	0.20m
Total rainfall depth	57.2mm	56.0mm
Total rainfall duration	9.75hr	24.25hr
Max. rainfall intensity	14.4mm/hr	7.4mm/hr
Event frequency best estimate	10%-5% AEP (10yr-20yr return period)	50%-20% AEP (2yr-5yr return period)

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