Barnsley Metropolitan Borough Council

BULLING DYKE

Problem Definition Report

CONFIDENTIAL

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Problem Definition Report

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PROJECT NO. 70096452

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1 INTRODUCTION

1.1 PROJECT DESCRIPTION

WSP have been commissioned by Barnsley Metropolitan Borough Council (BMBC) to investigate flooding problems within the vicinity of Station Road in Wombwell, Barnsley. The report summarises the problem definition and includes recommendations and further work to progress to feasibility and development of a concept design.

1.2 PROJECT BACKGROUND AND SCOPE

The River Dove (main watercourse) and the Bulling Dyke (ordinary watercourse) run parallel to one another through the town of Wombwell. Historic flooding indicates that fluvial flood risk from these two watercourses is significant and resulted in 194 properties flooding in June 2007, primarily within the vicinity of Station Road and Stonyford Road.

In June 2022 WSP was commissioned by Barnsley Metropolitan Borough Council (BMBC) to build a baseline hydraulic model of the Bulling Dyke to establish the flood mechanism of the watercourse, with particular focus on the culvert conveying the Bulling Dyke under Station Road. The original scope included collecting up-to-date watercourse and topographic survey and CCTV condition survey of the Station Road culvert.

Following discussions between WSP, BMBC and the Environment Agency (EA) and a further review of available data, it was felt that the original scope did not adequately reflect the hydraulic interaction between the River Dove and Bulling Dyke, as outlined in a 2009 Jacobs Viability Report and 2013 BMBC project appraisal report. That is to say that the interaction of floodwaters from the right bank of the River Dove and flows from the Bulling Dyke are foreseen to be an important control on flooding to properties on Station Road, Wombwell and connected nearby roads. It was agreed that it would not be appropriate to establish the flood risk mechanisms to the Station Road area by considering only the Bulling Dyke.

A high-level review of the existing River Dove model (used most recently by Enzygo, 2018) revealed a combination of incomplete, assumed, missing and/or outdated data amalgamated from a series of previous surveys and inconsistent LiDAR data. Subsequent discussion between WSP, BMBC and the EA in August 2022 resulted in the original scope being updated. It was decided to include an updated baseline hydraulic model build of the River Dove from upstream of the Bradberry Balk Lane bridge to the outfall at the River Dearne, to combine with the Bulling Dyke model. This was to better reflect the hydraulic interaction between floodwaters from the right bank of the River Dove and floodwaters from the Bulling Dyke, which are foreseen to be an important control on flooding to properties on Station Road, Wombwell and connected nearby roads.

The final scope therefore consisted of the following tasks:

- Site Reconnaissance
- Watercourse and Topographic Survey of the Bulling Dyke and River Dove down to the Dearne River
- CCTV Condition Survey of Station Road Culvert
- Flow Estimation of Bulling Dyke and River Dove
- Baseline Hydraulic Modelling of Bulling Dyke and River Dove

- Problem Definition Drawings

1.3 AIMS OF THE STUDY

The aim of this study is to provide establish the key flood risk mechanisms in the Station Road – Stonyford Road area of Wombwell, through a hydraulic model build. As part of this, the relative importance of the River Dove and the Bulling Dyke in contributing to flooding will be determined. The outcomes of the study will be used to inform recommendations for future work, with an overall aim to form the basis of a Flood Alleviation Scheme (FAS) for Wombwell at a later stage.

1.4 STRUCTURE OF THIS REPORT

This report presents a breakdown the current problem understanding in the study location, followed by a discussion of the flow estimation and baseline model build, before drawing conclusions from the modelling results to establish the key mechanisms . Following this, the report presents recommendations for future work towards the development of a flood scheme.

A more detailed overview of the scope of works is provided below:

- **Site description and data collection.** Includes an overview of the site and understanding of key flood risk mechanisms based on a data gathering exercise. Data collection includes:
  - desk-based data collection from freely available information, including flood history and previous studies
  - site reconnaissance undertaken in summer 2022 to improve site understanding and identify any potential constraints or issues;
  - surveys and investigations undertaken;
- **Hydrology and Modelling.** Details of the flow estimation and the updated model build of the River Dove and Bulling Dyke.
- **Problem Definition.** A summary of the modelling results and key flood risk mechanisms in the areas of interest. Conclusions from the problem definition will be used to identify the primary source of flood risk within the study area, followed by a comparison to previous studies.
- **Recommendations and Further Work.** On the back of the Problem Definition, this provides suggested steps to take the work towards the next stage of assessment.

2 SITE DESCRIPTION AND DATA COLLECTION

2.1 SITE LOCATION

The site is located around the town of Wombwell, Barnsley, South Yorkshire and contains stretches of both the Bulling Dyke and River Dove. The River Dove begins at the outfall of the Worsborough Reservoir and drains a large, primarily rural catchment (55 km^2), whilst the Bulling Dyke drains a smaller, moderately urbanised catchment (3.3km^2) covering most of Wombwell. Both watercourses outfall at the River Dearne. Throughout the site, the River Dove features several structures which may impact flow, including bridges on Bradberry Balk Lane, Dove Valley Way, and Stonyford Road. The Bulling Dyke in the area of interest features a bridge on Valley Road and a key culvert on Station Road.

The site location and study area are shown by the red outline in Figure 2-1. The aim of this study is to establish the key flood risk mechanisms in the area of interest around Station Road and Stonyford Road, shown in Figure 2-2.

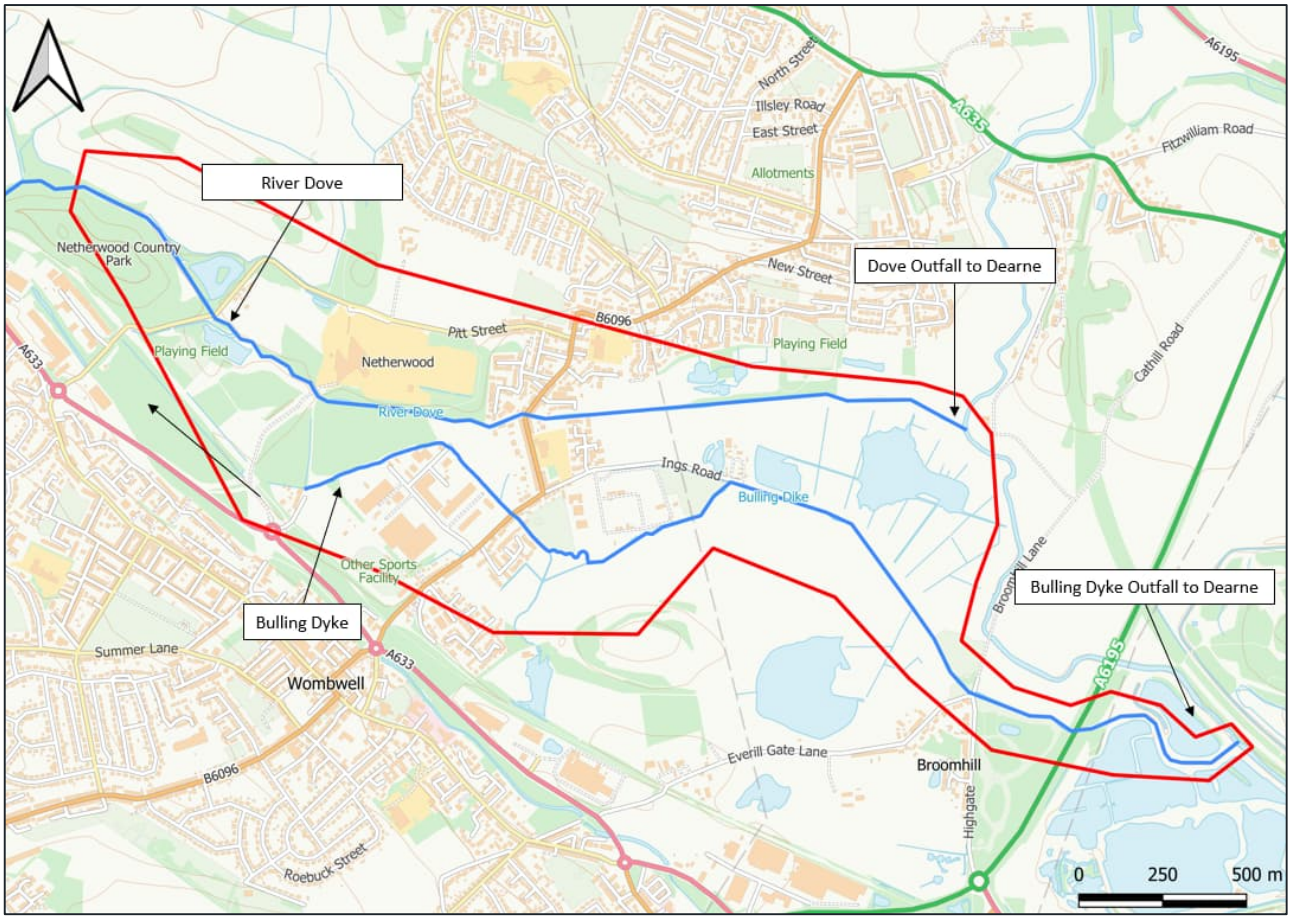

Figure 2-1 - Site Location and Study Area

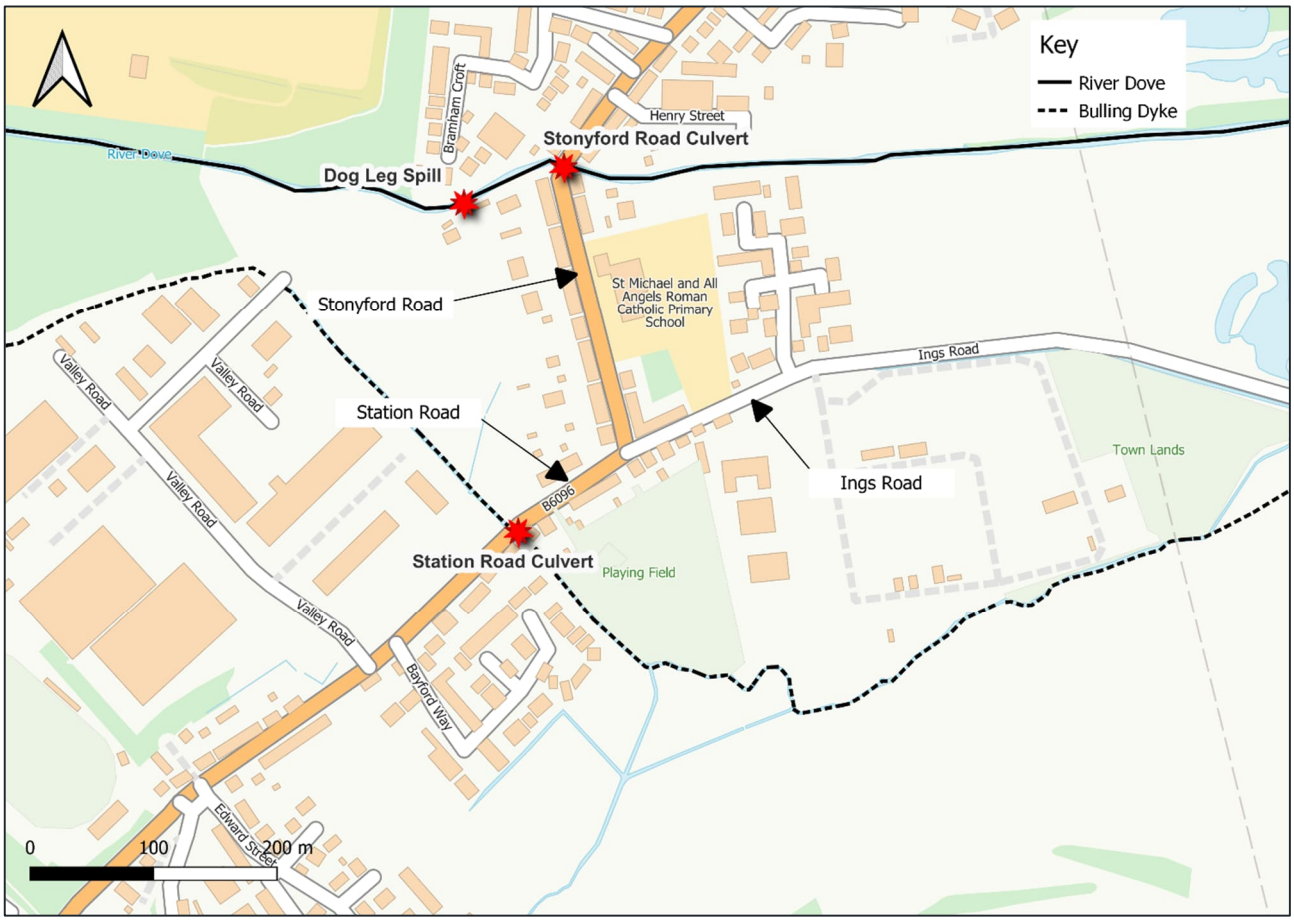

Figure 2-2 – Area of Interest

2.2 OVERVIEW OF DATA GATHERING

Prior to commencing with the main analyses of this study, a data gathering exercise was undertaken to collect a range of primary and tertiary data sources. Multiple sources of information have been used throughout the development of the baseline hydraulic models to inform the study. Table 2-1 summarises the range of data sources that were collected as part of the desk-based review.

To supplement the information collected from the desk-based review, a site reconnaissance exercise was undertaken in July 2022 to provide relevant background information and further the understanding of flood risks and mechanisms prevailing in the site. The findings of the site visit were used to inform each stage of the project, from hydrological analysis through to hydraulic modelling, ahead of defining the Problem Definition.

Table 2-1 – List of Available Information

Information	Date Published
Utility record service plans (PAS 128 Type D)	March 2022
British Geological Survey (BGS) superficial and bedrock geology	July 2022
British Geological Survey (BGS) borehole records	July 2022
Aerial Maps from Google maps, Bing Maps, Magic.	July 2022
Environment Agency flood maps and flood history	July 2022
Previous Flood Studies	July 2022
Site Reconnaissance and photography	July 2022
CCTV survey	January 2023
River channel cross sections survey	July 2023

2.3 SITE RECONNAISSANCE

A site reconnaissance exercise including both desk-based assessment and field survey was conducted in July 2022. The purpose of this activity was to identify any potential constraints or issues that may affect the delivery of the project.

Table 2-2 summarises some of the key constraints and issues identified during the reconnaissance exercise.

Table 2-2 - Constraints summary from desk-based review

Title	Description
Cartography	The site is located approximately 2 miles away from Broomhill landing ground, sited at the former RAF Broomhill. Any works which require a crane may need to be discussed and agreed with the airfield operator in advance of construction.
Watercourses	Bulling Dyke watercourse is an ordinary watercourse under the jurisdiction of Danvm Drainage Commissioners (IDB) who are the lead local flood authority (LLFA) responsible for this watercourse. Any works within Bulling Dyke are likely to require ordinary watercourse consent supported by appropriate assessments for the management of land drainage, flood risk and environmental impact. The River Dove and River Dearne are main rivers under the jurisdiction of the Environment Agency within the Danvm drainage commissioners (IDB) area. Any works within the main rivers are likely to require a flood risk activity permit supported by appropriate assessments for the management of land drainage, flood risk and environmental impact.
Flood Risk	The site is in Flood Zone 2 with a medium probability of flooding from rivers and the sea. Previous studies and flood history show extensive flooding from localised watercourse flooding when the Flood History is summarised in Section 2.4.
Ground	The bedrock geology of the site is the Pennine middle coal measure formation consisting of mudstone, siltstone, and sandstone. The site is partially overlain with alluvium superficial deposits consisting of a clay, silt, sand, and gravel. In parts of the site, no superficial deposit information is available. Borehole records are available for the site indicating ground water levels ranging from 1.5-4m below ground level within the site. The Broomhill Flash nature reserve is to the east of the site with marshy ground observed during site reconnaissance. The site is located within a coal mining reporting area.
Utilities	Utility record service plans available denote the presence of utilities within the vicinity of station road. This includes buried and overhead telecommunications, buried low and medium pressure gas, buried 11kV and LV electricity, water supply and foul sewerage. The Wombwell waste water treatment works are located east of the study area.
Culverts	Three culverts are present on Bulling Dyke within the study area. For more information refer to section 2.4.
Drainage	Surface water and highway drainage is present on Bulling Dyke within the study area. For more information refer to section 2.4.

2.4 REVIEW OF FLOOD HISTORY AND PREVIOUS STUDIES

FLOOD HISTORY

As outlined in Section 1.3, there are several key flood risk mechanisms within the site, primarily fluvial. The River Dove responds rapidly to rainfall events which has led to difficulties in providing flood warnings to local residents. Owing to this risk, there are various sites within Wombwell and the surrounding areas that have experienced flooding for a number of years according to a range of anecdotal evidence, although there is limited information regarding historic flooding in the area in part due to lack of gauging of flows along the River Dove.

In June 2007, Wombwell and the surrounding area flooded twice during the wettest month in Yorkshire since records began. Records from BMBC suggest that up to 194 properties may have been affected, with significant impacts to the Station Road area to the South of Stonyford Bridge.

More recently in November 2019 Barnsley experienced heavy rainfall equivalent to a 1 in 23-year rainfall event. The incident resulted in 100 residential properties and 14 commercial properties being flooded internally. The caravan site, Cotterdale Gardens, and Station Road (including Elm Cottages) were the areas worst affected by flooding.

Additional recorded flood events include the 2000 autumn floods and January 2008 floods, with the area continuing to come close to flooding in recent years.

A flood history map from the Environment Agency showing the recorded flood outlines of historic flood incidents can be seen in Appendix A.

There are a number of embankments along the River Dove and Bulling Dyke, the majority of which are maintained by the Environment Agency (Appendix A). As the embankments are downstream of the area of interest they provide limited protection from the River Dove and Bulling Dyke to the properties at risk of flooding in the Station Road and Stonyford Road vicinity.

OPTIONS VIABILITY STUDY (JACOBS, 2009)

A viability study was completed for the catchment by Jacobs in September 2009 in response to the 2007 floods (Appendix B). The study built on an initial assessment of the flood problem to determine if a flood risk management scheme would be economically viable. ISIS hydraulic models of the River Dove and Bulling Dyke were constructed by JBA consulting for the project and a detailed technical review, economic analysis and environmental assessment carried out by Jacobs. The study identified flooding in Wombwell to be caused by insufficient channel capacity which caused the River Dove to spill at Pitt Bridge and the Dog Leg (see Section 2.5 Key Areas of Interest for overview on flood mechanisms), in addition to out of bank spills along the Bulling Dyke at Station Road culvert and the Caravan Site.

The report went on to detail catchment wide management strategies for length of the Dove from Worsborough reservoir to the west of the confluence with the River Dearne. It demonstrated that flood risk management options including raised defences and storage would reduce the risk of flooding to properties from the River Dove and Bulling Dyke, and that these options were both economically and environmentally viable.

PROJECT APPRAISAL REPORT (BARNSLEY MBC, 2013)

BMBC produced a project appraisal report (Appendix B) in 2013 with the aim of bringing forward a robust case to secure the support of the Environment Agency to permit Flood Defence Grant in Aid (FDGiA) funding to construct a raised flood defence to protect the area proposed for a development at the rear of the properties to Stonyford Road. It was concluded that the construction of a raised flood defence along the northern boundary of the development site on the north and south banks of the River Dove would be the most economically advantageous option and would satisfy the needs of a wide range of stakeholders. It was concluded that the flood defence would provide benefit to for around 188 properties currently at significant risk adjacent to the River Dove in Low Valley.

LOW VALLEY HYDRAULIC MODELLING – FLOOD MAP CHALLENGE (ENZYGO, 2018)

Enzygo produced a technical note (Appendix B) detailing the approach and results of a hydraulic modelling investigation carried out for the River Dove and Bulling Dyke, with the aim of launching a flood map challenge on the backdrop of a local planning applications. A 1D-2D linked Flood Modeller hydraulic model was constructed using from an existing 1D HEC-RAS model of the River Dove developed by Opus in 2013, combined with a 1D ISIS model of the River Dove and the Bulling Dyke developed by JBA as part of the Jacobs 2009 Options Viability Report. Flood mapping demonstrated that there were substantial differences in the flood extents in the Low Valley area compared to the Environment Agency's online flood mapping.

With regards to key flood risk mechanisms, the model suggested that although areas on the right bank of the River Dove upstream of Stonyford Bridge remain a risk, the removal of the dilapidated Pitt Bridge and its replacement with the New Bridge has eliminated the associated flood mechanism and significantly reduced flood extents in the area. This concentrated the primary sources of flooding to Stonyford Road and Station Road on the River Dove right bank 'Dog-leg' spill and the interaction with the Bulling Dyke upstream of the Station Road Culvert.

2.5 KEY AREAS OF INTEREST

The data collection exercise (in the form of site reconnaissance and a review of previous studies and flood history) was used to inform an up-to-date understanding of the key flood risk mechanisms in the Stonyford Road and Station Road area of Wombwell, prior to commencing modelling in this study.

The key flood mechanisms are summarised as follows:

- **Dog-Leg Spill** – Spills from the right bank of the River Dove immediately upstream of Stonyford Bridge at the 'Dog-Leg'. Flood waters originating from this spill impact properties on Stonyford Road, Station Road, Ings Road, and a Waste Water Treatment Works (WWTWs) located off Ings road.
- **Upstream of the Dog-Leg Spill** – Spills from the right bank of the River Dove. Flood waters affect the Valley Road Industrial Estate and flow into the Bulling Dyke, increasing flows in the ordinary watercourse channel to heighten flood risk in the vicinity of Station Road.
- **Station Road Culvert Spill** – Flows are surcharged around the along the Bulling Dyke due to limited capacity to convey flood waters. This impact of this flood mechanism to surrounding area of Station Road is exacerbated by accompanied flows from Upstream of the Dog-Leg Spill on the River Dove.
- **Caravan Site Spills** – A combination of left bank spills from low spots in the embankment along the Bulling Dyke and right bank spills from the River Dove has potential to cause flooding to the caravan park off Ings Road. This can be exacerbated when flows in the River Dearne are high and back up in the River Dove and/or when the River Dearne overtops its embankments in to the floodplain to the west of the site.

An overview of the key flood risk mechanisms can be seen in Figure 2-3. Historically, flooding from the Bulling Dyke has been closely linked to floodwaters originating from the Pitt Street Bridge along the River Dove, which directed water to the top of the Bulling Dyke. The removal of this bridge has since removed the flood risk mechanism directing flows to the most upstream point of the Bulling Dyke.

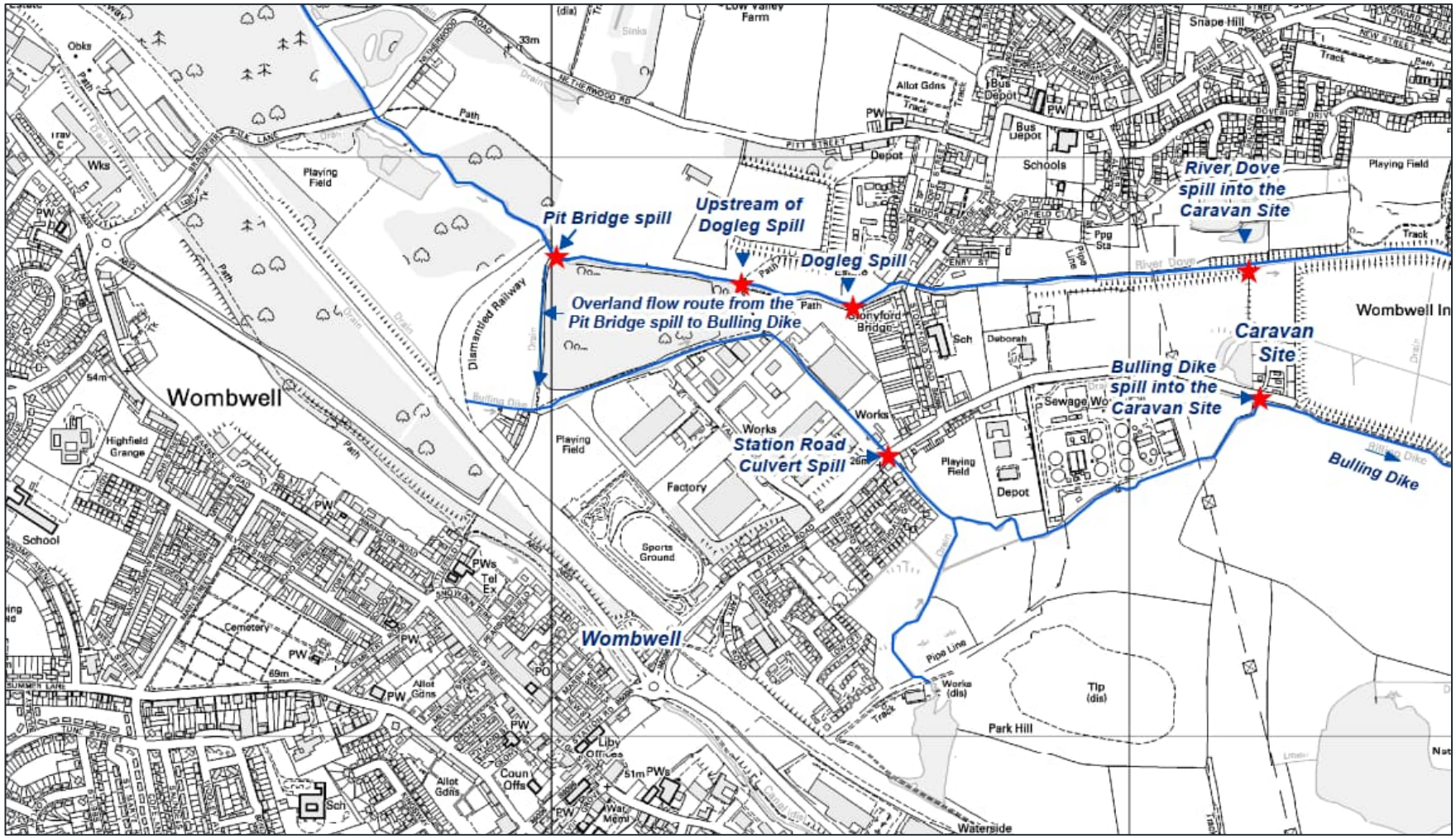

Figure 2-3 - Key flood mechanisms (Jacobs, Dove and Dearn Options Viability Study, 2009)

2.6 SURVEYS AND INVESTIGATIONS

Having undertaken a data collection exercise to gain an understanding of the flood risk mechanisms relevant to the area of interest, a series of site-specific surveys were commissioned to support the hydraulic model update ahead of determining the problem definition (Table 2-3).

Table 2-3 - Surveys and investigations summary

Survey	Date Complete	Appendix Ref	Comments
Watercourse Survey	July 2023	C	Including Bulling Dyke and adjacent length of the River Dove.
Topographic Survey	July 2023	C	Selected reaches of topographic levels on river banks
Condition and connectivity survey	December 2022	C	Survey of drainage, sewerage, and culvert infrastructure, mostly on Station Road.

WATERCOURSE AND TOPOGRAPHIC SURVEY

A watercourse survey was required of the Bulling Dyke and River Dove in the vicinity of Wombwell to inform and support the generation of a new baseline hydraulic model and determine the flood risk mechanisms in the key areas of interest. The scope of the survey included:

- Survey of open channel cross sections
- Survey of open channel structure faces (particularly culverts, bridges, and weirs)
- Survey of riverbank tops (topographic features)

Watercourse survey data was collected within the required reaches of the River Dove and Bulling Dyke in July 2023, with revisions made to the Bulling Dyke survey in December 2023. The survey specification determined boundary cross-section locations at a sufficient upstream location on the River Dove to account for any backwater effects of key structures. The upstream boundary cross-section for the Bulling Dyke was located near its source at Littlefield Lane. The downstream boundary cross section locations for both watercourses are their respective outfalls into the River Dearne.

The River Dove survey consisted of 17 open channel cross-sections and 6 in-line structures (with their associated upstream and downstream sections). The Bulling Dyke survey consisted of 19 open channel cross-sections, and 9 in-line structures (with their associated upstream and downstream sections).

Six bank reaches in total required survey at locations which represent key overbank spills that control the onset of fluvial flooding, the location of which can be seen in Figure 2-4 . These were:

- Right and left bank of the Bulling Dyke running parallel to Stonyford Road and to the south of Valley Road industrial estate.
- Right and left bank of the River Dove in the vicinity of the Dog Leg.
- Right bank of the River Dove upstream of the Stonyford Road Culvert.
- Left bank of the Bulling Dyke directly south of the Caravan Park

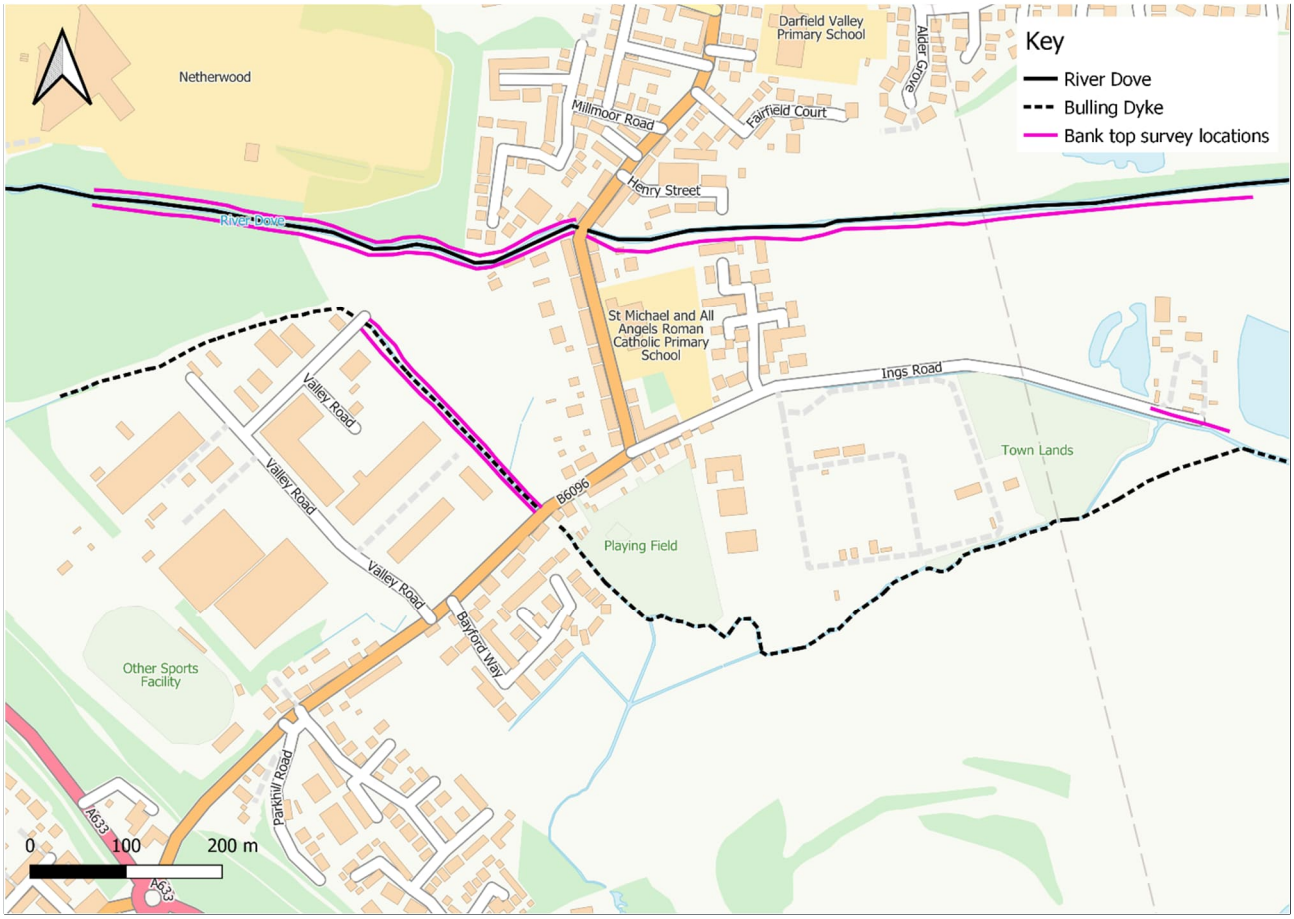

Figure 2-4 - Bank Top Survey Locations

CONDITION AND CONNECTIVITY SURVEY

CCTV survey of the Station Road Culvert was collected to get detailed understanding of the condition and use of the culvert, to obtain sewer asset information to confirm hydrological pathways/connections, and to benefit further stages of assessment beyond this initial problem definition phase.

The site locations are as follows:

- Littlefield Lane, Wombwell, Barnsley, S73 8DG
- Valley Road, Wombwell, Barnsley, S73 0BS
- B6096 Station Road, Barnsley, S73 0BS

The survey included:

- All assets condition and connectivity survey
- Pipework and chambers defect survey by CCTV

A video of station road culvert was recorded on the 12th of December 2022. The culvert was shown to be constructed of brickwork, with a transition to concrete mid-way down the length. The culvert is poorly maintained with settled deposits of rubble at the downstream end accounting for a 20% cross-sectional area loss.

3 HYDROLOGY AND MODELLING

3.1 HYDROLOGICAL FLOW ESTIMATION

Two previous flood estimations had been undertaken for the River Dove and Bulling Dyke (2009 JBA and 2016 JBA). Given the updates to methodology preferences of the Flood Estimation Guidelines and with the availability of latest HiFlows peak flows and FEH22 rainfall datasets, an updated Flood Estimation Calculation was undertaken.

PREVIOUS FLOOD ESTIMATIONS

An overview of the JBA 2009 hydrological assessment was available for the River Dove and Bulling Dyke, including details such as preferred FEH methodology and donor stations used in QMED estimation, plus flow splits. The JBA 2016 Hydrological Assessment update was not available, which was the source of the flows in the 2018 Enzygo Model. Therefore, whilst high-level comparisons of flow contributions were possible, direct comparison of the approaches and methodologies of flow estimations was not undertaken.

UPDATED FLOOD ESTIMATION

Point inflow hydrographs were required on the River Dove and Bulling Dyke for input to the hydraulic model. The default critical storms of the Bulling Dyke (4.5 hour Summer) and River Dove (11 hour Winter) were modelled in separate simulations for both watercourses. This was undertaken to ascertain any variation in flood risk mechanisms between the different storm profiles, to support the derivation of the critical storm for the area of interest as a whole. The 11 hour Winter storm was decided as the critical storm.

To determine the peak flows, a preference was given to the Statistical Method for the River Dove as it is based on real data and suited for larger catchments with low to moderate urbanisation. On the Bulling Dyke catchment, a preference for peak flows was given to the ReFH2 flows on the basis that the method can be better suited to more significantly urbanised catchments.

Inflow hydrographs were derived from ReFH2. For the River Dove, ReFH2 hydrographs were scaled to statistical peaks using the hybrid method. In total 4 point inflows were proposed, and 3 modelled as shown in Table 3-1. The Flood Estimation Calculation Record is available in Appendix D.

Figure 3-1 shows the hydrological catchments of the study.

Table 3-1 – Modelled inflow units

Hydrology Reference	Model Unit	Description
RD_Upstream	RD2816	River Dove catchment down to Stonyford Road Bridge
RD_INT	N/A	An intervening flow was proposed on the River Dove (RD_INT) for the area between Stonyford Bridge and the River Dearne, however flow discontinuities occurred during QMED estimation and so this was not required.
BD_Upstream	BD3344	Bulling Dyke catchment down to Station Road Bridge
BD_INT	BD_INT	Intervening flow representing the Bulling Dyke catchment between Station Road Bridge (DD_Upstream) and River Dearne (BD_Dearne).

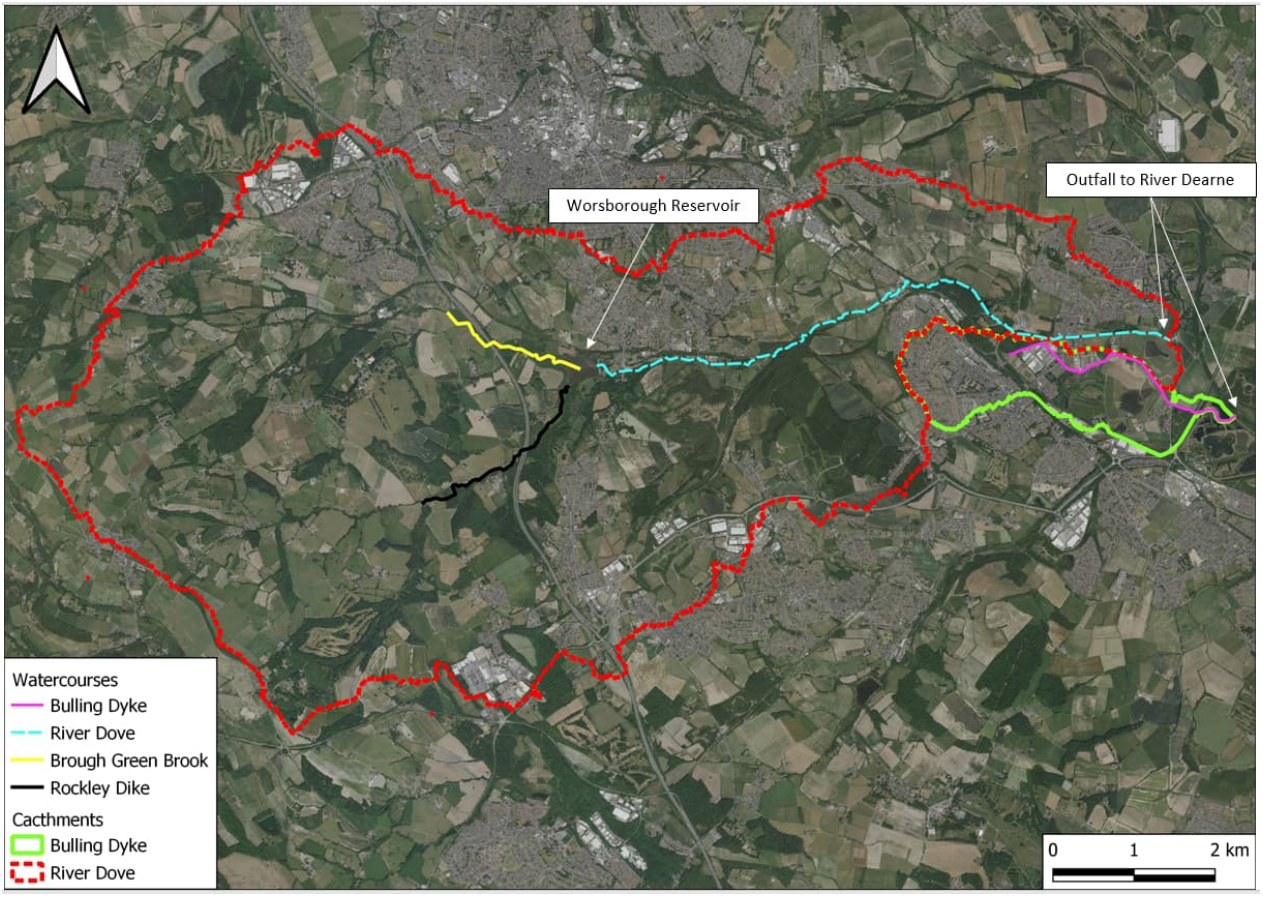

Figure 3-1 – Bulling Dyke and River Dove Catchments

3.2 BASELINE HYDRAULIC MODEL

MODEL OVERVIEW

A hydraulically linked 1D Flood Modeller Pro (FMP) and 2D TUFLOW model covering the River Dove and Bulling Dyke was developed. The two watercourses operate independently during low flow conditions and as such have been simulated as two separate reaches in the same model. All key structures, including Stonyford Road Bridge and Station Road Culvert have been represented in the model. The latest available LiDAR data, CCTV condition survey and the WSP watercourse survey (Section 2.6 Surveys and Investigations) were all used to inform build the model.

The River Dearne is modelled as the downstream boundary for both watercourses with a fixed level reflecting the maximum 10% AEP levels, extracted from the Don-Dearne model (2018) at the locations closest to the Dove and Bulling Dyke outfalls respectively. This is applied in the 1D model across all scenarios and return periods. As such, the role of the River Dearne in contributing to flood risk in the area of interest has not been fully assessed in this study, with the focus primarily on the risk originating from the River Dove and Bulling Dyke.

Full details of the hydraulic model construction and associated parameters are provided in Appendix E Technical Modelling Log. The limits of the 1D-2D model are shown in Figure 3-2.

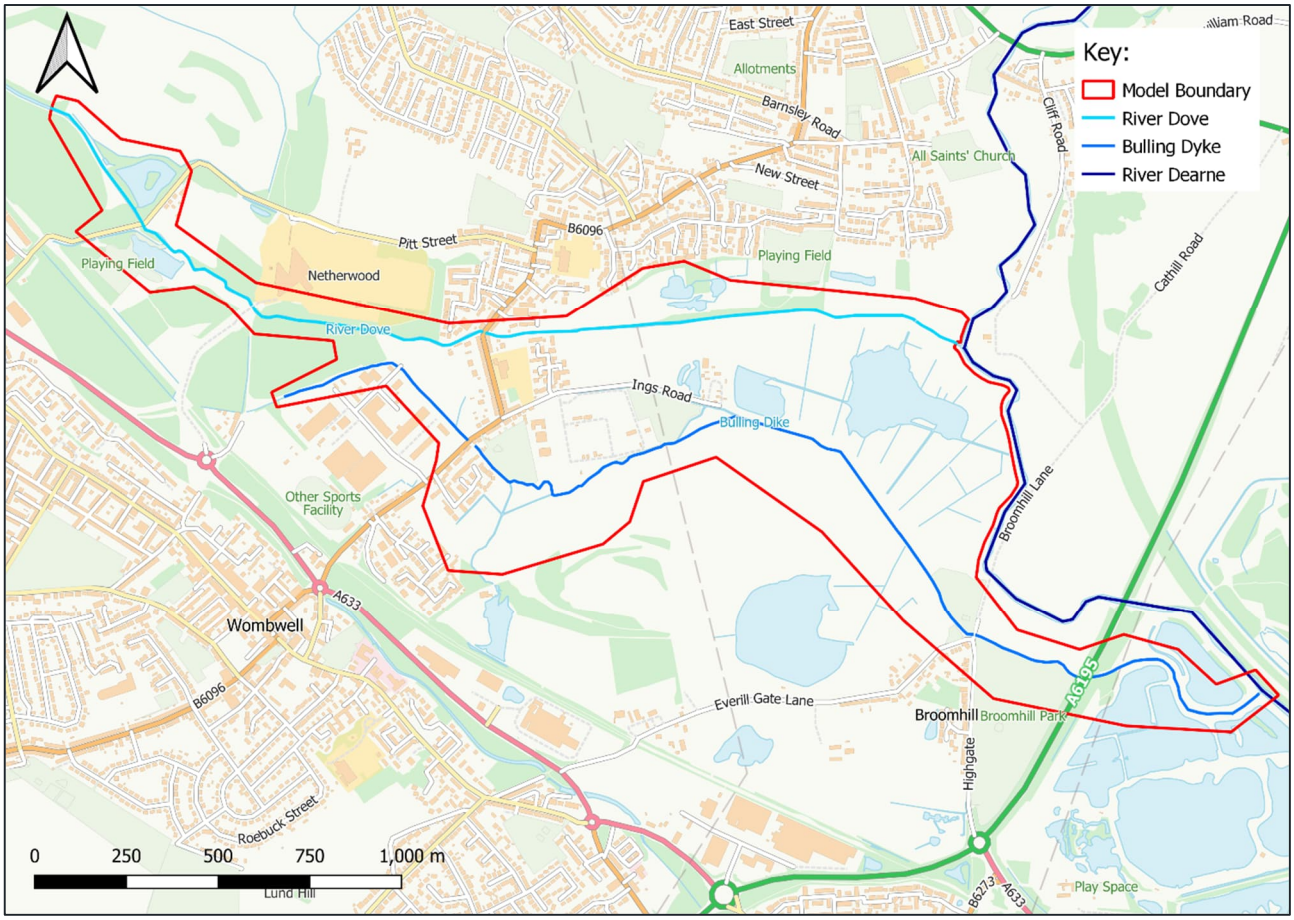

Figure 3-2 – Modelled watercourse extents and boundary

MODELLING SCENARIOS

To support the problem definition, 3 scenarios were simulated:

- **11 hour Winter Storm – River Dove and Bulling Dyke**. This scenario was simulated to understand the flooding impacts of a critical storm profile associated with River Dove.
- **4.5hr Summer Storm – River Dove and Bulling Dyke**. This scenario was simulated to understand the flooding impacts of a critical storm profile associated with the Bulling Dyke.
- **4.5hr Summer Storm – Bulling Dyke only (baseflow on River Dove).** This scenario was simulated to understand the flooding impacts of a localised flood on the Bulling Dyke, without the influence of the River Dove.

This outcome of these scenarios will highlight the relative importance of each watercourse in determining the flood risk mechanisms in the area of interest.

MODELLING EVENTS

To understand the onset of flooding for the different mechanisms in the area, the following return periods have been simulated:

- 2-year
- 10-year
- 20-year
- 30-year
- 50-year
- 100-year
- 100-year +28% climate change
- 1000-year,

The key design event used to map the flood risk mechanisms within the area is the 100-year + 28% climate change return period, which is reflected in the problem definition drawings (Appendix F).

SENSITIVITY TESTS

A blockage scenario has been modelled in which a 67% blockage has been applied to the Station Road culvert on the Bulling Dyke. This scenario was run for the 100-year + 28% climate change return period using the 4.5hr summer storm on the Bulling Dyke only and the 11hr winter storm for the Bulling Dyke and River Dove.

4 PROBLEM DEFINITION

4.1 INTRODUCTION

Following simulation of the 3 scenarios of the Baseline 1D-2D model, it has been possible to establish the flood risk mechanisms to support the problem definition. The key design event used to help identify the key sources of flooding within the catchment was 100yr + 28% climate change.

4.2 FLOOD RISK MECHANISMS

The scenario used to present all flood mapping was the 11-hour winter storm event on the River Dove and Bulling Dyke. Maps of the flood depths at each return period are shown in Appendix G Baseline Flood Maps. A detailed description of the key flood risk mechanisms and the onset of flooding within each area of interest is provided in Table 4-1. Diagrams of the flood risk mechanisms at the key design event are provided in the problem definition drawings in Appendix F.

4.5HR SUMMER STORM – BULLING DYKE ONLY (BASEFLOW ON RIVER DOVE)

A scenario of the Bulling Dyke only with no storm event simulated on the River Dove was modelled to understand the impact the Bulling Dyke has on flooding to properties around Station Road and Stonyford Road, without contribution from the River Dove. Flooding to properties from the Bulling Dyke was onset at the 1 in 1000-year event, occurring due to out of bank spills upstream of the surcharged Station Road culvert. Flooding only occurs along Station Road to the north of the culvert, impacting approximately 12 residential properties with depths of up to 24cm. At Elm Cottages, flood depths reach 12cm. There is no flooding to properties to the south Station Road culvert.

Additionally, the 1 in 1000-year return period simulated on the Bulling Dyke (with no contribution from the River Dove) shows no flooding to the Sewage Treatment Works, despite the combined model suggesting flooding to this location is caused by out of bank spills from the left bank of the Bulling Dyke. These results confirm that the River Dove is a major contributor to flood flows in the Bulling Dyke downstream of the Station Road culvert and exacerbates out of bank spills.

No flooding to properties from the Bulling Dyke occurs in return periods lower than the 1 in 1000-year event.

4.5HR SUMMER STORM – RIVER DOVE AND BULLING DYKE

A scenario of the 4.5-hour summer storm event was simulated on both the Bulling Dyke and River Dove to understand how the influence of the River Dove, using the Bulling Dyke critical storm profile. Figure 4-1 shows a comparison of flood extents between the event simulating the Bulling Dyke only against River Dove and Bulling Dyke. Maximum flood extents increase significantly when the River Dove is simulating a storm event compared to when it is only modelled with baseflow.

At the 1 in 1000-year return period when both the Bulling Dyke and River Dove are modelled, there is flooding to more than 50 properties along Stonyford Road, Station Road, and Cotterdale Gardens. Depths to properties along Station Road reach a maximum of approximately 40cm. At Elm Cottages flood depths reach 27cm, which is an increase of 15cm when compared directly to the 4.5-hour summer storm event for the Bulling Dyke only. There is flooding to Ings Road and the Sewage Treatment Works when the River Dove is modelled, which is not seen under the same conditions for the Bulling Dyke only.

Overall this highlights the contribution of the River Dove to flooding, and the limited impact of the Bulling Dyke even, when simulating the Bulling Dyke critical storm profile.

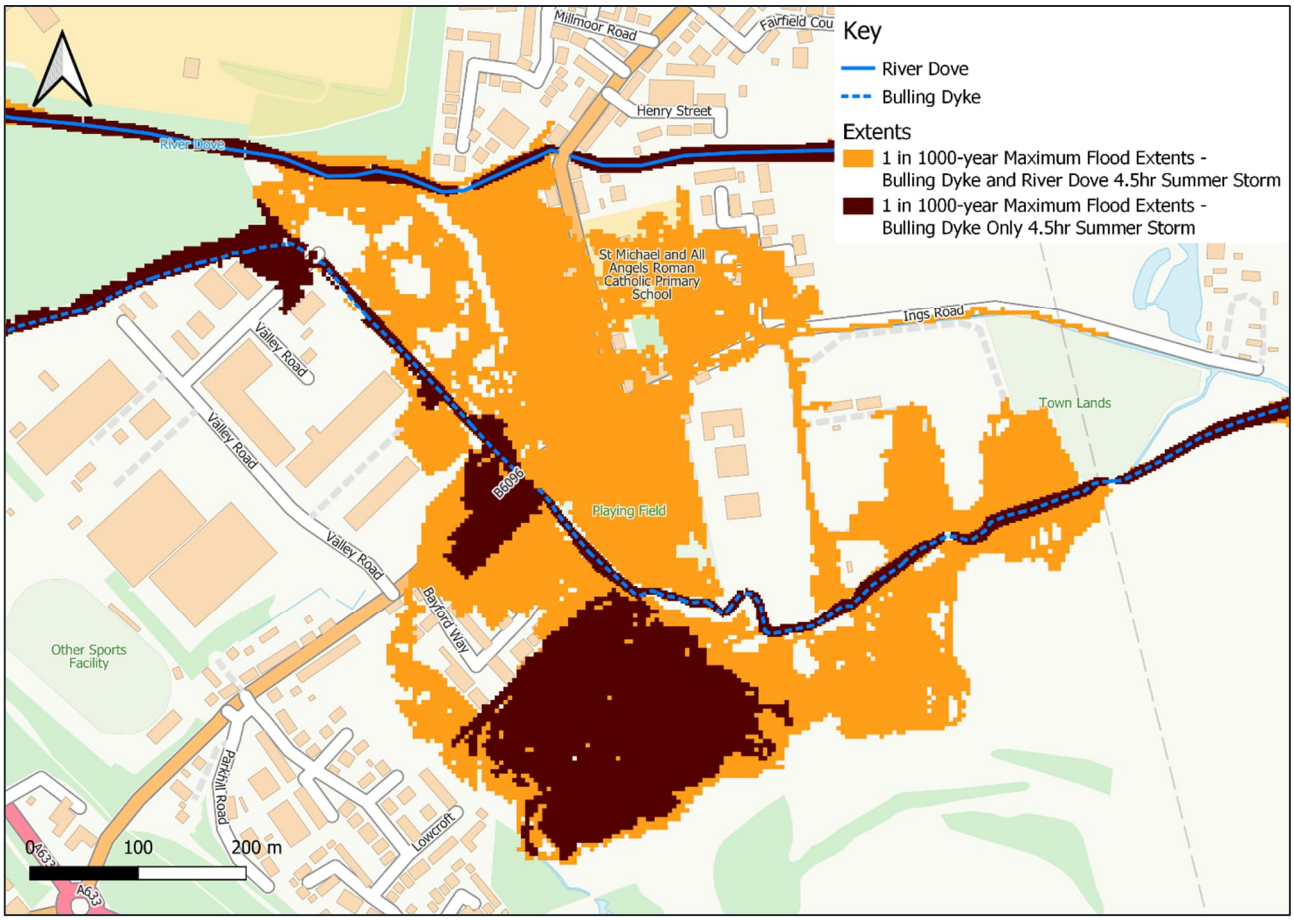

Figure 4-1 - Comparison of Maximum Flood Extents for the 4.5hour Summer Storm Event on the Bulling Dyke only and the Bulling Dyke and River Dove

11 HOUR WINTER STORM – RIVER DOVE AND BULLING DYKE

As the River Dove has been identified as key influence on flood risk within the catchment, the 11-hour winter storm event (critical storm profile for the River Dove) has been simulated on both watercourses. Compared to their respective inflows on summer 4.5hr event, the River Dove had a greater peak whilst the Bulling Dyke had a lower peak. The results across all return periods showed a further increase in flood depths and extents when compared to the 4.5-hour summer storm (Figure 4-2).

The 1 in 100-year + 28% CC event shows increased flooding to Stonyford Road, Station Road, Bayford Road and Cotterdale Gardens and the Sewage Treatment Works compared the equivalent 4.5-hour summer storm return period. Additionally, flooding to St Michal and All Angels Roman Catholic Primary School and Townsend Close is onset with the winter storm event. In total more than 100 residential properties are flooded, and at Elm Cottages flood depths reach 55cm.

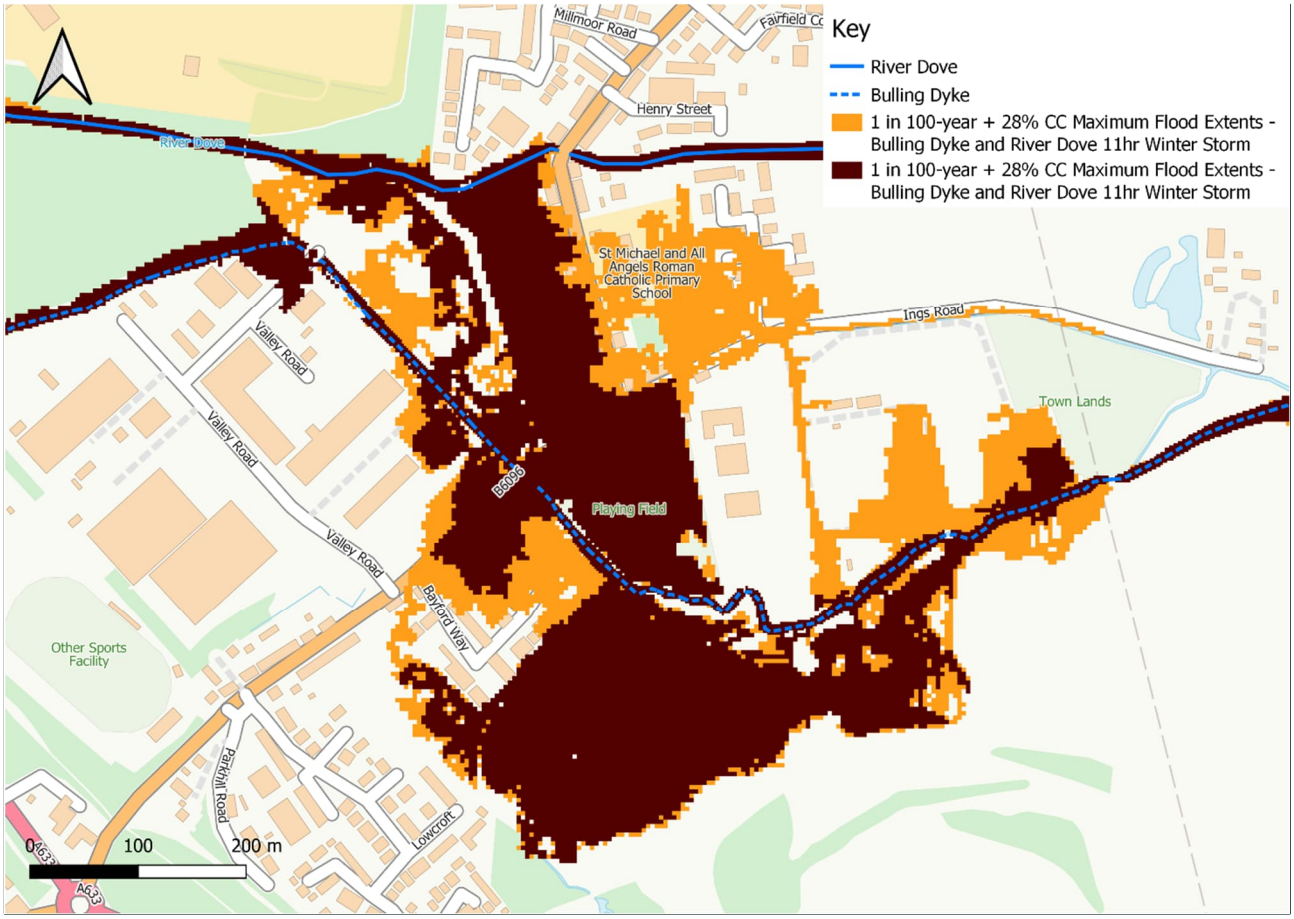

Figure 4-2 - Comparison of Maximum Flood Extents for the 4.5hr Summer Storm Event and the 11hr Winter Storm Event on the Bulling Dyke and River Dove

COMPARISON OF STORM SCENARIOS

The maximum flood extents of the events involving both watercourses is significantly larger around Stonyford Road, Station Road and Ings Road, confirming that the River Dove is the primary source of flood risk in the area. Additionally, the maximum flood extents and depths of the 11-hour winter storm event are larger than the 4.5-hour storm event, which confirms the River Dove as the key influence on flooding.

BLOCKAGE SCENARIO

Applying a 67% blockage to station road culvert results in a small increase to out of bank spills in the vicinity of Station Road and Bayford Way. The blockage scenario for the 1 in 100-year + 28% CC return period using the 11-hour winter storm event on the Bulling Dyke and River Dove increases the number of properties flooded by two when directly compared to the same event with no blockage. Flood depths at Elm Cottages increase by approximately 5 cm. There is no additional flooding to any other properties throughout the catchment as a result of the culvert blockage.

The blockage scenario for the 1 in 100-year + 28% CC return period using the 4.5-hour summer storm event on the Bulling Dyke only shows out of bank flooding to approximately 10 properties on Station Road. The out of bank flooding is limited to the area south of the Station Road culvert only. No other out of bank spills or property flooding occur elsewhere in the catchment. This is an

increase in property flooding when compared to the same event with no blockage, which did not show any out of bank flooding anywhere along the Bulling Dyke.

This further highlights the limited contribution the Bulling Dyke has on flood flows in the area of interest, as even with the addition of a 67% blockage to the Station Road culvert the River Dove is still the driving force of out of bank spills.

Table 4-1 - Key flood risk mechanisms for the 11-hour winter storm event on the River Dove and Bulling Dyke

Area	Flooding Mechanism	Flooding Onset	Mapping Location Reference (Appendix F)
Upstream of the Dog-Leg	Out of bank spills from the River Dove upstream of the Dog-Leg create overland flow paths running South to North towards the industrial estate on Valley Road. This overland flow enters the Bulling Dyke upstream of the Station Road culvert.	20-year return period	A
Stonyford Road St Michael and All Angels Roman Catholic Primary School and Townlands Close	Out of bank spills from the right bank of the River Dove at the Dog-Leg (upstream of Stonyford Bridge) generate flooding along Stonyford Road. At high return periods, the spills from the Dog-Leg cause flooding to St Michael and All Angels Roman Catholic Primary School and properties along Townlands Close.	30-year return period 100-year + 28% climate change return period	B
Station Road and Ings Road	The out of bank spills from the River Dove at the Dog Leg follow an overland flow path down Stonyford Road to the junction with Station Road and Ings Road, where they continue to cause flooding to properties.	10-year return period	C
Bayford Way and Cotterdale Gardens	The River Dove is the driving force of the flooding in this area, as overland flow from the Dog Leg runs along Station Road and continues south along Bayford Way and Cotterdale Gardens. There are limited out of bank spills from the Bulling Dyke in the vicinity of the Station Road Culvert. The water levels in the Bulling Dyke are exacerbated by the out of bank spills from the River Dove following overland flow paths and entering the Bulling Dyke.	100-year return period	D
Sewage treatment works	Flooding is a result of out of bank spills from the left bank of the Bulling Dyke. The flooding in this area is exacerbated by the impact of floodwater from the River Dove entering the Bulling Dyke further upstream, as well as overland flow from the River Dove along Ings Road	100-year return period	E
Caravan park	Flooding in this area is a result of out of bank spills from the River Dove following overland flow paths along Ings road. The model does not show any contribution to the flooding in this area from the Bulling Dyke. Flooding may be exacerbated in this area when water levels in the River Dearne are high, however no joint probability has been carried out to confirm this.	1000-year return period	F
Pitt Bridge	There is no flooding from the River Dove at this location following the replacement of Pitt Bridge.	N/A	G
Bradberry Baulk Lane	A localised region of flooding from the River Dove covering a wooded area, playing fields and ponds. The flood water does not follow any overland flow routes and does not contribute to flows in the Bulling Dyke. There is no flooding to properties at this location.	10-year return period	H

4.3 PROBLEM UNDERSTANDING AND DEFINTION

INFLUENCE OF THE RIVER DOVE AND BULLING DYKE

The primary source of flood risk to properties in the vicinity of Station Road and Stonyford Road is the River Dove, because of spills from the Dog Leg upstream of Stonyford Road culvert. The spills from the Dog-Leg are also the key source of flooding to Ings Road, Bayford Way and Cotterdale Gardens, Elm Cottages, Townslands Close, the primary school and the caravan park. When the watercourse is simulated individually, the contribution of the Bulling Dyke to out of bank spills is limited to the 1 in 1000-year return period, reflecting an insignificant control on flooding to Stonyford Road and Station Road

The Bulling Dyke causes flooding to the sewage treatment works via out of bank spills from the left bank in the 11-hour winter storm event for the Bulling Dyke and River Dove only. When the Bulling Dyke is simulated individually in the 4.5-hour summer storm event, there are no out of bank spills and no flooding to the sewage treatment works. This reflects how out of bank spills in the Bulling Dyke are driven by floodwater form the River Dove entering the Bulling Dyke in the vicinity of the Station Road culvert, increasing overall flows in the channel.

When a blockage to the Station Road culvert is introduced, there is very limited overall impact to flood depths and property flooding. The blockage causes a slight increase in out of bank spills from the Bulling Dyke, increasing the number of properties flooded along Station Road and Bayford Way by 2. The contribution of the Bulling Dyke to property flooding is still limited even under a worst case-scenario event, as the River Dove causes flooding to the majority of properties.

INFLUENCE OF THE RIVER DEARNE

Flooding onset may be underestimated in some locations, in particular the caravan site, as the interaction of the River Dearne with the Bulling Dyke and the River Dove as part of joint flooding probability has yet been fully investigated in this study. When flows are high in the River Dearne, it has the potential to back up and increase flows in each of the other two watercourses, increasing out of bank spills and contributing to flood risk.

The Environment Agency's Depth Grid Map for the 1% AEP + 30% CC including both the River Dove and River Dearne in the area of interest (Appendix A) shows that the Caravan park is inundated with over 2m of flood water. The equivalent return period from the model runs carried out in this investigation (1 in 100-year + 28% CC) including just the River Dove and Bulling Dyke do not show any flooding to the Caravan park. This indicates that flooding in this area is significantly influenced by the River Dearne.

4.4 COMPARISON TO FLOOD FISTORY AND PREVIOUS STUDIES

Previous studies have identified the depression along the left bank of the River Dove known as the Dog Leg to be the primary cause of flooding. When river levels are high in the Dove, the low point is overtopped and causes inundation to properties and gardens along Station Road and Stonyford Road. This is further exacerbated by flooding from the Bulling Dyke and surface water run-off.

Following modelling of the River Dove and Bulling Dyke by Jacobs in 2009, fluvial flooding from the River Dove at Pitt Bridge and the Dog Leg were identified as the key flood risk mechanisms. In total 164 properties were shown to flood in their modelled 1 in 100-year event (139 residential properties and 39 non-residential properties). Updated modelling by Enzygo in 2018 following the removal of

the dilapidated Pitt Bridge and its replacement with New Bridge highlighted the elimination of flood risk mechanisms at this location which significantly reduced the extent of flooding. Their modelled 1 in 100-year event showed flood extents covering Stonyford Road and Station Road, the sewage treatment works and the caravan site. The modelled extents showed no flooding to properties along Ings Road, Townsland Close, Bayford Way or Cotterdale Gardens.

The results from this model build are closely aligned with previous studies (particularly the Jacobs 2009 study), with the key flood risk originating from the Dog Leg on the right bank of the River Dove. The number of properties flooded in the 1 in 100-year return period in this model is 204. This is a combination of commercial and residential properties (including sheds and garages), with no thresholds applied.

4.5 CONCLUSION OF THE PROBLEM DEFINITION

This problem definition has identified the River Dove as the main source of flood risk in the area of interest. In the baseline scenario (in which regular maintenance would apply to key assets such as the Station Road culvert, similar to a 'Do Minimum' condition), the Bulling Dyke does not contribute to any additional property flooding that is not already onset by the River Dove at lower return periods and to greater flood depths.

Based on these results, any future options considered when developing a Flood Alleviation Scheme should focus on solutions which target the River Dove. As part of any solution, it may be helpful to consider increasing the capacity of the Bulling Dyke to attenuate flows originating from the River Dove. However, efforts to mitigate flood risk by solely focusing on improvements to the Station Road culvert are unlikely to result in any significant reduction to the number of properties at risk from flooding.

5 LIMITATIONS, RECOMMENDATIONS AND FURTHER WORK

5.1 LIMITATIONS OF THE STUDY

The primary limitations of the work undertaken in this commission are as follows:

- The contribution of the River Dearne to flooding in the area of interest has not been fully considered, and was limited to a fixed head-time boundary using a 10% AEP maximum level from the Don-Dearne model (2018).
- The Flood Estimation calculations were limited to ungauged methodologies, for example without use of Worsbrough Reservoir data where the rating curve was deemed inappropriate for use. Refer to Appendix D for more information on the limitations of the Flood Estimation.

5.2 RECOMMENDATIONS FOR FURTHER WORK

With respect to potential updates to the baseline flood model, the following recommendations are made:

- **River Dearne modelling** – future work might benefit from a greater understanding of the combined impact of the River Dove, Bulling Dyke and River Dearne to flooding in the study area. This could be done by including the River Dearne in the model that covering the reach from the Dove outfall to the Bulling Dyke outfall (with shot extensions upstream and downstream to take account of any localised effects of interactions). This could be accompanied by a joint probability analysis to include the River Dearne in the model to understand the realistic and/or worst-case permutations that would results in the critical flooding profile for the area of interest. This might be of more benefit to some receptors than others, particularly the caravan park which showed minimal flooding when flood risk was sourced only from the River Dove and Bulling Dyke.
- **Worsbrough Reservoir Guage analysis** – a range of hydrological analyses could be undertaken to improve the estimation of ReFH2 parameters such as hydrograph shape and Time to Peak, using the stage data from Worsbrough Reservoir.
- **Further Verification** – flood frequency analyses could be undertaken to understand the return period of more significant events, such as June 2007 and November 2019. This would benefit from improvements to the rating curve at the Worsbrough Reservoir, which the EA are looking at (as of March 2024).

Ahead of a prospective Feasibility Study, the following activities should be discussed:

- Option Identification and Appraisal – this would include hydraulic modelling of the proposed options, followed by an identification of a preferred option.
- Business Case Preparation – includes economics assessment with option costings, in line with a FDGiA calculator.
- Property threshold survey – this would improve property counts if an economics assessment is required by confirming the depth above which internal flooding occurs.

5.3 OTHER

Third party information has been used in the preparation of this report, which WSP UK Ltd, by necessity, assumes is correct at the time of writing. Whilst all reasonable checks have been made on data sources and the accuracy of the data, WSP UK Ltd accepts no liability for this data.

Appendix A

ENVIRONMENT AGENCY MAPPING

Appendix B

PREVIOUS STUDIES

Appendix C

SURVEYS

Appendix D

FLOOD ESTIMATION CALCULATION RECORD

Appendix E

HYDRAULIC MODELLING REPORT

Appendix F

PROBLEM DEFINITION DRAWINGS

Appendix G

BASELINE FLOOD MAPS

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