Environment Agency

Mytholmroyd flood investigation

Independent review into the flood event of 8/9 February 2020

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Glossary

Bulk bag	A large bulk storage bag often made of lightweight flexible polypropylene canvas and filled with granular material. Bulk bags are used to provide basic temporary flood protection.
Catchment	An area which drains water to a river.
Contractor	VBA (VolkerStevin, Boskalis Westminster and SNC-Lavalin's Atkins) was the appointed contractor commissioned to deliver the design and construction of the Mytholmroyd Flood Alleviation Scheme. Also see "design and construction contractor".
Datum	A fixed starting point on a scale or gauge.
Design and construction contractor	Responsible for the design and construction of a project. Often shortened in this case to "contractor".
Downstream	Looking in the natural river flow direction.
Flap valve	Hinged flaps at the end of pipes. They are used to allow culverts and pipes to discharge water into rivers, but when the river has a high water level they are closed to prevent river water travelling back up the pipe.
Flash flood	Sudden localised flooding as a result of heavy rainfall.
Flood event	A real life flood incident; or A theoretical flood event commonly described as a probability of occurrence.
Flood Warden	Flood Wardens are volunteers who undertake a variety of roles which may include raising awareness of flood risk, helping to communicate flood warnings, helping to prepare for flooding and helping during and after a flood incident.
Flood warning	The Environment Agency offer a flood warning service. This provides alerts via phone, email or text to tell you when flooding is expected. There are three levels of warnings:

	Flood alert – prepare Flood warning – act Severe flood warning - survive
Freeboard	The height of a flood defence is the modelled water level plus an allowance for freeboard. The freeboard allowance accounts for uncertainties. The term freeboard can also be used to describe the difference between defence height and flood level.
Gauge	In this context, an instrument that measures and gives a display of river level, depth, velocity or flow.
Hydraulic model	A hydraulic model uses mathematical equations to approximate the flow of water. A representation of the study area is generated using topographical information (for example, ground elevations, building locations, and land classifications such as fields, roads and gardens) together with hydrology data (such as river flows, both calculated and measured, and rainfall data). The mathematical equations are typically built into industry-standard software. The software then calculates flood extents/areas, water depth, water velocity and direction of flows.
Hydrology	The science of water and the movement of water on land.
IBS K-System barrier	A temporary flood barrier system.
Left bank	The bank on the left hand side of a river when looking in a downstream direction.
LiDAR	A method for measuring distance and a common method of surveying topography.
MFAS	Mytholmroyd Flood Alleviation Scheme.
Proprietary	Owned and legally controlled by a particular company
RAMS	Risk Assessment and Method Statement.
Return period	The frequency of a given flood event.

Right bank	The bank on the right hand side of a river when looking in a downstream direction.
SiteEye	A time lapse camera system used to record the progress of construction works.
Soffit	Top of the underside of a bridge.
Standard of protection (SoP)	The level of flood protection provided up to a given flood event.
Temporary works	Construction works which are required to enable permanent works to be built.
Topography	The arrangement of the natural and artificial features of land/area.
Topographical survey	A survey which captures key topographical features (such as roads, footpaths, buildings) to create a detailed map of an area with height information.
Upstream	The opposite of the natural flow direction in a river.
Wrack mark	Water level marks or indicators identified after a flood.

Acronyms

AOD	Above Ordnance Datum
CMBC	Calderdale Metropolitan Borough Council
DTM	Digital Terrain Model
FAS	Flood Alleviation Scheme
LiDAR	Light Detection and Ranging
LTA	Long-Term Average
SoP	Standard of Protection
VBA	A joint venture comprising VolkerStevin, Boskalis Westminster and SNC-Lavalin's Atkins commissioned to deliver the design and construction of the Mytholmroyd Flood Alleviation Scheme

Executive Summary

Arup have been commissioned to investigate the 9 February 2020 flood event in Mytholmroyd. This report sets out the findings of that investigation. The report sets out the situation as Storm Ciara arrived and describes how the flood on 9 February 2020 progressed and ultimately flooded homes and businesses in Mytholmroyd.

Historical rainfall data records that February 2020 was the wettest on record in the Calder catchment where Mytholmroyd is located.

When Storm Ciara arrived, the construction of the Mytholmroyd Flood Alleviation Scheme (MFAS) was partially completed and areas where the previous defences had been removed were replaced by temporary defences. MFAS is designed to better protect up to a flood event with a 2% (or 1 in 50) chance of occurrence in any one year. The Contractor had to provide a temporary flood defence level equal to that of the pre-MFAS level.

Analysing data from river gauges shows this event had a magnitude equivalent to at least a 1.33% (1 in 75) chance of occurrence in any one year. This means that the flood event on the 9 February 2020 exceeded the design criteria of MFAS.

As MFAS was under construction, temporary flood defences were provided in a number of locations where existing flood walls had been removed to allow construction of new defences. The type and locations of the temporary defences were:

- IBS K-System barriers and bulk bags opposite Burnley Road Academy;
- Bulk bags opposite Longfellow Court; and
- Bulk bags on the right bank of the River Calder at Calder Grove.

There were additional temporary defences at Elphaborough Close deployed by the Flood Wardens.

Photographs and videos from the Contractor and the local community were examined. Detailed river modelling was undertaken to assess the performance of the flood defences, in particular to understand the timing of the flooding and any impact the temporary defences had on the flooding to Mytholmroyd.

Our findings are:

- The storm was a significant event, second only to the flooding experienced in Mytholmroyd during Boxing Day 2015.
- Flood alerts and warnings (primary system) were issued, although the siren (secondary system) was not sounded when the flood warning was issued. Subsequent power failure caused by the flooding meant that the siren could not be sounded.
- The flood event exceeded the MFAS design criteria.
- The main cause was flooding from the River Calder.

- River water flowed under and between the temporary flood defences resulting in flooding occurring one to two hours earlier than might have been anticipated.
- Had the temporary flood defences been effective, the overall extent and depth of flooding would still have been very similar to that actually experienced on 9 February 2020.
- Had MFAS been completed it is highly probable that there would have been only limited overtopping of the defences.
- Had MFAS been completed it is highly probable there would have been residual flooding from surface water and/or Cragg Brook further upstream around Cragg Road.

1 Introduction

1.1.1 In February 2020 the Mytholmroyd Flood Alleviation Scheme (MFAS) was under construction. MFAS was designed and constructed by VBA (the Contractor).

1.1.2 On Sunday 9 February 2020 Storm Ciara brought heavy rain and Mytholmroyd experienced devastating flooding. As MFAS was under construction, there was a combination of fully constructed new flood defences and partially completed new defences. In addition, there were areas where construction of new defences had not started and the existing defences were still in place.

1.1.3 This report sets out the situation as Storm Ciara arrived and describes how the flood on 9 February 2020 progressed and ultimately flooded homes and businesses in Mytholmroyd.

1.1.4 This report summarises our investigation into:

- how the flooding occurred given that flood defences were in place;
- all sources of floodwater;
- the extent to which these sources contributed to the level of flooding in Mytholmroyd; and
- whether the failure of any of the flood defences influenced the flooding of properties and if this is the case, then were the flood defences adequate to cope with the high river levels experienced on 9 February 2020.

1.1.5 This report has been divided into the following sections:

- Section 1 – Introduction
- Section 2 – Background on the catchment description, an explanation of the need for temporary flood defences and the data sources used in this review.
- Section 3 – Review of measured rainfall and water level data recorded in the area.
- Section 4 – An overview of the defences active in Mytholmroyd on 9 February 2020.
- Section 5 – A timeline of the event generated from available data.
- Section 6 - A description of results from flood modelling developed to help to understand the events of 9 February 2020 and what would have been the impacts had the defences held.
- Section 7 – Conclusions of this report.

2 Background

2.1.1 Mytholmroyd, West Yorkshire, is located in the Upper Calder Valley with the River Calder flowing through in a west to east direction. Mytholmroyd is situated downstream of Todmorden and Hebden Bridge and upstream of Sowerby Bridge (see Figure 1 below).

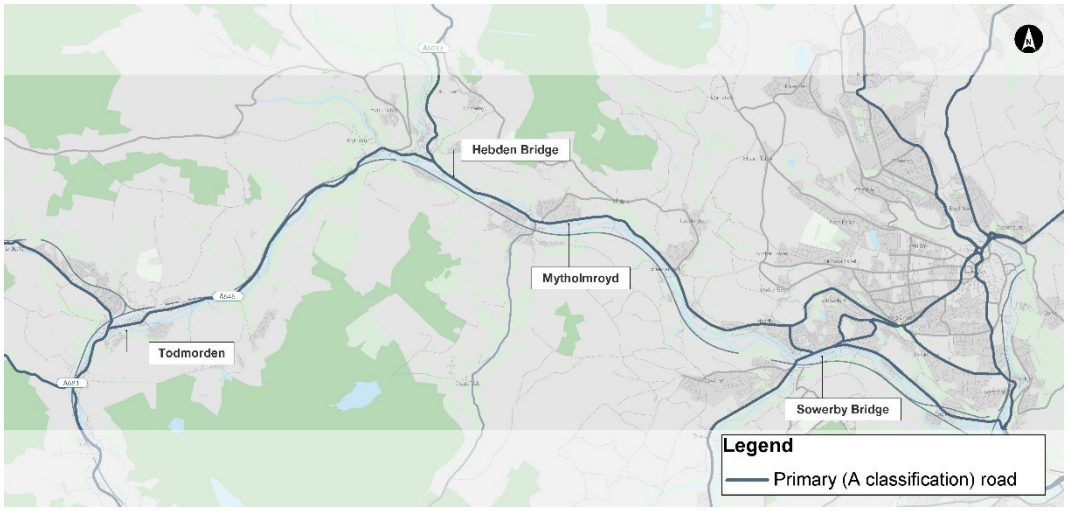


Figure 1: Map of Upper Calder Valley identifying the towns/villages of Todmorden, Hebden Bridge, Mytholmroyd and Sowerby Bridge

2.1.2 Cragg Brook, also known as Elphin Brook, flows into the River Calder in the centre of Mytholmroyd.

2.1.3 Mytholmroyd is in a steep sided valley, and the development of the village, dating from the 18th century, has constrained the river and floodplain.

2.1.4 The valley is particularly vulnerable to flash flooding, typically caused by intense downpours which turn roads, railways and hillsides into fast flowing channels for flood water. River levels also rise rapidly and can quickly spill out of the river channel. This can also combine with the drainage network which can result in significant flooding.

2.1.5 Previous significant events include those in 2008, 2012 and 2015. The Boxing Day 2015 flood resulted in approximately 300 properties and 70 businesses flooding as well as the church, church hall, two schools and the community centre. This was the most significant flood on record in Mytholmroyd.

2.2 Description of the Mytholmroyd FAS

2.2.1 Following the Boxing Day floods of 2015, the Environment Agency, in partnership with Calderdale Metropolitan Borough Council (CMBC) and the Contractor embarked upon the MFAS with design commencing in 2016 and construction starting in late 2017.

2.2.2 MFAS includes:

- new, raised and improved flood defence walls;
- the strengthening and flood proofing of structures adjacent to the river;
- the widening of the river in a number of locations; and
- the relocation of Caldene Bridge.

2.2.3 The scheme reduces the river flood risk to Mytholmroyd to a 2% or 1 in 50 chance of flooding in any one year.

2.3 Maintaining flood defences during construction of Mytholmroyd FAS

2.3.1 To construct MFAS, some of the existing flood defence walls were partially demolished to enable construction of the new flood walls on the same footprint.

2.3.2 Where existing flood defences were demolished to facilitate the construction of the new defence walls, temporary flood defences were installed to give the same level of flood protection.

2.3.3 The Contractor did this by using a proprietary temporary flood prevention system called a K-System Barrier made by IBS Technics. This is described below.

2.3.4 The Contractor also used bulk bags to plug smaller gaps in the flood defences as a temporary arrangement.

2.4 IBS K-System barrier

2.4.1 The K-System barrier is a modular flood prevention system which can be extended and adapted to suit the local topography. This is shown in Figure 2 below.

Figure 2: Typical installation of a K-Barrier System

2.4.2 The K-System barrier has a number sections that make up a barrier and rubber seals are fitted to seal the gaps between them. In addition, specific corner pieces are used to tie the barriers into areas where a straight barrier is not sufficient. The pressure of the flood water pushes down on the surface of the barrier and the seals to form a watertight barrier.

2.5 Data sources used in our investigation

2.5.1 In preparing this report, we have considered material from various sources including photographic and video evidence that the Contractor and members of the public have supplied to the Environment Agency. We have also reviewed photographs and videos published on social media.

2.5.2 Other information that we have considered includes the water levels recorded in the River Calder and surrounding rivers, and rainfall data.

2.5.3 We undertook hydraulic modelling of the River Calder and Cragg/Elphin Brook to facilitate the analysis of the flood event.

3 Measured rainfall and river level data

3.1.1 This section reviews the rainfall data from February 2020, and the subsequent change in river levels in Mytholmroyd.

3.2 Rainfall data

3.2.1 The Met Office dataset has rainfall records dating back to 1891. A review of this shows that February 2020 was the wettest February on record in the Yorkshire area.

3.2.2 The Calder catchment, in which Mytholmroyd is located, also experienced the wettest February on record. To put this into context, the Calder catchment had almost 280mm of rain in February which is over 3.5 times more than the long-term average (LTA). Table 1 provides an extract of the Met Office rainfall data for Yorkshire.

Met Office dataset commencing in 1891	February 2020 monthly rainfall total (mm)	1961-1990 LTA	February 2020 as a % of LTA	February 2020 position (since 1891)
Yorkshire area	188.1	58.6	321%	Wettest Feb
Swale catchment	191.2	59.9	319%	Wettest Feb
Ure catchment	308.5	84.6	365%	Wettest Feb
Nidd catchment	245.9	71.4	344%	Wettest Feb
Ouse catchment	113.6	38.9	292%	2nd wettest Feb
Wharfe catchment	281.1	75	375%	Wettest Feb
Esk catchment	133.7	56.5	237%	3rd wettest Feb
Rye catchment	140.1	57.2	245%	4th wettest Feb
Derwent catchment	113.2	44.7	253%	3rd wettest Feb
Aire catchment	238.1	64.8	367%	Wettest Feb
Calder catchment	279.5	74.9	373%	Wettest Feb
Don catchment	180.8	55.9	323%	Wettest Feb
Hull and Humber catchment	106.7	43.2	247%	2nd wettest Feb

Table 1: Summary of Met Office rainfall dataset since 1891 (Calder Catchment is highlighted in green)

3.3 River level data

3.3.1 The Environment Agency has a number of river gauges across the region. These provide information on the flow and/or water level within a river. Flow and level information is used to understand how a river is reacting to weather events.

3.3.2 We have used gauge data from stations in the Calder catchment at Elland, Halifax, Mytholmroyd, Hebden Bridge and Todmorden.

3.3.3 Due to the construction of MFAS, the original flow gauge in Mytholmroyd was taken out of service and a new gauge installed to measure the depth of water in the Calder.

3.3.4 The location of the temporary depth gauge is shown in Figure 3 below and noted by a blue pin symbol. The grey pin, in close proximity, is the Mytholmroyd flow gauge which was out of service in February 2020 due to the construction of MFAS.

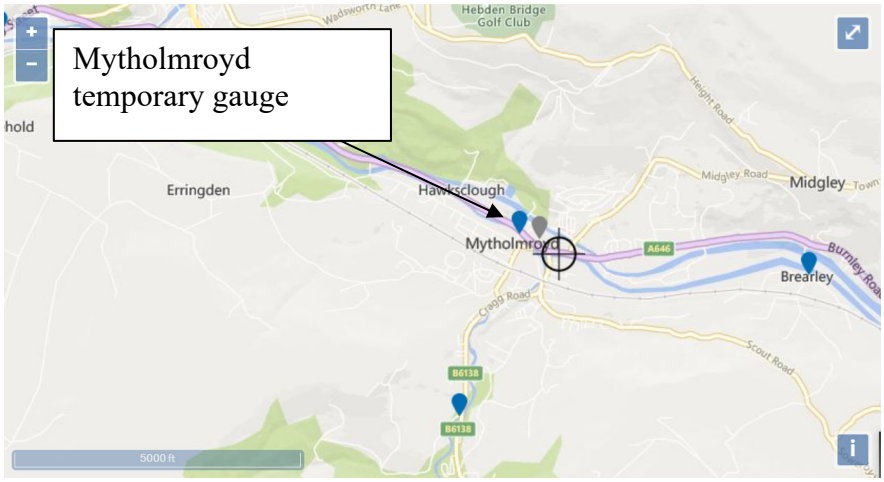


Figure 3: Location of the temporary Mytholmroyd depth gauge (from the Flood Warning Service)

3.3.5 We have reviewed the water levels in the River Calder from data from the Mytholmroyd temporary depth gauge. As can be seen below in Figure 4, on 8 February 2020, the water depth in the river was approximately 0.9m. This rose to 5.03m between midnight and 13:00 on 9 February 2020. This was an increase of 4.2m in only 13 hours.

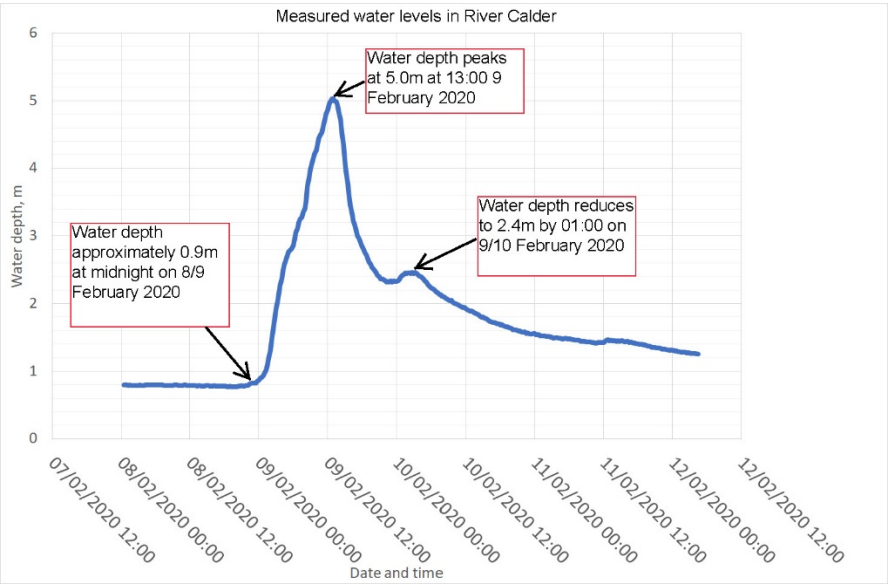


Figure 4: Time series data from Mytholmroyd temporary depth gauge

3.3.6 To place this flood event in context it was the second highest ever recorded, second only to the Boxing Day floods of 2015.

3.3.7 Analysis has shown that the 9 February 2020 event had a magnitude equivalent to a 1.33% (1 in 75) chance of occurring in any one year. This exceeds the design of the MFAS which was designed to better protect against a flood event of up to a 2% (1 in 50) chance of occurring in any one year.

4 Overview of the Flood defences in Mytholmroyd on 9 February 2020

4.1.1 This section gives an overview of the various flood defences that were in place in Mytholmroyd during Storm Ciara.

4.1.2 Permanent flood defences comprised (see Appendix A):

- Unaltered existing defences;
- MFAS defences under construction; and
- Newly completed MFAS defences.

4.1.3 Temporary defences comprised (see Appendix A and Figure 5 for locations):

- K-System barriers opposite Burnley Road Academy (Location A).
- Bulk bags opposite Longfellow Court (Location B).
- Bulk bags with polythene sheeting at Calder Grove (Location C).

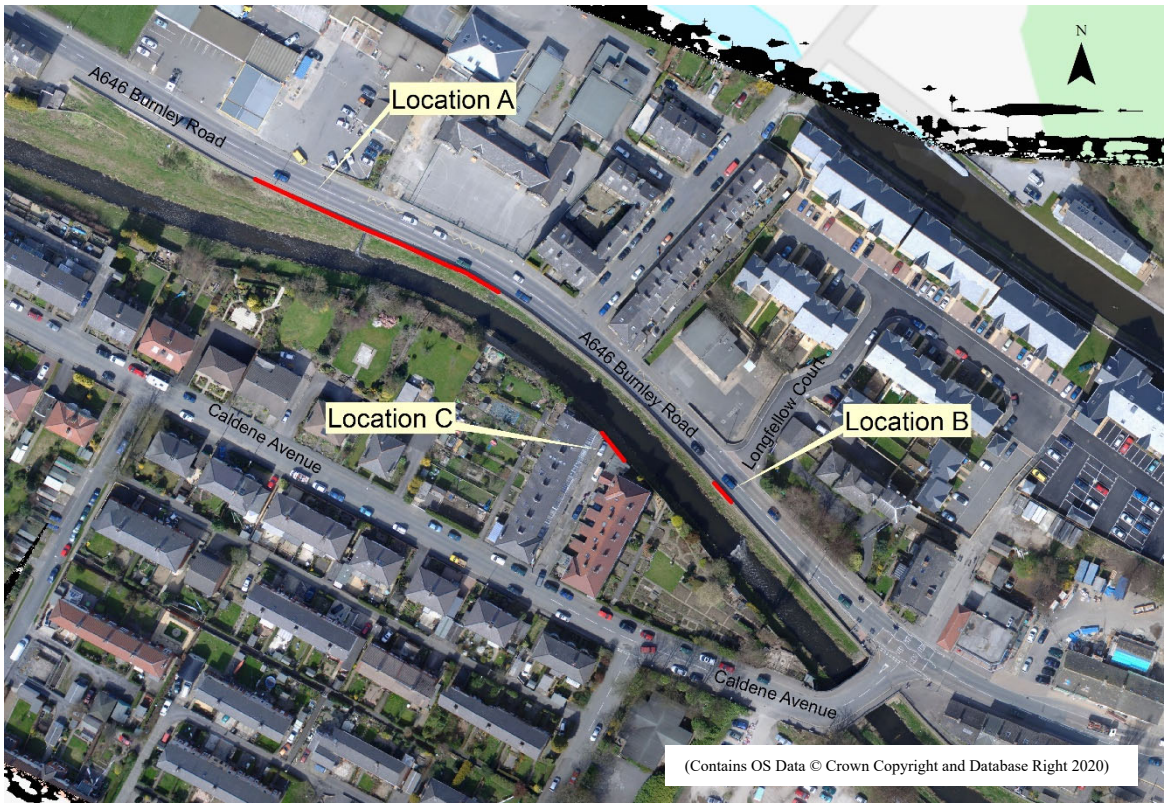


Figure 5: Location of temporary defences provided by the Contractor

4.1.4 Other defences comprised:

- Flood wardens deployed temporary defences on Elphaborough Close (Location D shown in Figure 6 below).

Figure 6: Location of temporary defences deployed by the Flood Wardens

4.2 Temporary defences provided by the Contractor

4.2.1 When Storm Ciara arrived, the construction of the MFAS was partially completed and areas where the previous defences had been removed were replaced by temporary defences.

4.2.2 The Contractor deployed different types of temporary flood defences as outlined in paragraph 4.1.3 above. These temporary defences had to provide a flood defence level equal to that of the pre-MFAS level.

4.2.3 There were three specific areas where the Contractor deployed temporary defences to fill gaps in the incomplete MFAS defences. These were opposite Burnley Road Academy; opposite Longfellow Court on Burnley Road; and on the right bank adjacent to Calder Grove. These are referred to as Locations A, B and C respectively, as shown in Figure 5.

K-System barriers opposite Burnley Road Academy (Location A)

4.2.4 This location had approximately 70m of K-System barriers placed parallel to the River Calder on Burnley Road. This is shown in Figure 7 below.

Figure 7: Photograph of K-System barrier on Burnley Road

4.2.5 Double height, filled bulk bags were placed between the K-System barriers (see Figure 8 below) and the new permanent flood defence walls. We noted that bulk bags are not one of the methods recommended by the manufacturer for joining the barriers to other features such as existing walls.

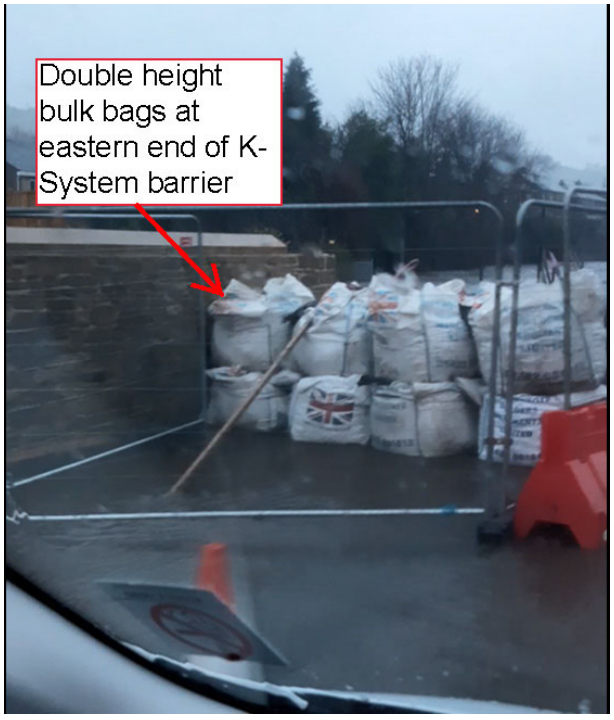


Figure 8: Bulk bags at end of K-System barriers

4.2.6 The height of the K-System barrier was 1.3m. Ground levels varied from 91.7mAOD at the downstream end to 92.3mAOD at the upstream end. This would mean that the top of the K-System barrier

was approximately 93.0mAOD at the downstream end to 93.6m at the upstream end.

4.2.7 We compared this to the pre-MFAS defences which were at a height of 93.0mAOD at the downstream end and 93.6mAOD at the upstream end.

4.2.8 Therefore, the K-System barrier height was the same as the pre-MFAS flood defences.

4.2.9 We noted that where K-System barriers were located near to an exposed edge of road surface, there is evidence of material under the road surface being washed away by the flood water which caused the road layers to crumble and allowed water to pass under the barrier. Figure 9 and Figure 13 clearly shows this.

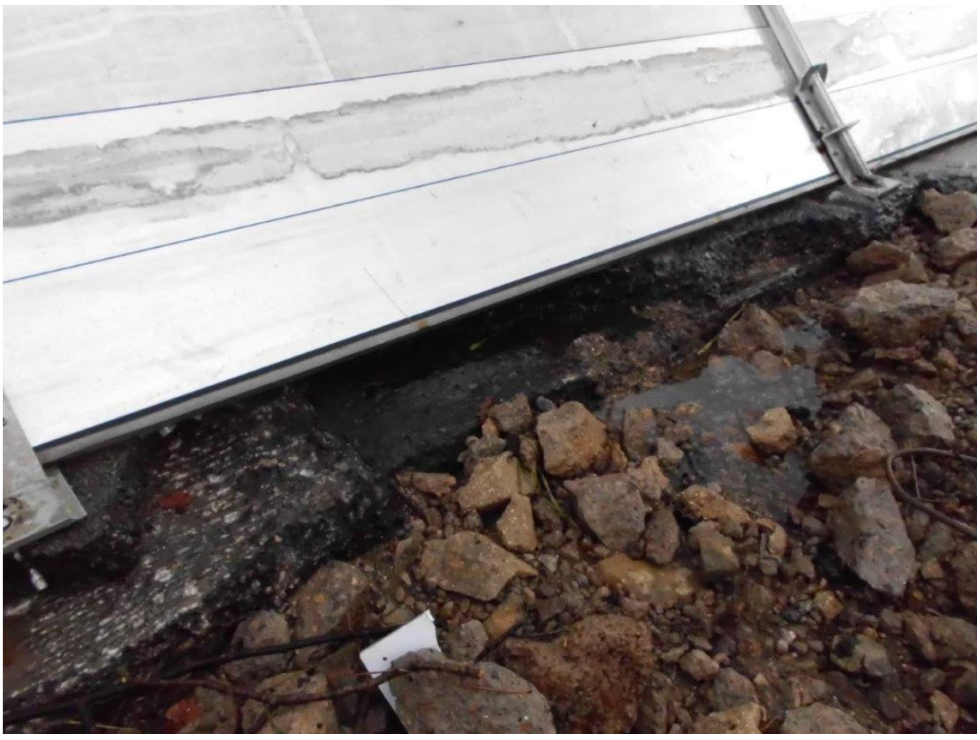


Figure 9: Photograph showing the exposed road edge and an area where the flood water has washed away tarmac and base material

4.2.10 It is not clear from the evidence whether a check on ground unevenness was undertaken, if a ground seal was used or if any sandbags were used to fill low spots.

Burnley Road opposite Longfellow Court (Location B)

4.2.11 Location B is a small gap between two sections of wall which were still under construction. The temporary defences in Location B consisted of an L-type arrangement of bulk bags as shown in Figure 10 below.

Figure 10: Image showing L-type arrangement of bulk bags

4.2.12 Bulk bags are typically 0.9m wide, by 0.9m deep by 0.9m high. We have estimated the gap as being 4m wide. It does not appear that the bags at Location B on Burnley Road (Figure 10) filled this gap sufficiently. We can also see that the bags were not filled to their full height.

4.2.13 At Location B, ground levels are approximately 91.3-91.4mAOD and the pre-MFAS flood defence was 92.7mAOD.

4.2.14 This would mean at most the top of the bulk bag would be 92.3m AOD. The bulk bags were approximately 0.4m lower than the pre-MFAS flood defence.

4.2.15 This location is close to the Mytholmroyd temporary depth gauge which recorded a peak flood level of 93.25m AOD. This shows that the flood water would have overtopped these temporary defences.

Bulk bags at Calder Grove (Location C)

4.2.16 Bulk bags were deployed as temporary flood defences at this location on the right bank of the River Calder (Caldene Avenue side) at the end of Calder Grove (see Figure 11 below). The bulk bags were covered with polythene sheeting.

Figure 11: Snapshot of video showing bulk bags with polythene sheeting

4.2.17 There is no evidence of overtopping or water coming through these bulk bags at Calder Grove.

4.3 Temporary defences provided at Location D

4.3.1 Flood Wardens deployed temporary defences at the entrance to Elphaborough Close as shown in Figure 12 below. Elphaborough Close is situated just off Cragg Road and is situated on higher ground (see Figure 6). These defences were not associated with MFAS.

Figure 12: Temporary barrier at Elphaborough Close

4.3.2 We have received no evidence to show flooding on Elphaborough Close.

5 Timeline of flood event on 8/9 February 2020 in Mytholmroyd

5.1.1 This section describes the timeline of flooding using the data sources listed in Section 2.5. Figure 13 is a map with photographs and video stills of key events.

5.1.2 Many of the photographs and videos were not time stamped, therefore it is possible some flooding happened earlier than indicated in the timeline.

	Description
8 February 2020	
20:19	Flood alert issued on Upper Calder Catchment. This notified residents who were signed up to the Flood Warning Service to be prepared.
9 February 2020	
Before 08:00	Heavy rain, roads are wet with puddles/ponding of water on Burnley Road. River levels in the River Calder are rising.
08:22	Surface water flooding on Burnley Road by the new bridge/Dusty Millar Pub.
08:34	Burnley Road is flooded from the Dusty Millar pub to the Fire Station. Flooding at Sainsbury's is approximately 10-20cm deep. River water is coming through the bulk bags at Location B.
08:54	Flood warning issued for the River Calder at Central Mytholmroyd and the River Calder at Cragg Brook in Mytholmroyd. This was to inform residents who were signed up to the Flood Warning Service that flooding was expected in Mytholmroyd. The siren (secondary warning system) was not activated at the time of the primary flood warning. Subsequent power failure caused by the flooding meant that the siren could not be sounded.
09:13	Flood water on Burnley Road just downstream of New Road bridge is 30-40cm deep. There is no overtopping of the new defences by St Michael's Church. Flap valves opposite St Michael's Church were open draining surface water into the river. It is unclear if they stayed open

	throughout the flood. If they remained open these might have contributed to the flooding by allowing river water to enter onto Burnley Road.
09:16	River water can be seen coming under the K-System barrier at Location A.
09:17	River water is flowing under the bulk bags which were deployed at either end of the K-System barrier (Location A). The water level in the River Calder is lower than the top of the temporary defences demonstrating that the temporary barriers were not effective.
10:26	Flooding on Burnley Road in front of White Houses.
10:27	Surcharging of surface water system on Burnley Road in front of White Houses.
10:33	River level is at the underside of the new bridge.
10:39	River level is at the underside of the old Caldene bridge.
10:52	Flooding on Caldene Avenue and the new bridge which could be from surface water or river flooding.
10:53	Mytholmroyd Community Centre is flooded.
11:11	The rears of White Houses are flooded.
11:14	The K-System barrier is still visible above the water level.
11:19	Flooding to Scar Bottom Cottages.
11:34	Elphaborough Close barrier which was deployed by Flood Wardens is functioning and protecting properties. This would have diverted flows down Cragg Road.
11:46	Bulk bags at Longfellow Court are still visible and above the water level.
11:49	Water levels in the River Calder are at the top of K-System barrier.
12:00	Overtopping of MFAS defences at St Michael's Church.

12:07/12:08	Old Caldene bridge is overtopped and debris is accumulating on the upstream side of the new bridge.
12:54	Cragg Brook is contained within the new defences but flooding can be seen on Streamside Fold. It is unclear if this is surface water or river flooding.
12:57	New Road is flooded and flooding at the Shoulder of Mutton Inn. Seepage is coming through the Cragg Brook defences onto New Road.
13:00	River levels peaked on the River Calder.
13:02	Area surrounding St Michael's Church is flooded.
15:02	Water from Burnley Road is flowing into the River Calder opposite St Michael's Church due to river levels receding.
16:28	Water from the River Calder continues to flow over the bulk bags at Longfellow Court (Location B) onto Burnley Road. Bulk bags have collapsed.

5.2 Surface water flooding

5.2.1 Surface water flooding is caused by rainwater not being able to drain away through the drainage system or soak into the ground. It flows overground and can be routed along roads.

5.2.2 We have examined evidence showing surface water flooding on Hall Bank Lane and Scout Road, which may have led or contributed to the flooding on New Road.

5.2.3 The flooding that Mytholmroyd Community Centre experienced may have been a combination of surface water and river flooding based upon available evidence. Photographs and videos show flooding on Caldene Avenue, but as the photographs were typically looking towards the new bridge/Burnley Road, it difficult to confirm the source.

5.2.4 It is clear from the evidence that surface water flooding contributed to the flood event experienced on 9 February 2020, but from the evidence available, we have not been able to quantify this through this review.

Figure 13: Photographs showing flooding and times in key locations

6 Flood modelling of Storm Ciara in Mytholmroyd

6.1.1 Hydraulic modelling is a technical process used to simulate the flow of water and is widely used to analyse flood events.

6.1.2 This section describes the flood modelling that we carried out to simulate the effects of the flooding on 9 February 2020 based upon the temporary defences.

6.1.3 We have modelled the following three scenarios:

- Modelling simulation of the flood defences on 9 February 2020 (Model 1) – this provides confidence that the model is able to replicate the actual flood event well;
- Modelled simulation as per Model 1 above but with no seepage through/under temporary defences (Model 2) – this enables us to understand if the temporary defences had held whether the impacts would have been different; and
- Modelled simulation of the flood event of 9 February 2020 with a completed MFAS scheme (Model 3) – this enables us to understand if the MFAS had been completed what the impacts, if any, might have been.

6.1.4 Our findings from the modelling work are summarised below.

6.2 Model inputs

6.2.1 For this review, we used an existing Environment Agency flood model, which was built to assess the design of MFAS. This model included the River Calder through Mytholmroyd and the lower section of Cragg Brook. The original model is termed the 'MFAS design model' in this report.

6.2.2 Our model had to be updated to reflect that MFAS was incomplete on 9 February 2020.

6.2.3 Our modelling includes representation of the measured water levels in Hebden Water and upstream Yorkshire Water reservoirs on 8/9 February 2020 since these affect drainage of the catchment. This means that flows used in the model were as close as practicable to the actual river flow.

6.3 Results of Model 1

6.3.1 This section details the results of our modelling of the actual flooding that occurred on 9 February 2020 based on our assessment of the status of the temporary defences on that day.

6.3.2 Our model simulated the water coming under the K-System barriers at Location A (see Figure 13) and water coming through between the bulk bags at Location B (see Figure 10).

6.3.3 The modelled simulation of the flood defences on 9 February 2020 (Model 1) provides us with confidence that the model replicates the actual flood event well.

6.3.4 On the left bank/Burnley Road side of the River Calder our model shows flooding before 9am on the 9 February 2020 caused by water coming under/through the temporary defences and flowing down Burnley Road. We show a good match with the River Calder temporary gauge at Mytholmroyd, and with the timing and extent of flooding when compared with wrack mark data and photographs.

6.3.5 The flooding on the right bank at the Mytholmroyd Community Centre is likely to have been caused by both surface water and river flooding. The evidence suggests that surface water flooding might have occurred before river flooding. Most of the photographs/videos typically look towards Burnley Road, which means that we cannot determine conclusively if flooding is coming from the River Calder or from surface water runoff. We have not modelled the surface water flooding; however our modelling does show flooding in this location from the River Calder. The model indicated that flooding would have occurred a little later than was observed, however the overall flood extent and depths in this area match well with recorded data.

6.3.6 At St Michael's Church, again, we believe that this is likely to have flooded from both the river and from surface water. We have seen photographs showing surface water flooding on New Road, but there are only a few photographs of the area around the church. The available photographs show overtopping of the new MFAS defences in a couple of locations in this area. Our model shows overtopping of the new flood defences, but not in all of the locations observed, and at a slightly later time than observed. On 9 February 2020, we can see that there was overtopping from Burnley Road back into the River Calder opposite St Michael's Church which may have caused a local rise in water levels which the model cannot replicate. There were also works in the river channel downstream of this location, between St Michael's Church and Greenhill Industrial Estate, which would have affected water levels in this area. Again, the overall flood extent and water depths from the model provide a good match with those observed.

6.3.7 Our model also predicted flooding to Streamside Fold, including some property flooding. There are only a few photographs from Streamside Fold but there are images on social media clearly showing the road into Streamside Fold as flooded.

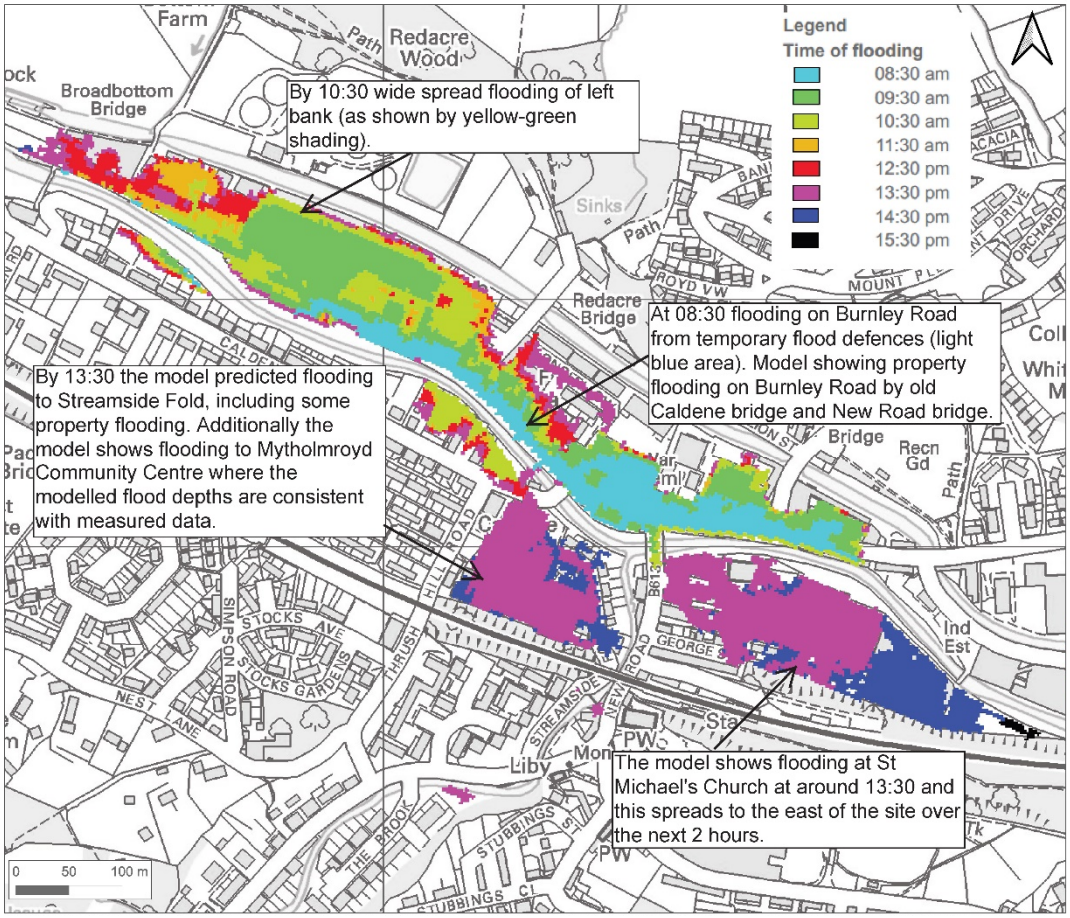


Figure 14: Flooding predicted by Model 1

6.4 Results of Model 2

6.4.1

This section details the results of our modelling of the flooding that occurred on 9 February 2020 based on the operation of the temporary defences with no seepage under the K-System barriers or between the bulk bags. This means that flooding could only have occurred if these defences had been overtopped, that is, the water level in the river channel was higher than the top level of the temporary defences.

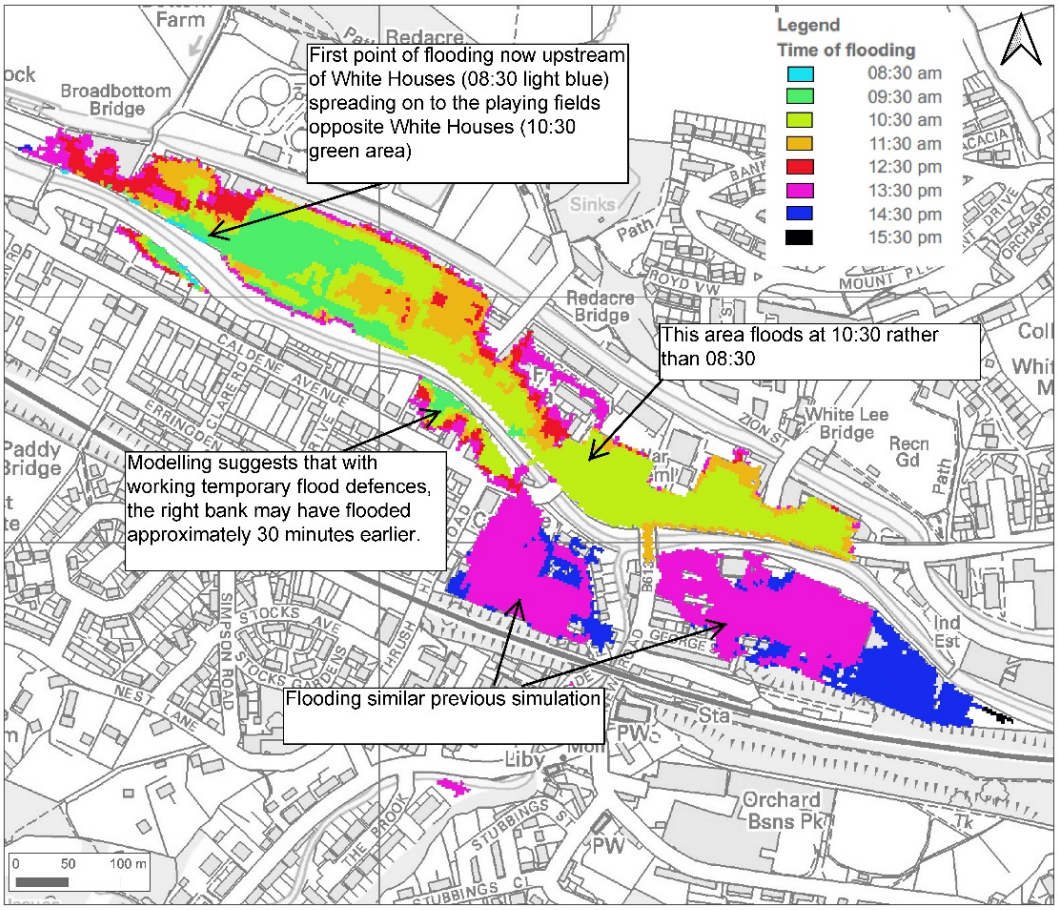


Figure 15: Flooding predicted by Model 2

6.4.2 Figure 15 shows that if the temporary defences at Locations A and B had performed as intended, properties between the old Caldene Bridge and New Road bridge would have flooded between one to two hours later. Flooding would have occurred at 10:30 (Model 2) rather than 08:30 (Model 1). At White Houses, the delay to the onset of flooding would have been approximately 30 minutes to one hour.

6.4.3 Our modelling has shown that if the temporary defences had performed as intended, the overall extent and depth of flooding would ultimately have been very similar to that experienced on 9 February 2020.

6.4.4 However, there would have been a delay to the onset of flooding and the first location of flooding would have been near to White Houses rather than next to the temporary defences (Locations A and B).

6.5 Results of Model 3

6.5.1 This section details our modelling of the flooding that occurred on 9 February 2020 but assuming that the MFAS had been completed.

6.5.2 Our modelling showed that if the MFAS had been completed, the flood event would have likely been contained within the defences, although the flood water would have been at the cusp of overtopping.

This is due to the freeboard allowance built into the defence height. The results of the modelling are shown in Figure 16 below.

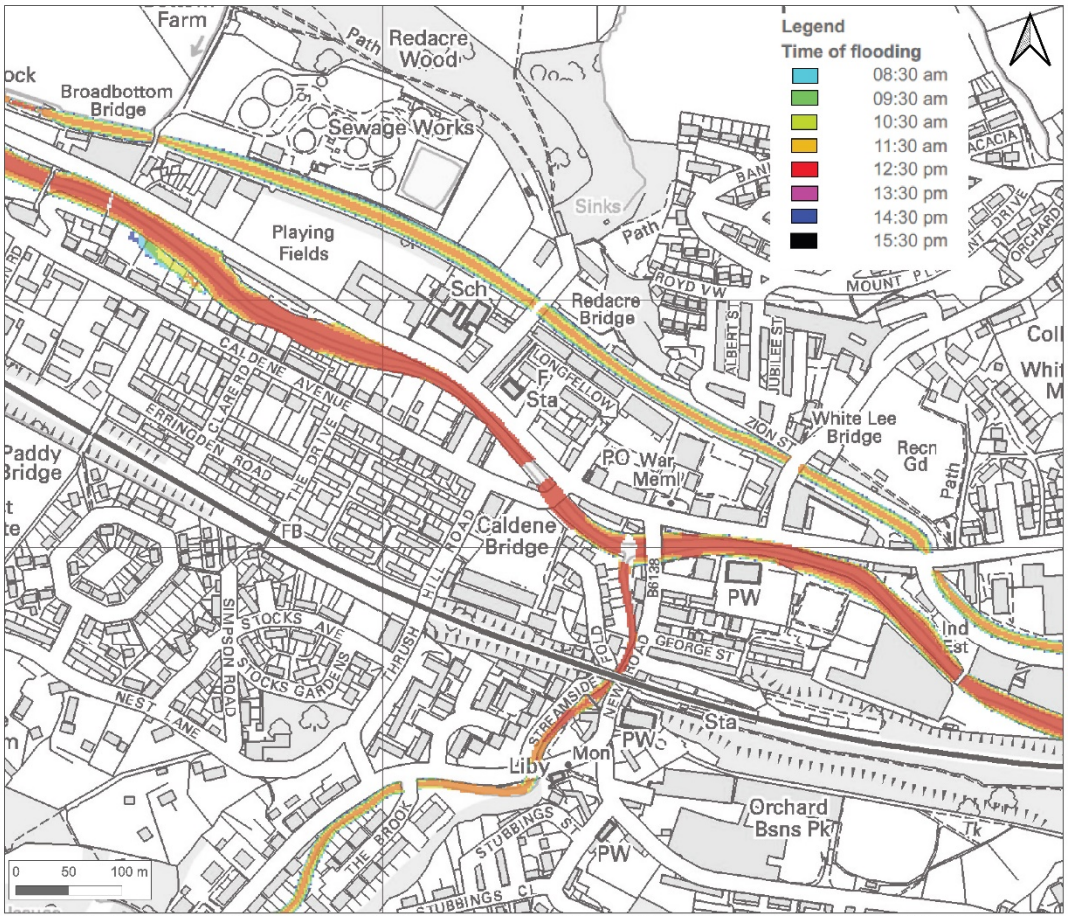


Figure 16: Flooding predicted by Model 3

6.5.3 Under this scenario, we are not able to say how much, if any, flooding would have occurred as we have not modelled surface water flows or the drainage system.

6.5.4 Additionally, due to wave action, debris etc. in the river, there may have been some areas of local overtopping but it is likely that this would have been isolated.

6.6 Summary of modelling results under various conditions

6.6.1 When looking at the modelling of the events of 9 February 2020, our model provides a good comparison to the real life events.

6.6.2 Overall, our modelling has demonstrated that the deficient installation of the temporary defences resulted in flooding to property earlier than would have been experienced had the temporary defences performed as intended.

6.6.3 Specifically, in the area downstream of the old Caldene Bridge, the flooding happened 1 to 2 hours earlier than would have been expected

had the temporary defences worked as intended and at White Houses, the flooding would have happened 30 minutes to one hour earlier.

6.6.4 The peak flood extent and flood depths experienced are likely to have been very similar whether the temporary defences functioned or not due to the severity of the flood event experienced.

6.6.5 Based on the final design of MFAS, had the scheme been completed, it is our view that the flood waters from the River Calder and Cragg Brook would have been contained within the new defences.

6.6.6 However, there may have still been flooding due to the surface water system being overwhelmed by a very intense period of rainfall that could not then be discharged into the flooded river. We have not modelled this as part of this review.

7 Conclusions

7.1.1 On 9 February 2020, Mytholmroyd was hit by heavy rain and the village flooded.

7.1.2 The main source of flooding was the River Calder.

7.1.3 This was a significant flood event, second only to that of Boxing Day 2015.

7.1.4 There was flooding from surface water due to the drainage system being overwhelmed by the heavy rain.

7.1.5 River water came through the bulk bags and under the K-System barriers. This happened before the river level had reached the top of the temporary flood defences.

7.1.6 Modelling has shown that if the temporary defences had performed as intended, that is flood water could not have flowed through/under the temporary defences, then the flooded depth and extent would have been very similar to that experienced. However, flooding would have been delayed on the Burnley Road side of the river in Mytholmroyd by one to two hours.

7.1.7 The flood event was greater than the design standard of protection that the MFAS provides for. However, it is our view that the river flows would have been contained within the new defences had the scheme been completed. This is because allowances are built into flood defence designs to allow for uncertainties. In reality there may have been small areas where the defences were overtopped due to waves or debris, but this would have been relatively minor.

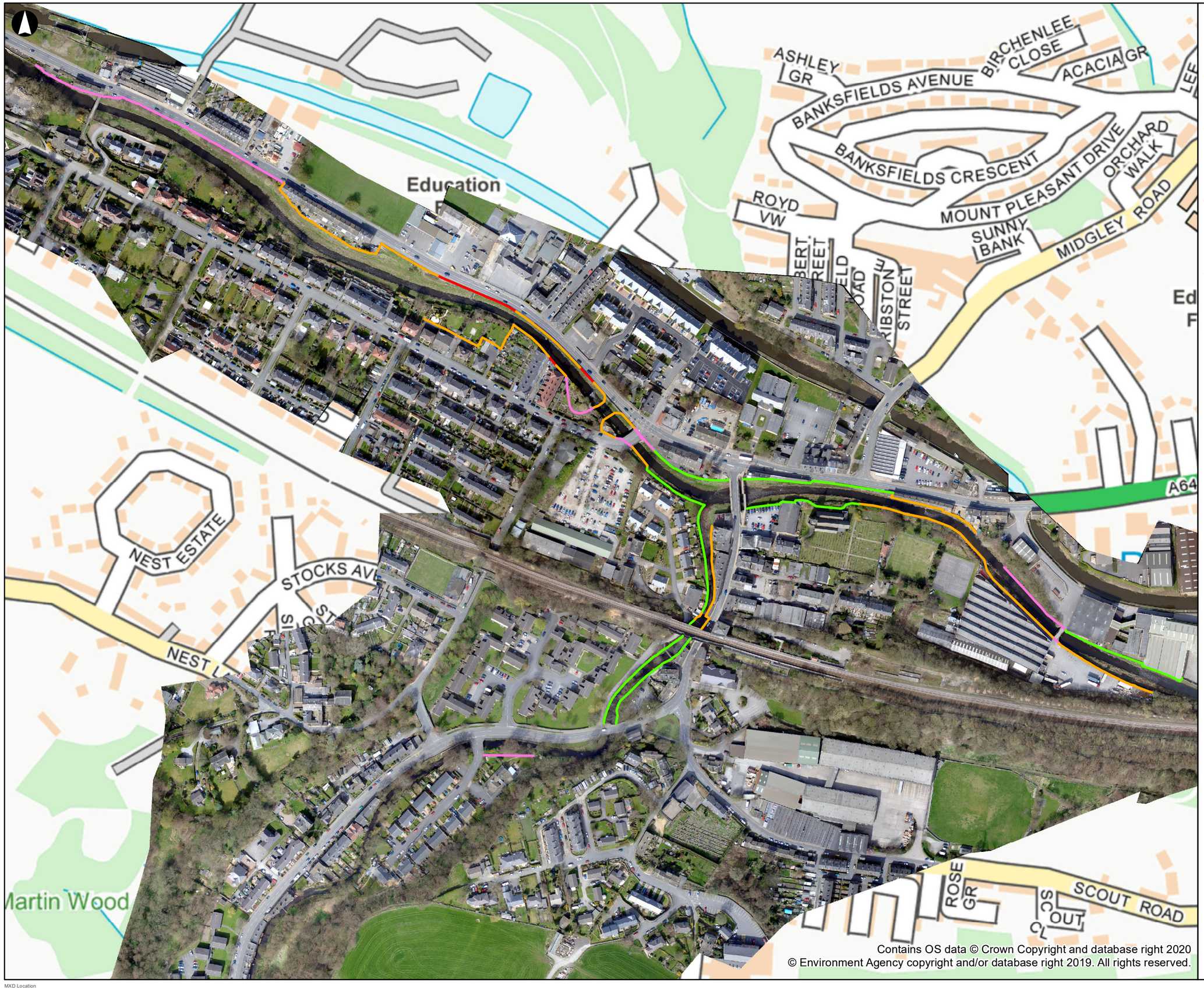
7.1.8 It is also possible that there still would have been some flooding to Mytholmroyd from Cragg Brook, around Cragg Road, and from the surface water system being unable to cope with the heavy rainfall.

Appendix A

Indicative location and progress of existing, temporary, partially completed and completed flood defences in Mytholmroyd on 9 February 2020

A1 Indicative location and progress of existing, temporary, partially completed and completed flood defences in Mytholmroyd on 9 February 2020

A3



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Legend

- Completed MFAS defences
- Partially completed defences
- Temporary flood defences placed while MFAS was under construction
- MFAS works not started

Issue	Date	By	Chkd	Appd
P1	2021-06-21	AL	JL	JL

Metres
0 40 80 160

ARUP

The Arup Campus
Blythe Gate
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Client

Environment Agency

Job Title

Mytholmroyd flood investigation - Independent review into the flood event of 8/9 February 2020

Indicative location and progress of existing, temporary, partially completed and complete flood defences in Mytholmroyd on 9 February 2020

Scale at A3

1:3,200

Job No	Drawing Status
274242-20	**Issue**

Drawing No	Issue
001	**P1**

MXD Location