Flood Investigation: March 2020
Tidal Flooding



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1 Non-Technical Summary

Bristol City Council (BCC) is the Lead Local Flood Authority (LLFA) for the Bristol area and as such it has a duty under the Flood and Water Management Act (2010) to investigate flooding incidents, as it sees necessary and appropriate. The purpose of such investigations is to establish the relevant Risk Management Authorities (RMA) involved in a flooding incident and determine the actions that have or will be taken to complete the RMA's functions in relation to the flood event. A formal investigation is typically only required if a flood event affects five or more properties within an area (for example a street). The flood events considered by this investigation were the tidal floods experienced on the 11th and 12th March 2020. These events failed to meet the criteria for triggering a formal flood event. However, due to the potential for tidal flood events to be more significant, it is fundamental that we learn any lessons and use the event to increase our understanding of the River Avon; BCC's Local Flood Risk Management Strategy also recommends flood investigations are undertaken to better understand their causes; for this reason we have produced this report.

This report outlines the flooding experienced in March within the Bristol region; this occurred due to high astronomical spring tides combining with a storm surge, causing an increase in tidal levels and flood extents. To our knowledge, no essential infrastructure flooded and only one property flooded internally. This flood event did however significantly impact roads along the River Avon.

BCC (as LLFA and Highways Authority) and the Environment Agency (EA) have been established as the relevant RMA's and are deemed to have fulfilled their risk management functions, due to actions taken to prepare for, respond to and investigate these flooding events. The following actions were carried out before, during and after the high tides by BCC, evidencing it took proactive action and preformed their duties as an RMA:

- Liaised with the EA and utilised knowledge and experience to interpret data and weather warnings to inform local actions.
- Undertook GIS analysis of topographic levels to highlight vulnerable areas along the road network to notify the BCC Highways Maintenance Team of roads at risk of flooding.
- Informed residents and businesses located in known high risk areas of the potential for flooding and recommended precautionary actions to protect property.
- Utilised social media to inform the public of the potential risk of flooding, as well as proposed actions such as road closures.
- Monitored tide levels leading up to the peak high tides of the series, to determine if previous tide level forecasts were accurate.
- Recommended road closures to BCC's Civil Protection Unit and Highway's Team and ensured they were in force ahead of the peak relevant high tides.
- Compared predicted and actual high tides to determine uncertainty associated with current forecasting.
- Analysed the reasons for the high magnitude storm surge received.

- Gathered visual evidence (videos and photographs) of tidal flood extents at known vulnerable areas and compiled data and evidence of the extent and effect of the high tides through this report for future reference and information.

Several recommendations have been made, notably:

- The EA and Met Office to continue to make improvements to flood and tidal forecasting and liaise closely with BCC during flooding events.
- BCC and the EA to investigate potential flood risk mitigation measures in Sea Mills, through focusing upon gaining a better understanding of the flood risk posed to Sea Mills, through improved modelling of the area.
- BCC to continue to develop and implement the emerging Bristol Avon Flood Strategy and the Portway flood defence scheme.
- BCC to continue to use its Flood Plan guidance document when responding to flood warnings and forecasts.

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2 Introduction and Background

2.1 LLFA Investigation

In agreement with the Flood and Water Management Act, a full flood risk investigation must be conducted by LLFAs in an urban area if flooding affects five or more properties within a specific area (such as a street). However, BCC (as LLFA) can decide to undertake an investigation where deemed necessary or appropriate. This is applicable to the entire BCC area.

Responsibility of the LLFA
(In accordance with Section 19 of the Flood and Water Management Act 2010)

19 Local authorities: investigations
(1) On becoming aware of a flood in its area, a LLFA must, to the extent that it considers it necessary or appropriate, investigate:

(a) which risk management authorities have relevant flood risk management functions, and

(b) whether each of those risk management authorities has exercised, or is proposing to exercise, those functions in response to the flood.

(2) Where an authority carries out an investigation under subsection (1) it must:

(a) Publish the results of its investigation, and

(b) Notify any relevant risk management authorities.

The duty for an LLFA is to investigate flooding incidents in its area (where appropriate or necessary) to identify which authorities have relevant flood risk management functions, and what they have done or intend to do. The LLFA is required to publish the results of any full investigation and notify any relevant authorities.

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2.2 Site Locations and Topography

The areas that were affected by the two flood events were those located adjacent to the River Avon within the BCC boundary. This included the following locations:

1. Sea Mills Lane, Sea Mills
2. The Portway, beneath the Clifton Suspension Bridge
3. Floating Harbour Entrance Lock and Junction Lock
4. Cumberland Road
5. Commercial Road and Bathurst Basin
6. Clarence Road
7. Cattle Market Road
8. Crew's Hole Road Footpath

These locations are shown on Figure 1 in the above order, starting with Sea Mills Lane (in the west) and along the river into the central area and then eastwards ending at the final known flooded location of Crew's Hole Road footpath.

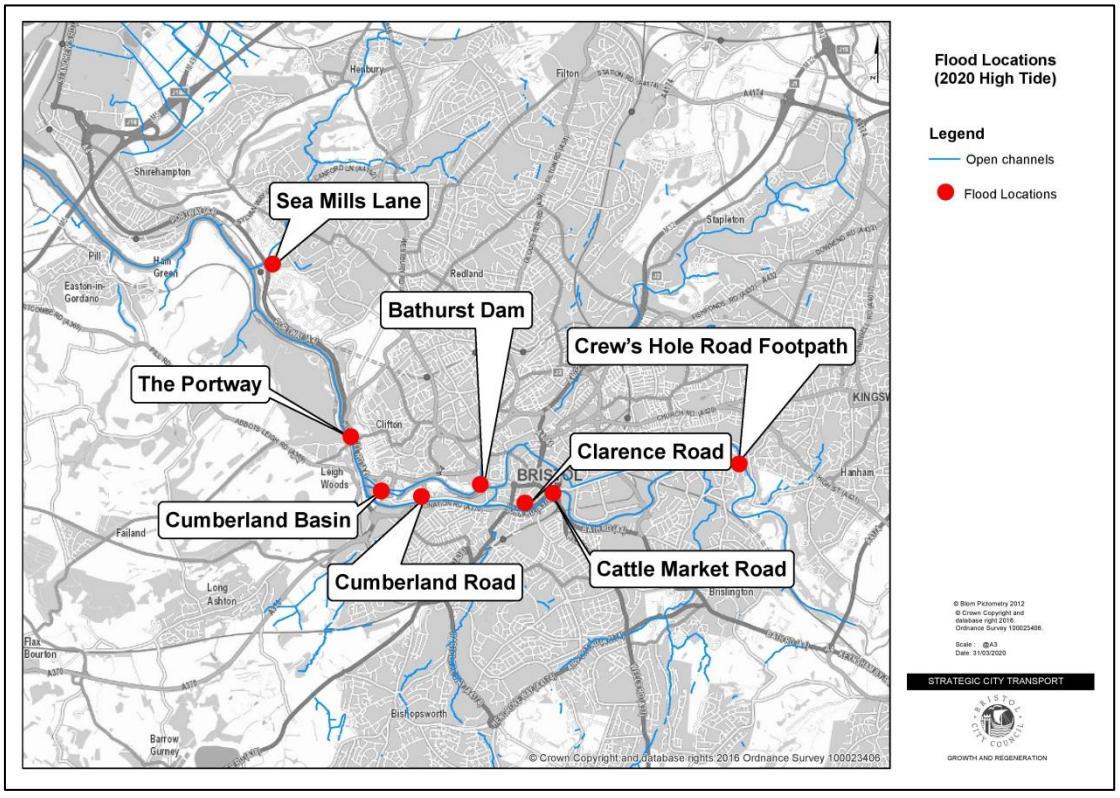


Figure 1. *Bristol 'watercourses map' showing areas affected by flooding from the tidal River Avon on 11th and 12th March 2020.*

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3 Flooding Events

3.1 Tide Forecasts

In the week leading up to the 11th and 12th March high tides, BCC had received multiple flood warnings and high tide predictions from the EA; these were generated using the Avon Flood Forecasting Model.

The first (yellow) warning (medium likelihood of minor flooding impacts occurring) was issued on the 9th March in the form of a Flood Guidance Statement from the EA (Flood Warning Duty Officer). The EA forecasted Avonmouth high tide levels of 8.29mAOD for the evening of the 11th March and 8.10mAOD for the morning of the 12th March (Appendix A). Based on knowledge obtained from previous tide events, BCC added 150mm to these predictions to estimate high tide levels in the city centre; predicting 8.44mAOD for the evening of the 11th March and 8.26mAOD for the morning of the 12th March in the city centre.

On the 10th March the EA updated their tide forecasts in accordance to changes in weather patterns. The EA's forecast consisted of a prediction made by the Avon Flood Forecasting model and included a manual uplift of 200mm by the EA's Monitoring and Forecasting Duty Officer (MFDO) to account for the uncertainty in the forecasts and weather patterns, where applicable. The EA forecasted Avonmouth high tide levels of 8.46mAOD for the evening of the 11th March and 8.44mAOD for the morning of the 12th March (Appendix B). Applying the 150mm uplift resulted in predictions of 8.61mAOD for the evening of the 11th March and 8.59mAOD for the morning of the 12th March in the city centre. This demonstrated a significant increase in the tidal predictions closer to the event, specifically the 12th March event whereby the forecasted peak tide increased by 0.33m when compared to the previous days' forecast.

Final tide prediction data made before the high tides, was obtained by BCC from the EA after the high tides occurred. This showed that the EA forecasted Avonmouth high tide levels of 8.53mAOD for the evening of the 11th March and 8.30mAOD for the morning of the 12th March (Table 1) (Appendix C). Adding 150 mm to these predictions, produced a forecasted high tide level in the city centre of 8.68mAOD for the evening of the 11th March and 8.45mAOD for the morning of the 12th March in the city centre (Table 2).

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Table 1. *Forecasted Avonmouth tide levels (data from the EA).*

Date	Time	Forecasted Astronomical High Tide Level (mAOD)	Forecasted High Tide Level With Storm Surge Adjustment (mAOD)	Storm Surge (m)
11.03.2020	21:00	7.79	8.53	0.74
12.03.2020	09:00	7.98	8.30	0.32

Table 2. *Forecasted city centre tide levels (EA data from Table 1, with 0.15m added by BCC).*

Date	Time	Forecasted Astronomical High Tide Level (mAOD)	Forecasted High Tide Level With Storm Surge Adjustment (mAOD)	Approx. Storm Surge (m)
11.03.2020	21:15	7.79	8.68	0.89
12.03.2020	09:15	7.98	8.45	0.47

3.2 Recorded High Tides

The EA provided BCC with their recorded tidal levels from their monitor at Avonmouth (Table 3). BCC downloaded the recorded tidal levels from the monitor at Bedminster Bridge (Table 4). These both suggest that the tides received were higher than predicted, so the surge component of the tide was underestimated.

Table 3. *Measured Avonmouth tide levels (data from the EA).*

Date	Time	Recorded High Tide Level (mAOD)	Storm Surge (m)	Prediction Forecasting Error (m)
11.03.2020	21:00	8.63	0.84	0.10 underestimated
12.03.2020	09:00	8.44	0.46	0.14 underestimated

Table 4. *Measured city centre tide levels (data from BCC's Bedminster Bridge monitor).*

Date	Time	Recorded High Tide Level (mAOD)	Storm Surge (m)	Prediction Forecasting Error (m)
11.03.2020	21:15	8.81	1.02	0.13 underestimated
12.03.2020	09:10	8.67	0.69	0.22 underestimated

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3.3 Tide Forecasting Uncertainty

Figure 2 shows the peak high tide levels predicted by the EA prior to the high tide events (with BCC 150mm adjustment for city centre predictions) and the recorded tidal curve on the 11th and 12th March at Bedminster Bridge.

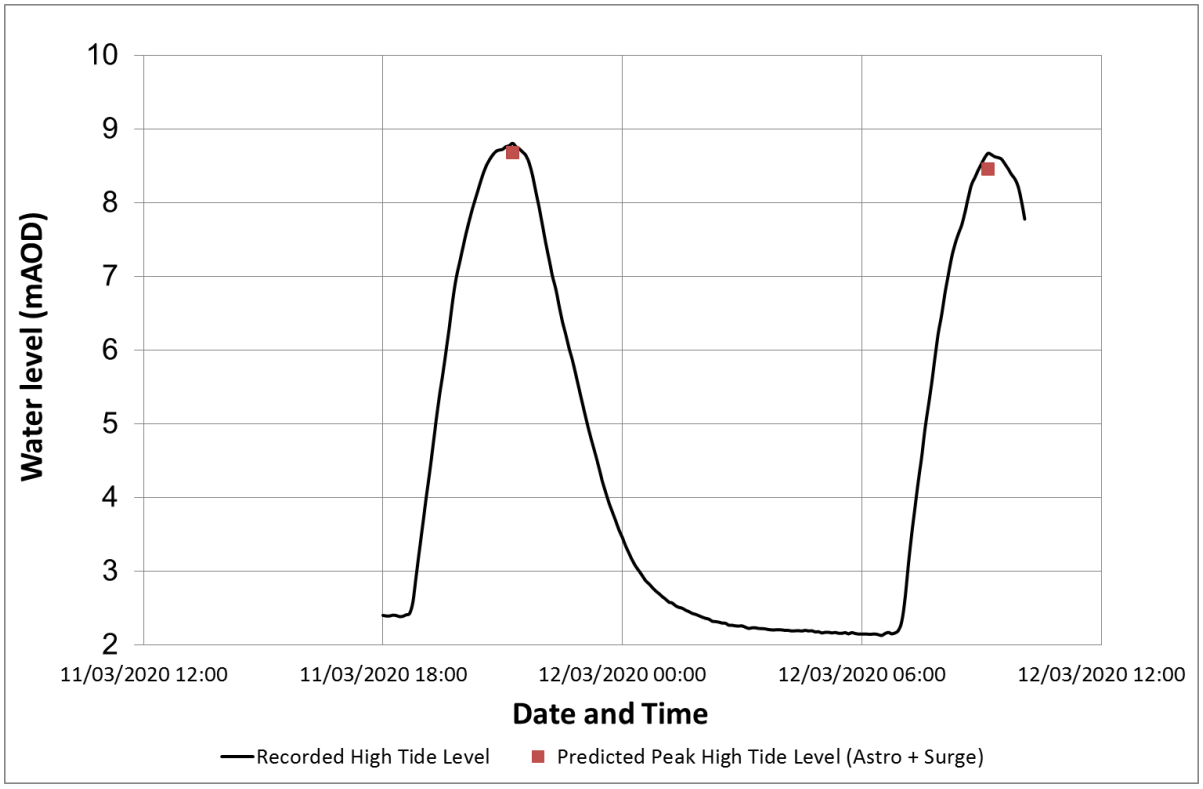


Figure 2. *Scatter graph comparing predicted (astronomical and surge) city centre (Bedminster Bridge) peak high tide levels, with recorded city centre high tides on the 11th and 12th March 2020.*

Predictions were relatively close to the recorded tide levels, however there was still some underestimation of the peak high tide level for both events (Figure 2), despite manual uplift being added to the Avon Flood Forecasting model prediction by the EA's (MFDO). For example, during the 11th March, the maximum predicted (Flood Forecasting model plus manual uplift) high tide level at Bedminster Bridge was 8.68mAOD, however 8.81mAOD was recorded (0.13m under estimated) (Table 4). Furthermore, on the 12th March, the maximum predicted high tide level at Bedminster Bridge was 8.45mAOD, however 8.67mAOD was recorded (0.22m under estimated) (Table 4). The 12th March event had the biggest difference between the predicted and recorded high tide, which could be associated with the change in wind direction from south-westerly (on the evening of the 11th March) to westerly (on the morning of the 12th March); the surge on the 12th could have been higher due to westerly winds having a greater impact upon pushing water up the River Avon, when compared to south-westerly winds on the 11th.

Underestimation of the high tide level in the city centre was also partially caused due to an underestimation of adjusted tidal forecasts for the city centre. BCC

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added 0.15m to Avonmouth values to predict city centre values; BCC do this because as the tide rises, water is forced up the River Avon, where the river channel narrows, so the water level is forced to increase in height to compensate for the narrowing river channel. This adjustment of 0.15m contributed to the underestimation of tide levels in the city centre, as on the 11th March event, the increase in tide level from Avonmouth to Bedminster Bridge was actually 0.18m and on the 12th March it was 0.23m; this suggests that lower peak high tides, result in a greater water height difference between Avonmouth and the city centre. This could be explained by the average channel cross section between Avonmouth and Bedminster Bridge, whereby highly silted lower portions of banks creates a v-shaped channel for low flows and walled banks, creates a more of a rectangular channel for high flows. V-shaped (lower flow) channels mean that whilst water surges up the river, it increases in height quicker, whereby rectangular (higher flow) channels, mean as water surges up the river, it increases in height at a slower rate.

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3.4 Floating Harbour Levels

During tidal flood conditions, water can flow into the Floating Harbour via two primary routes; firstly, direct overtopping of tidal water from the River Avon via low spots at Entrance Lock, Bathurst Basin and St Philips Marsh and secondly from the River Frome which flows directly into the Harbour.

In preparation for both the high tides events, Bristol City Docks team pre-lowered the level of the Floating Harbour; this was to allow for extra capacity within the Harbour for floodwater. In addition, the EA kept all four of the Eastville Sluices open, thus reducing the fluvial flood flows entering the Floating Harbour. During the two flood events discussed in this report, tidal flood water flowed into the Harbour at Bathurst Basin (Plate 1) and Junction Lock (Plate 2). The existing formal defences and buildings that act as de-facto defences located in St Phillips Marsh, prevented flooding of Albert Road and surrounding areas.

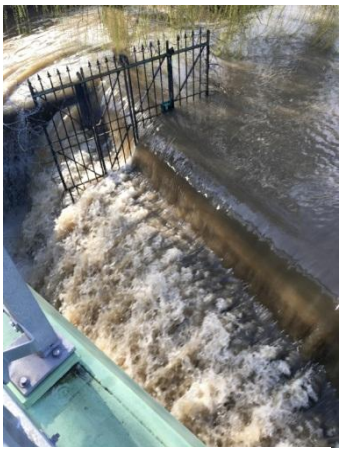


Plate 1. *Overtopping at Bathurst Basin.*



Plate 2. *Overtopping at Junction Lock (Cumberland Basin).*

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3.5 Flood Extents

Areas adjacent to the River Avon with topographic levels below the recorded high tide levels (indicated in Table 3 and Table 4), at the locations mentioned in Section 2.2, suffered tidal flooding. The extent of flooding at Sea Mills, the Portway and Cattle Market Road on the 11th and 12th March 2020 are shown below in Plate 3, Plate 4 and Plate 5.



Plate 3. *Flooding along Sea Mills Lane at 8:30 am on the 11th March 2020.*



Plate 4. *Flooding along the Portway, at 12:55 pm on the 12th March 2020.*



Plate 5. *Flooding along Cattle Market Road (time taken unknown).*

Tidal monitors are located at a significant distance apart along the River Avon at: Avonmouth, the City Centre (Bedminster Bridge) and Netham Weir; therefore it is difficult to accurately quantify flood depths and durations for the locations mentioned in Section 2.2., especially given that the tide level varies significantly along the River Avon (highest at Netham and lowest at Avonmouth). Table 5 estimates the maximum high tides at each of the locations that flooded, through assuming tide height increases in a linear pattern with distance upstream between Avonmouth and Bedminster Bridge. The actual high tide levels measured also show that between Avonmouth and Bedminster Bridge, the tide level increased by 0.18mAOD.

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Table 5. *Estimated tide levels for the 11th March high tide at vulnerable locations along the River Avon (assuming a linear tide height increase with distance upstream in relation to Avonmouth, where 1 km upstream equates to 0.013m increase in tide height).*

Location	Distance Upstream of Avonmouth Gauge (km)	Measured High Tide Level (mAOD)	Estimated High Tide Level (mAOD) (Based on Distance Upstream of Avonmouth and Change in Tide Level Measured Between Avonmouth and Bedminster Bridge)
Avonmouth	0	8.63	
Sea Mills Lane (Sea Mills)	7		8.72
The Portway, under Clifton Suspension Bridge	10.5		8.77
Cumberland Basin Road	11		8.77
Junction Lock	12		8.78
Bathurst Basin Dam	13.5		8.78
Bedminster Bridge	14	8.81	
Clarence Road	14.1		8.81
Cattle Market Road	14.5		8.82

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Table 6. *Estimated maximum flood depths in each flooded location (using estimated tide heights in Table 5 and the current minimum elevation of flood defence structures / current road level, according to BCC LIDAR data).*

Location	Tidal Defences	Defence Structure Height or Ground Height (m AOD)	Estimated High Tide Level (m AOD)	Approximate Estimated Max Flood Depth (m)
Sea Mills Lane	No	Ground: 8.00	8.72	0.72
The Portway, beneath the Clifton Suspension Bridge	Yes (Defacto)	Defence: 7.80 Ground: 8.00	8.77	0.77
Cumberland Basin Road	No	Ground: 8.40	8.80	0.40
Junction Lock	Yes	Defence 8.90 Adjacent Ground: 8.50	8.80	Overtopping into Floating Harbour
Cumberland Road	Yes	Defence: 9:20 Ground: 8.40	8.80	-
Bathurst Basin Dam	Yes (Defacto)	Defence: 8.30	8.78	Overtopping into Floating Harbour
Clarence Road	Yes	Ground: 8.60	8.81	0.21
Cattle Market Road	Yes (Defacto)	Defence: 7.80 Ground: 7.20	8.82	1.02

Cattle Market Road is considered to be the most vulnerable location according to Table 6, with the highest estimated tide level received and one of the lowest levels of protection.

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Information regarding road closure duration was provided by BCC's Highways Team and has been used to provide an estimate for flood durations at each location (Table 7). The Portway and the roads around Cumberland Basin were closed for approximately 4.5 – 5 hours on the evening of the 11th and again on the morning of the 12th March. This suggests that roads were flooded for approximately 4.5 hours in these locations. Commercial Road and Clarence Road were not closed, however may have experienced some very shallow flooding for a short period of time. Cattle Market Road and Sea Mills Lane experienced significant flood depths (Table 6) and therefore considering they are not major roads, were not reopened between the evening high tide on the 11th March and the morning high tide on the 12th March. Although road closure data cannot indicate flood durations in these locations, flood depth information, reports from Highways Maintenance Officers and flood durations in other locations, suggest that they are likely to have experienced flooding for around 5 hours.

Table 7. *Approximate duration of flooding at various locations along the River Avon based on road closure durations.*

Location	Road Closure Times	Approximate Duration of Flooding
Sea Mills Lane	19:00 (11th) - 11:00 (12th)	Unknown - road closure between events remained in place, due to it being a minor road.
The Portway, beneath the Clifton Suspension Bridge	20:00 – 00:30 (11th) 07:00 – 11:00 (12th)	4. 5 hours 5 hours
Cumberland Basin Road	20:00 – 00:30 (11th) 07:00 – 11:00 (12th)	3.5 hours 4 hours
Commercial Road	Remained Open	0.5 hours
Clarence Road	Remained Open	0.5 hours
Cattle Market Road	20:00 (11th) – 11:30 (12th)	Unknown - road closure between events remained in place, due to it being a minor road.

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3.6 Flood Impacts on Residential Property

One report of internal residential flooding was received during the high tides on the evening of Wednesday 11th and the morning of Thursday 12th March; this was along Sea Mills Lane, where tide levels exceeded the property's demountable flood barrier (which was installed in advance of the high tide) and came through the side gate into the rear of the property (which is lower lying than the front of the property).

The flood gates at Shirehampton were closed on both occasions by the EA, protecting several properties. In addition, the Cumberland Road flood wall was successful in protecting residential and commercial properties from flooding along Avon Crescent, Cumberland Road and Commercial Road.

3.7 Flood History

Before the March high tides discussed within this report, the highest recorded tide level on record occurred in 1981, however the 2020 March events exceeded the 1981 event by 0.01m, meaning they are now the highest on record. Table 8 summarises other recent events within a similar magnitude to the events discussed within this report.

Table 8. *Approximate high tide levels from tidal events (data obtained from BCC Preliminary Flood Risk Assessment).*

Year	Approximate Maximum Tide Level (mAOD)	Impacts and Comments
1981	8.80	Event caused by a significant surge (approx. 1.6m). Several properties inundated, including some on Avon Crescent
1999	8.60	Event caused by surge of approx. 0.7 – 1m. Flooding of Avon Crescent and some evacuation of properties required
2011	8.40	Notable that due to favourable weather conditions, no surge experienced
2014	8.65	Storm surge of 0.8m contributed to high tide which resulted in flooding to residential areas adjacent to the River Avon

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4 Cause of Flooding

Due to a relatively wet winter, catchments were saturated, so any rainfall would have reached river systems relatively quickly, however prior to the high tide events, relevant catchments contributing to the River Avon received only sporadic, light rainfall. Rainfall was therefore not a significant factor in producing this flood event.

Relatively high astronomical tides, (but not highest astronomical tides of the year) were predicted, so this was a major factor into the flooding incurred, but most significant was that they combined with a low pressure system to cause a large surge; this surge was also further intensified by south-westerly/westerly winds ranging from 8-15m/s.

5 Risk Management Authorities

One aim of this report is to understand the role of each RMA, as identified in Section 2.1. It also aims to summarise the response taken prior, during, and after the event, to then inform this report's recommendations in preparation to reduce the severity of a flood event of a similar nature in the future.

As this event was purely tidal, any actions identified are explicitly for managing a repeat event of this nature.

5.1 Bristol City Council

BCC as a whole, took a proactive approach in preparing and executing actions to deal with the high tides, by carrying out duties under the Flood And water Management Act (2010). Listed below are different teams within BCC who were involved in providing a response, as the LLFA to the flood risk posed by the high tides in March 2020. Appendix D shows a timeline of actions undertaken by the Flood Risk and Data Management Team:

5.1.1 Strategic Transport (Flood Risk and Data Management)

- Utilised knowledge and experience to interpret data and weather warnings to inform local actions.
- Discharged role as a LLFA in accordance with the BCC Flood Plan.
- Liaised closely with the EA Duty Officers to ensure a co-ordinated approach to managing the event.
- Undertook GIS analysis of topographic levels to highlight vulnerable areas along the road network.
- Utilised GIS analysis results, knowledge gained from various studies and historical events to notify the BCC Highways Maintenance Team of roads predicted to flood, so that signage and closures could be appropriately implemented.
- Notified those residents and businesses at most risk of flooding such as:

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- Properties on East St (Bedminster) in case of issues with the Malago culvert being propped open with debris.
- St Mungo's Charity regarding rough sleepers.
- Paintworks to ensure the flood gates were put in place.
- High risk businesses in St Phillips, such as the Animal Rescue Centre.
- Residents at Sea Mills Lane.

- Advised BCC's internal Communications Team of messages to be released on social media, to inform the public of road closures.
- Communicated with the public and other RMAs.
- Collated data on site during the flood event.
- Provided advice to the following teams, as follows.

5.1.2 Marine Services (City Docks)

- Completed actions in accordance with the BCC's Flood Plan.
- Pre-lowered the Floating Harbour, providing extra storage capacity.
- Ensured function of Floating Harbour control structures and assets through the tidal events.
- Monitored tide levels and resulting rises in the Floating Harbour water level.

5.1.3 Highways and Traffic Management (a designated Risk Management Authority)

- Completed actions in accordance with the BCC's Flood Plan.
- Actively managed and closed roads and car parks, such as the Portway, Sea Mills Lane, Cattle Market Road, Brunel Lock Carpark, Cumberland Basin Road, River Avon footpath at Crew's Hole Road and St Phillips.
- Instructed maintenance contractors to be on location at known vulnerable locations, such as the Portway to pump tide water off the highway.
- Coordinated traffic on vulnerable and disrupted highways; officers were in location on the Portway to manage traffic and a decision to keep the Portway closed overnight on the 11th was made in the interest of safety, given the tide exceeded the forecasted tide.

5.1.4 Civil Protection Unit

- Completed actions in accordance with the BCC's Flood Plan.
- Initiated and chaired a FloodCall to discuss with relevant internal parties.
- Coordinated and managed the response of BCC.
- Ensured media were kept updated and informed, resulting in publication of good information.

5.1.5 Communications and Marketing

- Informed the public of forthcoming potential flooding and disruption via the BCC website, radio press releases and other media including social media.

5.2 Environment Agency

- In partnership with the Met Office, provided flood guidance statements and predictions in the lead up and during the high tides.
- Flood Warning Duty Officer shared information with BCC and issued timely Flood Alerts and Flood Warnings.
- Opened Eastville sluice gates to allow higher river flows from the River Frome to outlet at the River Avon downstream of Black Rocks.
- Provided clearances of main river watercourses for which they are responsible, to enable regular flow and prevent backing up and blockage during any potential tide locking.
- Closed the flood gates along the River Avon, such as at Shirehampton.
- Undertook pre and post tide checks, including clearance of key structures and screens.
- Had Flood Reconnaissance and Community Information Officers at locations around Bristol.
- Appointed a flood warden for Sea Mills and arranged for the delivery of property flood resilience.

5.3 Lower Severn Internal Drainage Board

- This report focuses on the central area of Bristol. However, the Lower Severn Internal Drainage Board discharged their duties by managing the rhine network within the Avonmouth area.

5.4 Other RMAs

As the events described here relate to tidal flooding and did not impact upon the strategic trunk road network, they were not relevant to other RMAs, such as Wessex Water or the Highways Agency. Hence these RMAs have not been considered in this report.

6 Recommendations

Tidal event forecasting is crucial in enabling all authorities to undertake appropriate actions and provide sufficient information and warnings to the public. As evidenced in Section 3.3. the storm surge component of tidal forecasting can have a very significant contributory aspect in increasing the height of astronomical tide levels. Furthermore, surge predictions during these high tides had some inaccuracies, as a higher tide than was predicted, occurred. Therefore, in line with recommendations of the Pitt Review[1] and the Flood and Water Management Act 2010, it is recommended that the EA and Met Office continue to make improvements to tidal forecasting. In addition, it is recommended that close liaison continues between the EA, the Met Office and BCC when tidal flood events are predicted, to ensure appropriate actions are proposed.

There is a lack of reliable data on previous flood depths, due to an inconsistency of methods to measure flood depths over time. Local data can also greatly improve our understanding of the flood and tidal surge mechanisms in the River Avon and can be used to validate forecasting models and predictions. Therefore, BCC will continue to collect hydrological data of the River Avon through the use of the monitor on Bedminster Bridge. This will also provide a consistent approach to measure flood depths over time and reduce uncertainty in data collected. The EA will also continue to monitor water levels at Avonmouth and Netham Weir to ensure local data is collected along the length of the River Avon.

Tidal predictions for localised areas are uncertain, therefore the EA and BCC will aim to discuss if improvements can be made to the forecasting models to reduce this uncertainty.

Flooding of the road, parked cars and a property along Sea Mills Lane, combined with many properties deploying their own individual flood barriers/gates, highlights that Sea Mills is an area which is particularly vulnerable to flooding during high tide events. Furthermore sea level rise from climate change will inevitably mean that this area will be at an increased risk from tidal flooding in the future. Currently BCC only has limited 1D modelling of this area, so the area's flood risk is relatively poorly understood, when compared to the understanding of flood risk to the city centre and Avonmouth. Therefore, BCC and the EA need to focus upon gaining a better understanding of the tidal flood risk posed to Sea Mills through commissioning a model of the area (an aim of the emerging Bristol Avon Flood Strategy). This model can then be used to inform on the current and future flood risk to the area, before investigating what flood risk interventions could be implemented and their feasibility.

The Portway and Cattlemarket Road were significantly affected by tidal flood water and had to be closed; as suggested in the above paragraph, sea level rise from climate change will mean these roads will become more regularly

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flooded and to greater depths and extents in the future. Additionally, the Portway is an important main transport route into and out of Bristol and therefore protection against flooding, under more frequent and larger events in the future is important. Therefore to prevent further tidal flooding at Cattle Market Road, the emerging Bristol Avon Flood Strategy and the Portway flood defence scheme should continue to be developed and implemented as a priority.

BCC, as LLFA, will continue to use its Flood Plan guidance document (updated in 2017) when responding to flood warnings and forecasts to ensure appropriate action and internal processes and procedures are followed. Using BCC's Flood Plan will also ensure internal teams within BCC understand their role and their expected actions to be undertaken during such an event.

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7 Summary

On the 11th and 12th of March 2020, Bristol experienced a flood event as a direct cause of an astronomical high tide, combined with a high storm surge caused by a low-pressure system and westerly winds. This flood reached a peak of 8.81mAOD and affected several areas across Bristol, including:

1. Sea Mills Lane, Sea Mills
2. The Portway, beneath the Clifton Suspension Bridge
3. Entrance Lock and Junction Lock
4. Cumberland Road
5. Commercial Road and Bathurst Basin
6. Clarence Road
7. Cattle Market Road
8. Crew's Hole Road Footpath

Places inundated with flood water included residential and highway infrastructure. Flood gates were closed at Shirehampton and property flood defences were successful in keeping out flood water in Sea Mills, in all but one property. Combining Met Office data and EA guidance ensured that key stakeholders were kept up-to-date and well informed.

BCC, along with other RMA's took a proactive approach in preparing and executing actions to deal with the high tides. Up to date data and forecasting ensured that decisions were made in time to allow for sufficient preparation, reducing the risk of flood to infrastructure and residential homes.

Informed by the evidence of this report, there are key recommendations made to ensure that future preparations greatly reduce the risk of flooding further as follows:

- Improving tidal forecasting, whilst continuing RMA communication.
- BCC and the EA to investigate potential flood risk mitigation measures in Sea Mills, through focusing upon gaining a better understanding of the flood risk posed to Sea Mills, through improved modelling of the area.
- Continue to develop and implement the emerging Bristol Avon Flood Strategy and the Portway flood defence scheme.
- Continuing internal BCC operations.

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8 Appendices

Appendix A *- EA's Avonmouth tide level forecasts (produced on the 9th March 2020).*

Date	Time (GMT)	Astro Water Level (m)	Surge (m)	Peak Water Level (mAOD)
09/03/2020	19:30	7.24	0.40	7.64
10/03/2020	07:45	7.61	0.31	7.92
10/03/2020	20:00	7.68	0.14	7.82
11/03/2020	08:30	7.94	0.14	8.08
11/03/2020	**20:45**	**7.85**	**0.44**	**8.29**
12/03/2020	**09:00**	**7.98**	**0.13**	**8.11**
12/03/2020	21:30	7.67	0.48	8.15

Appendix B *- EA's Avonmouth tide level forecasts (with the EA's Duty Officer's surge uplift added), (produced on the 10th March 2020).*

Date	Time (GMT)	Astro Water Level (m)	Surge (m)	Peak Water Level (mAOD)
10/03/2020	20:00	7.65	0.17	7.85
11/03/2020	08:30	7.94	0.27	8.21
11/03/2020	**20:45**	**7.85**	**0.61**	**8.46**
12/03/2020	**09:15**	**7.95**	**0.49**	**8.44**
12/03/2020	21:30	7.67	0.46	8.13
13/03/2020	09:45	7.62	0.10	7.72
13/03/2020	22.15	7.05	0.21	7.26

Appendix C - *Most recent forecast from the EA's National Flood Forecasting System (provided to BCC retrospectively).*

Date	Time (GMT)	Astro Water Level (m)	Surge (m)	Peak Water Level (mAOD)	Observed Water Levels (m)
10/03/2020	20:00	7.68	0.29	7.97	7.99
11/03/2020	08:30	7.94	0.06	8.02	8.35
11/03/2020	**21:00**	**7.79**	**0.74**	**8.53**	**8.63**
12/03/2020	**09:00**	**7.98**	**0.31**	**8.30**	**8.44**
12/03/2020	21:30	7.67	0.24	7.91	8.07

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Appendix D *- Timeline of actions undertaken by BCC Flood Risk Management Team.*

Monday 9th March:

- Received predicted Avonmouth tide levels (astronomical and surge predictions) from the EA Flood Warning Duty Officer.
- Converted Avonmouth tide levels predictions to city centre tide levels (added 150mm) to predictions to get an indication of flood risk to the city centre and whether current flood defenses will provide protection.
- Received and interpreted Flood Guidance Statement Yellow Warnings from the EA.

Tuesday 10th March:

- Received updated predicted Avonmouth tide levels (astronomical and surge predictions) from the EA Flood Warning Duty Officer.
- Converted updated Avonmouth tide levels predictions to city centre tide levels (added 150mm) to predictions to get an indication of flood risk to the city centre and whether current flood defenses will provide protection.
- Received and interpreted Flood Guidance Statement Yellow Warnings from the EA.
- Undertook GIS analysis of topographic levels along the River Avon using GIS 'low lying land' layer, to highlight vulnerable areas along the road network.
- Advised First Group and internal BCC teams (Emergency Planning, Highways and Traffic, Highway Maintenance, Harbour Office, Operations Centre, Citizen Services, Civil Protection) of high tide levels, timings of when they were expected and roads predicted to flood.
- Harbour Office advised to pre-lower the floating harbour and contact the EA to open Eastville Sluices.
- BCC Communications Team and News Desk Team advised via email to warn general public of potential flooding around the River Avon via social media (Facebook and Twitter) and other media channels.
- Contacted St Mungo's (homeless charity) and warned of high tide and advised to check areas along the river used by rough sleepers (particularly Gods Garden by Cumberland Road near Bathurst Basin, opposite the old gaol; River Malago outfall by Coronation Road, opposite Asda car park; the slipway by Gaol Ferry Bridge).
- Contacted businesses at risk of flooding and warned of high tides (Bristol Animal Rescue Centre on Albert Rd).
- Contacted businesses along East Street in Bedminster and warned of high tides and potential risk of flooding (history of flooding from tide flap into the Avon being wedged open from debris).
- Advised Civil Protection Unit to set up a Flood Call on 11th.

Wednesday 11th March:

- First Group and internal BCC teams (Emergency Planning, Highways and Traffic, Highway Maintenance, Harbour Office, Operations Centre, Citizen Services, Civil Protection) given an update via email of high tides expected (levels and times).

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- Highway Teams advised on which specific roads to close (The Portway – an hour before high tide on evening of the 11th in both directions and on the morning of the 12th in the outbound direction only. Sea Mills Lane, Cattle Market Road, Brunel Lock Carpark, Cumberland Basin Road, River Avon footpath at Crew's Hole Road and St Phillips (between Totterdown bridge and Cattle Market Road)). Also advised on which roads to monitor, where current predictions suggest only shallow flooding (Brunel Lock Road, Clarence Road, Crews Hole Road, Footway along A and B Bond).
- Civil Protection Unit set up a FloodCall in the afternoon with First Group and internal BCC teams (Emergency Planning, Highways and Traffic, Highway Maintenance, Citizen Services, Harbour Office, Public Relations, Civil Protection Unit, Operations Centre, Flood Risk Team).
- Residents of Sea Mills contacted to warn of high tides and advised to install flood barriers to protect their properties.
- Contacted BBL Batteries (Albert Road) to warn of high tide and potential for flooding.
- Contacted Paintworks to warn of high tide and advised to put in flood barriers.
- Monitored Bedminster Bridge's tidal gauge leading up to the high tide to monitor accuracy of predicted storm surge.
- Contacted internal BCC Highway teams to advise of higher than expected tide and advised to now keep the Portway closed in both directions for both high tides.
- Contacted BCC Communication's Team with update on road closures.

Thursday 12th March:

- Took pictures of the high tide at various vulnerable locations along the River Avon (Bathurst Basin, Cattle Market Road, Cumberland Basin, The Portway, Sea Mills).
- Downloaded tidal gauge data recorded from Bedminster Bridge monitor.

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