

Flood Investigation Report South Craven



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Records of the public sewer system included are a facsimile of the statutory record provided by Yorkshire Water Services Ltd. For the purposes of this report minor sewers and other non-relevant data have been omitted from the plans for clarity.

Purpose

This document has been prepared specifically for the purpose of meeting the requirements of Section 19 of the Flood and Water Management Act 2010.

The purpose of this report is to investigate which Risk Management Authorities (RMAs) had relevant flood risk management functions during the flooding incident, and whether the relevant RMAs have exercised, or propose to exercise, their risk management functions (as per section 19(1) of the Flood and Water Management Act 2010). It does not address wider issues beyond that remit, nor include recommendations for future actions.

The supporting data has been put together based on records of internal property flooding and road closure information from a variety of sources. While every effort has been made to verify the locations of the Section 19s identified, the nature of the data and the methods used to collate this information mean that it does not include every occurrence of flooding. This data only identifies where flooding has been reported and is indicative only.

Acknowledgements

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North Yorkshire County Council Flood Risk Management Team

North Yorkshire County Council Highways Department

North Yorkshire County Council Emergency Planning Unit

The Environment Agency

Yorkshire Water Services Ltd

Craven District Council

South Craven Catchment Flood Group

Councilor Barrett

Sutton in Craven Community Primary School

Dates of Inspections

Thursday 15th September and 17th November 2016

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1 Executive Summary

On the 26th of December 2015, the South Craven area experienced flooding from rivers, surface water and ground water. The flooding was a result of the significant rainfall event on the 25th and 26th December and saturated ground conditions resulting from almost record breaking rainfall in the November and December.

Data shows that in the Aire catchment, November 2015 was the second wettest since 1909. In addition, the Aire catchments also received almost twice the long term average rainfall for December. So it was onto an already saturated catchment that the rainfall of Christmas Day and Boxing Day fell. This resulted in an additional 100% of the month's long term average rainfall falling within 48hours in some locations.

Six communities in South Craven have been identified as being most affected by the Boxing Day Event, resulting in the internal flooding of 74 properties in Low Bradley, Cononley, Kildwick, Cross Hills, Glusburn, and Sutton-in-Craven. All these communities have a history of flooding although mechanisms and sources may have differed in the past.

The saturated catchment and significant rainfall event resulted in a substantial amount of surface water runoff. Surface water flooding affected each of the six communities, the steep surrounding agricultural land quickly conveyed the surface water towards the affected communities. Historic masonry culverts became overloaded resulting in flooding in Low Bradley and Kildwick, in addition this intensified the flooding in Sutton-in-Craven. The highway drainage systems across the South Craven area became overwhelmed, in some cases this was exacerbated by gravel and sediment conveyed by the surface water blocking highway gullies. Surface water from agricultural land discharged onto the highways resulting in significant flows on the roads, in a number of cases roads were described as looking like 'rivers', surface water conveyed by highways effected the flooding in all six communities.

As the surface water in the catchment progressed downhill there was a sharp rise in the river levels of the Aire, Holme Beck, Eastburn Beck and other smaller watercourses. The River Aire over topped its banks resulting in the flooding of properties in Cononley, Kildwick and Cross Hills. The river levels in the Sutton Beck, Holme Beck, Long Dike and Mill Ing Beck cause the rivers to come out of bank in some sections; resulting in property flooding in Sutton-in-Craven, restricting use of essential infrastructure in Sutton-in-Craven and on the A629. High levels in many of the local watercourses restricted the ability of surface water systems to discharge, exacerbating flooding to a greater or lesser extend in all locations.

Ground water caused flooding in Sutton-in-Craven and aided flooding in Glusburn. Ground water flooding was a result of prolonged heavy rainfall increasing aquifer

depths, this increased the flooding from the surcharge of underground masonry culverts and drains.

There are common sources impacting the communities of South Craven, with the interaction of flood waters in upstream communities effecting communities downstream. Some of the surface water in causing flooding in Glusburn continues on to effect properties in Sutton-in-Craven. The River Aire directly effects the communities of Cononley, Cross Hills and Glusburn, in addition the main Aire river levels are likely to have impeded the discharge of other local rivers and watercourses.

This report has identified the actions and responses of the Risk Management Authorities (RMAs) who have responsibilities for the management of flood risk in the South Craven area. It is understood that all Risk Management Authorities have undertaken appropriate activities in response to the flood event, in line with their duties and responsibilities under the Flood & Water Management (2010) Act.

The actions of local residents, emergency services and Risk Management Authorities reduced the severity of the flooding through the issuing of flood warnings, sandbagging, pumping, closure of roads and the clearing of drains during the event. Without the quick decisive actions of these parties the flooding in South Craven would have been significantly more extensive.

2 Introduction

2.1 Flood and Water Management Act (2010)

In his review of the summer 2007 floods, Sir Michael Pitt recommended that local authorities should be given a duty to investigate flooding.

The Flood and Water Management Act 2010 (FWMA), defines the roles and responsibilities of 'Risk Management Authorities' and designates the unitary or upper tier authority for an area as Lead Local Flood Authority (LLFA).

The LLFA has responsibility for leading and co-ordinating local flood risk management. Local flood risk is defined as the risk of flooding from surface water runoff, groundwater and small ditches and watercourses (collectively known as ordinary watercourses). The responsibility to lead and co-ordinate the management of tidal and fluvial flood risk remains that of the Environment Agency (EA).

The Act also implements the recommendations made by Sir Michael Pitt that local authorities should have a duty to investigate flooding from all sources.

2.2 Section 19 Investigation Requirement

North Yorkshire County Council (NYCC), as LLFA, has a responsibility under Section 19 of the FWMA to investigate significant flood incidents in its area. Section 19 States:

(1) On becoming aware of a flood in its area, a lead local flood authority 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.

Section 14 of the FWMA grants the LLFA power to request information associated with its functions. These powers have been exercised in the preparation of this report.

2.3 Trigger for Section 19 Report

The incident has been assessed in line with the criteria set out in Section 3 of the North Yorkshire County Council Local Flood Risk Strategy (2015) and has been judged to warrant a formal Section 19 investigation on the basis of:

- Number of properties internally flooded
- The depth, area or velocity of flooding reported
- The frequency of flooding
- The nature and extent of critical infrastructure impacted by the flood

2.4 Location

South Craven is a County Council electoral division of NYCC. The communities of Cross Hills, Glusburn, and Sutton-in-Craven are situated within this division. The communities of Cononley, Kildwick and Low Bradley are situated in the Airedale County Council electoral division. However for the purpose of this report the communities investigated are collectively referred to as South Craven. South Craven predominantly consists of agricultural land with a number of communities located close to main rivers¹. Information relating to these communities is shown in Table 2.1²:

Report Chapter	Location	Properties Flooded	Main River/watercourse/canal in vicinity
4	Low Bradley	9	Middle Beck, Mill Ing Beck
5	Cononley	18	River Aire, Cononley Beck
6	Kildwick	10	River Aire, Leeds and Liverpool Canal
7	Cross Hills	19	River Aire, Holme Beck, Eastern Beck
8	Glusburn	8	Holme Beck, Glusburn Beck
9	Sutton-in-Craven	10	Holme Beck, Sutton Beck, Long Dike
	Total	74	

Table 2.1 Key information for the locations in the study area with relation to this report

The communities studied in this report are located within 2km of the River Aire and the A629, and are found between 3.5km and 8km south of Skipton, as shown in Figure 2.1.

¹ OS Maps

² NYCC reports of flooding map, 26th December 2015

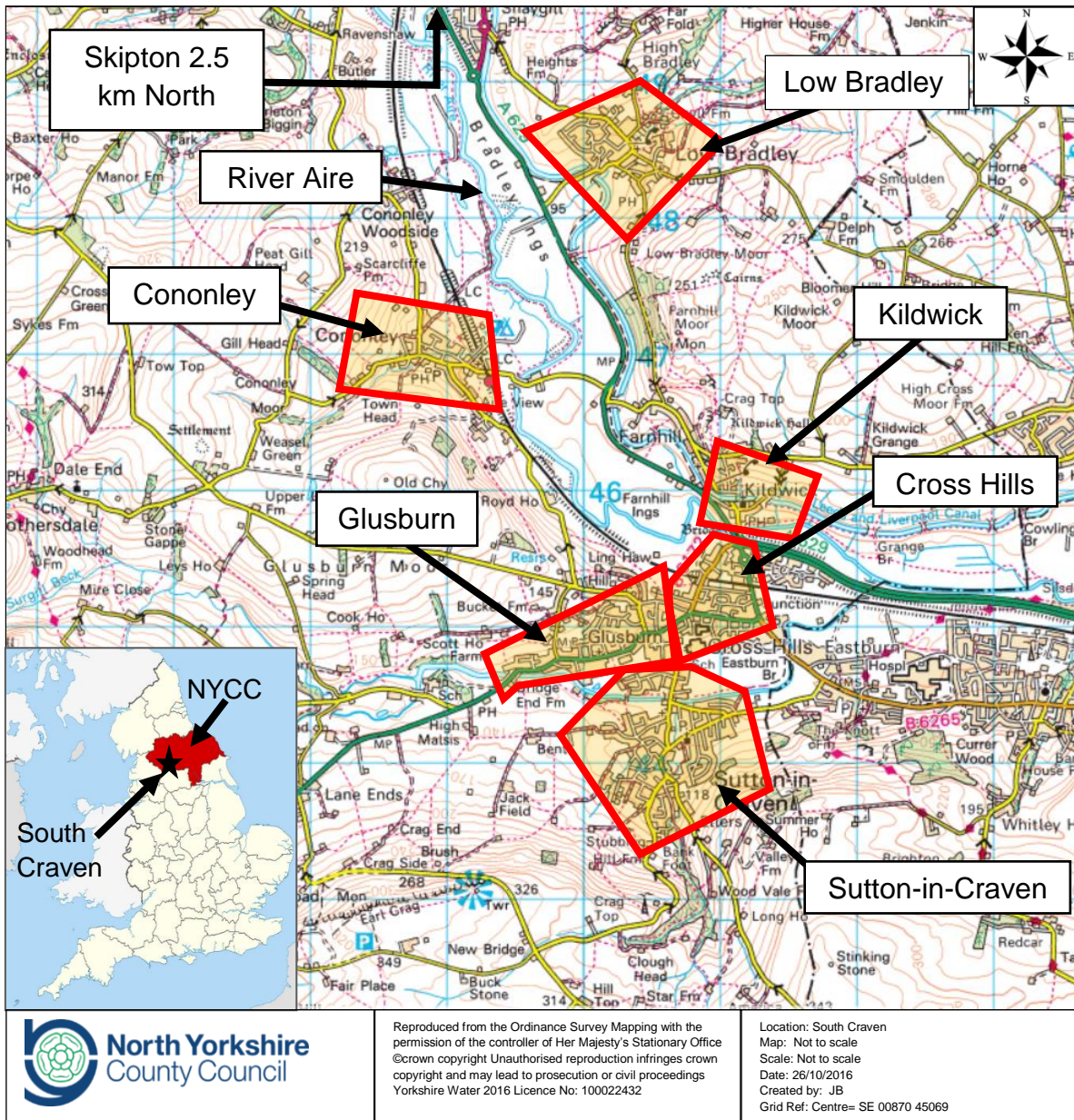


Figure 2.1 Study area location map of communities related to this report (Source: NYCC)

2.5 Topography

South Craven is a steep upland catchment, with undulating terrain the majority of which is agricultural land¹. The communities detailed in this study are all located in valleys on the low lying land, Figure 2.2 shows the low lying land of some of the study areas. The steep catchment can be seen by the land falling in elevation from 371m near Hutchins stone (south west of Sutton-in-Craven) to 110m at Holme Beck in Sutton-in-Craven over a distance of approximately 3.25km¹.

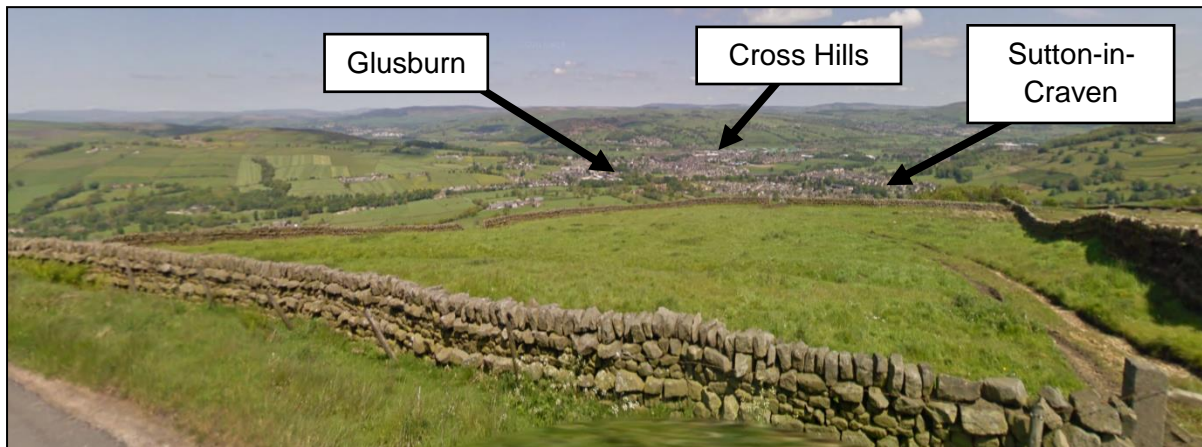


Figure 2.2 Community elevation in relation to surrounding land (Google Maps)

2.6 Main rivers and Watercourses

The study areas in this report are predominately located next to main rivers and watercourses. There are a number of main rivers³ and watercourses that influenced the events of Boxing Day 2015 these will be introduced in this section. The main river locations are shown in Figure 2.3, the largest being the River Aire.

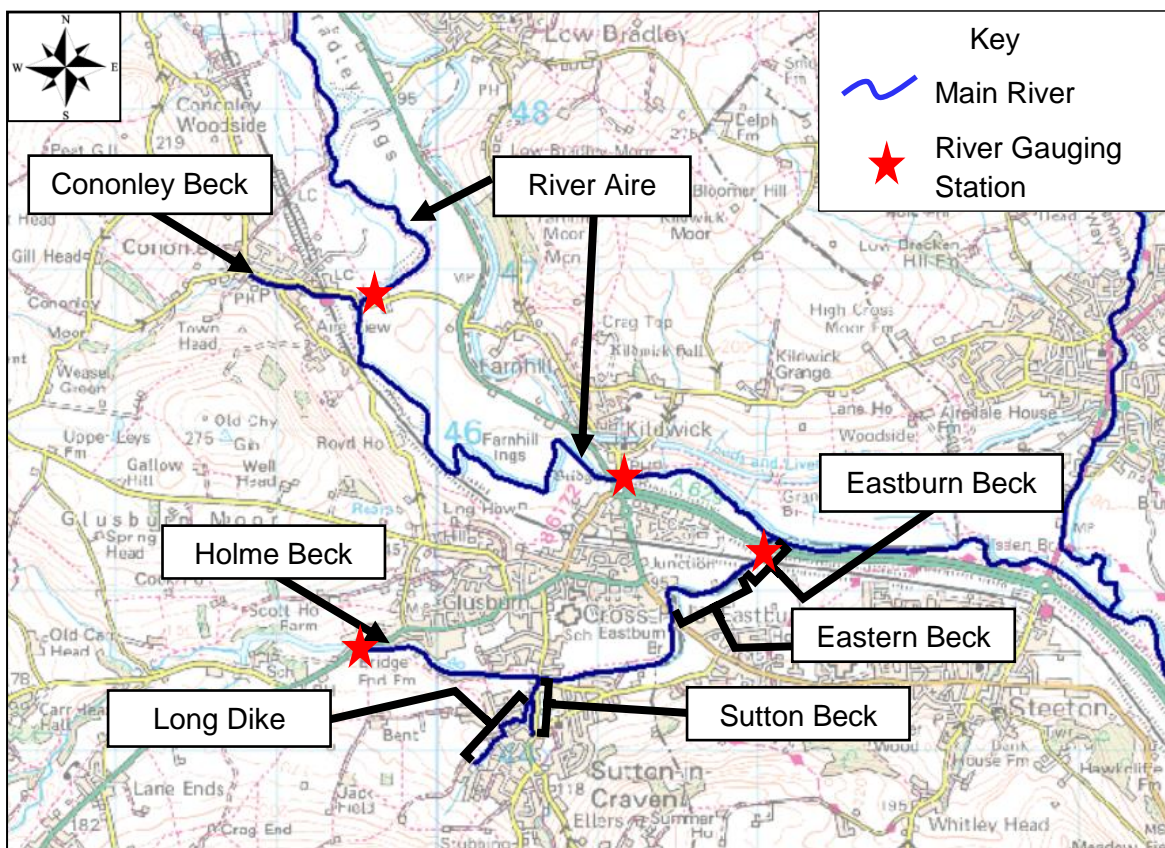


Figure 2.3 Map of Main rivers in the area of interest (Source: EA)

³ Main River Network map, Environment Agency

Main rivers are larger rivers and streams that the EA take the lead in managing the risk of flooding. Smaller watercourses are sometimes classified as main rivers, this is normally due to the high risk of flooding posed by the watercourse.

2.6.1 The River Aire

The River Aire is classified as a main river running from its source at Malham, in the Yorkshire Dales National Park, to Airmyn where it discharges into the River Ouse. It is approximately 148km in length⁴. The South Craven area is in the Upper Aire Catchment⁵. The river enters the area from the north, passing in between Low Bradley and Cononley, it then changes direction heading to the East and runs between Kildwick and Cross Hills. All of the watercourses in this area discharge into the River Aire¹.

River Aire levels are measured at two gauging stations at Cononley (Grid Reference: SD9973046925, Stage Level: 89mAOD) and Kildwick (Grid Reference: SE0110645684, Stage Level: 87.28mAOD). The data from these stations show the normal range of water depth is between 0.06m and 1.06m at Cononley, and between 0.2m and 1.21m at Kildwick⁶. Environment Agency records indicate that river flooding is possible when the Aire rises above 1.06m at Cononley or 1.45m at Kildwick. There is no tidal influence on River Aire in this area - tidal influence is up to Chapel Haddlesey, 60km southeast of Kildwick.

2.6.2 Leeds and Liverpool Canal

The Leeds and Liverpool Canal began construction in 1770⁷ and runs approximately parallel and to the North of the River Aire in this area, as Shown in Figure 2.4. The canal forms a barrier to smaller watercourses running from higher ground to the north towards the Aire valley floor and the river. These watercourses pass through culverts under the canal – for example Middle Beck/ Mill Ing Beck⁸ at Low Bradley and the Watercourse in Kildwick at Barrett's Bridge.

⁴ River Aire Fact File, Environment Agency

⁵ Catchment Data Explorer, Environment Agency

⁶ Flood information Services, Environment Agency

⁷ Leeds and Liverpool Canal, Canal & River Trust

⁸ Site Inspection

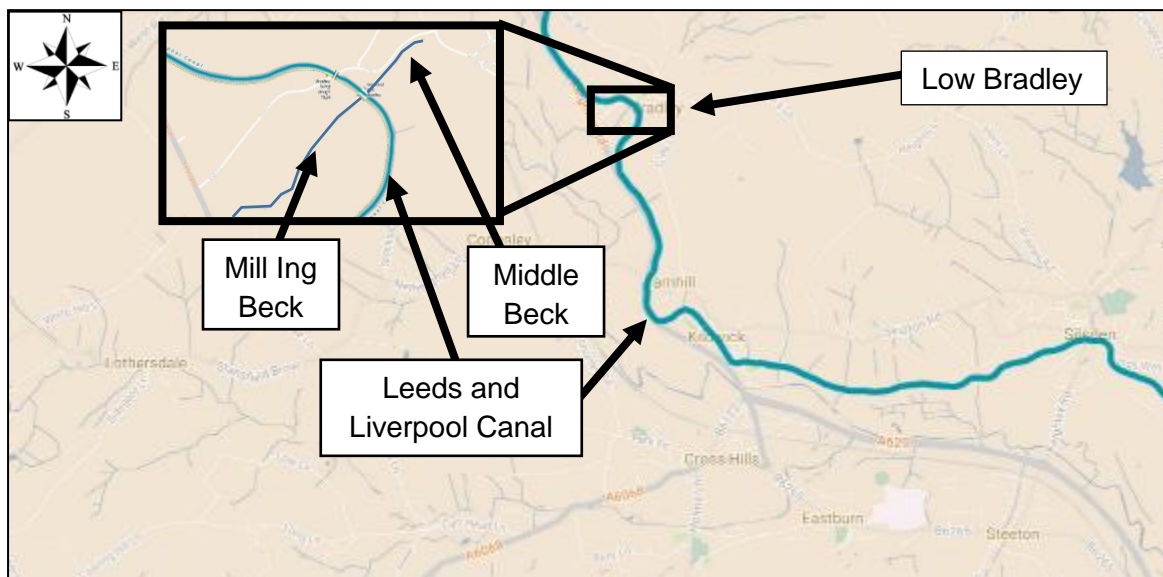


Figure 2.4 Leeds and Liverpool Canal (Source: Canal River Trust)

2.6.3 Glusburn Beck, Holme Beck, Eastern Beck and Eastburn Beck

Glusburn Beck is fed by a network of watercourses draining the moors around Lothersdale and Cowling to the west of Glusburn. On entering the village the watercourse changes its name to Holme Beck, and as it progresses downstream to Eastern Beck finally and Eastburn Beck¹ before flowing into the Aire at Kildwick Ings, as shown in Figure 2.3.

Downstream of Glusburn Bridge the watercourse is categorised as a main river and whilst upstream it is an ordinary watercourse³. As it passes through Sutton-in-Craven the beck passes over a number of weirs and under a footbridge and Holme Lane, it then travels under Skipton Road to the East of Cross Hills

The river level is gauged at Glusburn Bridge (Grid Reference: SD9955344635, Stage Level: 109.62mAOD), and at Cross Hills (Grid Reference: SE0203545263, Stage Level: 88.62mAOD). Results show the normal range of water depth is between 0.1m and 0.38m, and between 0.12m and 0.44m respectively⁹. According to the Environment Agency, river flooding is possible when the river level is 0.44m at Glusburn and 1m at Cross Hills.

2.6.4 Cononley Beck

Cononley Beck is classified as a main river, and flows through Cononley from west to east, as shown in Figure 2.3. Cononley Beck follows Nethergill Lane to the south until Cononley where it follows Main Street to the south east, the river is culverted in a number of sections in the village, and it then proceeds to follow Cononley Lane until it discharges into the River Aire just downstream of Mill Bridge.

⁹ Flood information Services, Environment Agency

2.6.5 Sutton Beck

Sutton Beck is a main river downstream of Main Street in Sutton-in-Craven, and an Ordinary River upstream. The river flows through Sutton-in-Craven from south to north on the eastern side of Sutton Park, and discharges into Holme Beck downstream of Bridge Road. Upstream of Main Street the river is culverted a number of times.

2.6.6 Long Dike

Long Dike is categorised as a main river downstream of where it passes Willow Way¹⁰. Long Dike runs approximately parallel to Crag Lane entering Sutton-in-Craven from the southwest, it is culverted under Croft Hill, it then runs behind a row of houses and enters another culvert, at North Road it reemerges where it discharges into the Sutton Beck, opposite Hazel Grove Road. The path the culvert takes from where it is last culverted at North Road is not known exactly.

2.6.7 Middle Beck/ Mill Ing Beck

There are a number of water courses to the north of Low Bradley that converge before the village to form Middle Beck. Middle Beck runs through the middle of Low Bradley from northeast to southwest it passes under Ings Lane and then under the Leeds and Liverpool Canal by an inverted siphon where it becomes Mill Ing Beck, as shown in Figure 2.4. An inverted siphon is where a channel must dip below an obstruction, in this case the Leeds Liverpool Canal, to form a U shaped flow path. The water flowing in at one end simply forces the water up and out the other end, however solids like sand and gravel will accumulate. The watercourse then proceeds downstream where it is culverted under the A629, after which it is renamed the Laithehouse Beck, which discharging into the River Aire.

2.6.8 Historic Culvert System

South Craven appears to have been modified to enable the development of mills and quarries in the area. A complex system of culverts are present in some areas where water has been channelled to support industry. Though some of the industrial development has declined, many of the culverts remain and their presence may not be formally recorded. Where culverts exist, the responsibility for their maintenance rests with the riparian owner.

2.6.9 Green Lane, Glusburn

There is a masonry culvert running down the western side of Green Lane which takes discharges from the agricultural land to the west of Green Lane and a from further up Green Lane¹¹, before discharging into Holme Beck. The route the culvert takes has been determined from observations on the site visit and information given by local residents, and is shown in Figure 2.5. There is a significant flow path flowing

¹⁰ Main River Network map, Environment Agency

¹¹ Site inspection & discussion with local Councillor

from the agricultural land to the North West to Glusburn via Green Lane¹², as shown in Figure 2.6, it is believed that a large proportion of this flow path is conveyed by the Green Lane Culvert.

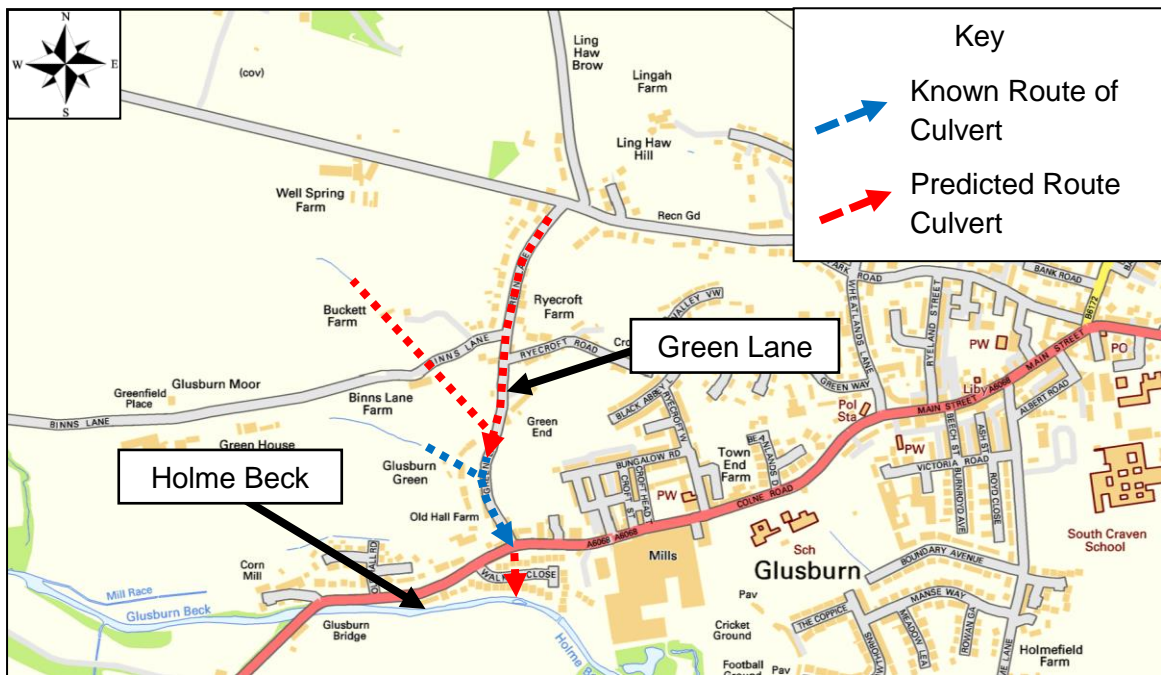


Figure 2.5 Green Lane Culvert Route.

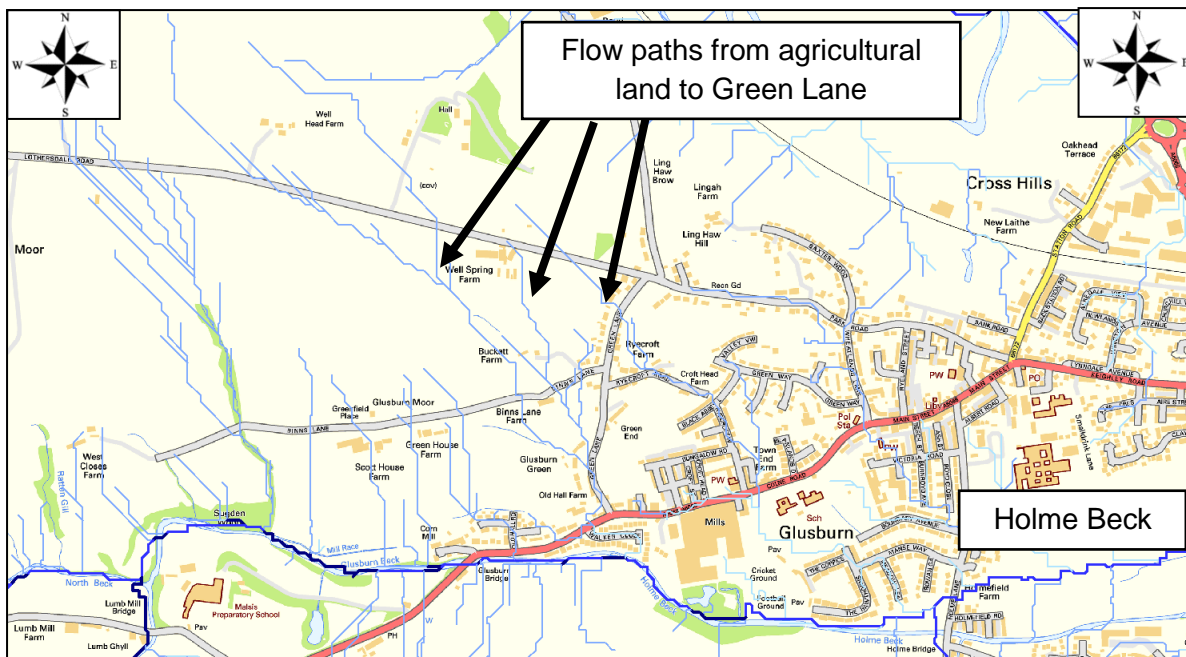


Figure 2.6 Rolling Ball analysis* for Glusburn identifying indicative overland flow routes

¹² NYCC Rolling Ball Analysis – identifying indicative overland flow routes

***Rolling ball analysis uses the Environment Agency LIDAR Digital Terrain Model and simulates the path of water across the terrain, identifying where it is most likely to flow as a result of topography (the flow-paths).**

2.6.10 Former Yeadon House, Sutton-in-Craven

There is evidence of a historic culvert to the west of Ash Grove. From drainage drawings it was seen that a surface water drainage system running from the visible historic structure to Ash Grove, as shown in Figure 2.7. From satellite imagery, there is evidence of a culvert route, where ground depressions can be seen as green lines on freshly cut grass to the west and to the east there are signs of a historic structure. A path from the watercourses to the west to Ash Grove can be seen in Figure 2.7, the predicted route of the culvert runs along a significant flow path seen from the rolling ball analysis, as shown in Figure 2.8. As the route which water takes as it runs off the land reflects the local topography, it is possible that a watercourse previously followed this route and has been culverted to enable development to take place.

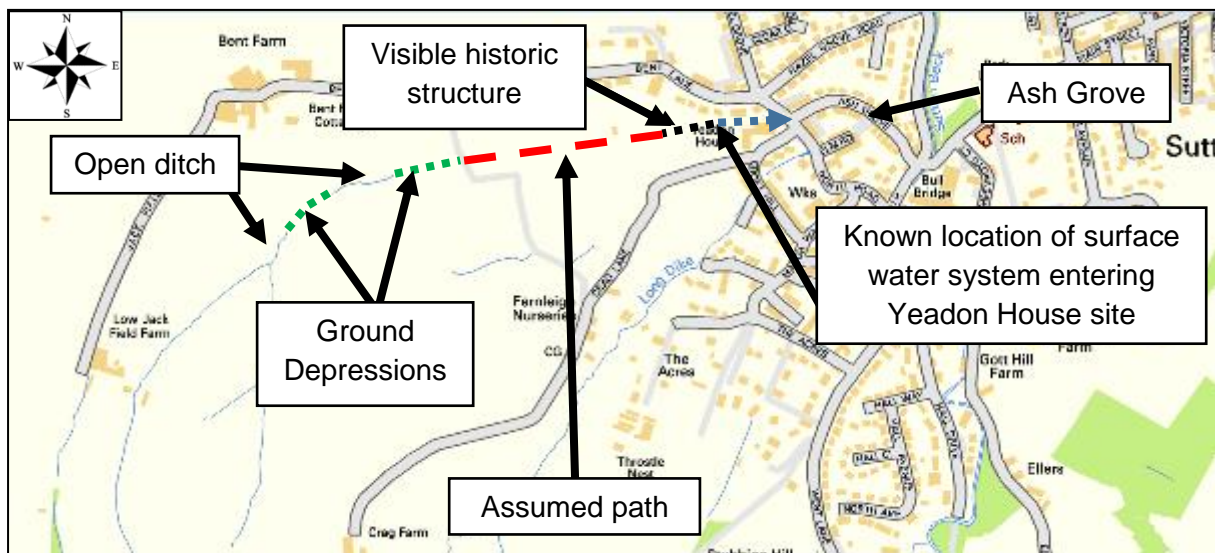


Figure 2.7 Predicted route of Sutton Historic Culvert

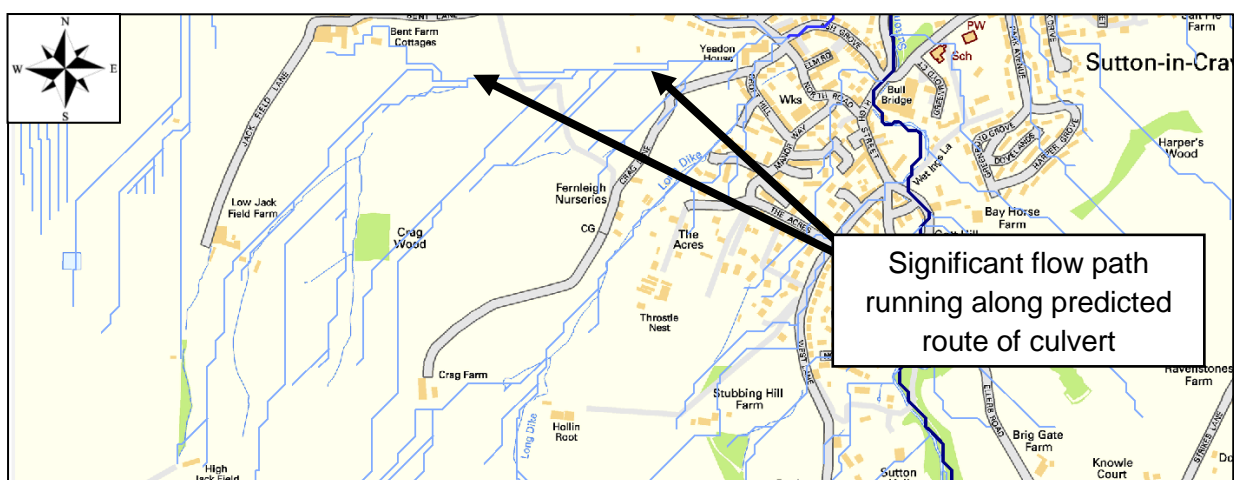


Figure 2.8 Rolling ball analysis for Sutton Historic Culvert predicted location

2.6.11 Lidget Road, Low Bradley

An old masonry culvert of interest runs down Lidget Road (Lidget Road Culvert) from south east to north west, where it discharges into Middle Beck¹³, as shown in Figure 2.9. It has not been able to determine the age of the culvert, however inspection of maps has revealed properties at Moor View, which are built on top of the culvert, were construction around 1989. Observations from OS Mapping and a NYCC Highways camera survey carried out after the flood event indicate that it is likely other historic culverts are discharging into this system, opposite the Bradley Methodist Church, Main Road and College Road¹⁴. The highway drainage system for Lidget Road and part of College Road, is thought to discharge into the Lidget Road Culvert. The culvert route and connectivity was determined using the report from the NYCC Highways CCTV investigation and through discussions with local residents.

¹³ NYCC Highways CCTV investigation & Discussion with Low Bradley Resident

¹⁴ Site inspection & discussion with local residents

2.7 South Craven Geology and Hydrogeology

The underlying bed rock in the South Craven area is Millstone Grit which has a low permeability. Part of the South Craven area sits on top of a minor aquifer with a high soil leaching class, as shown by the area highlighted in Figure 2.10. The high soil leaching class indicates that the top soil is highly permeable with a shallow water table.

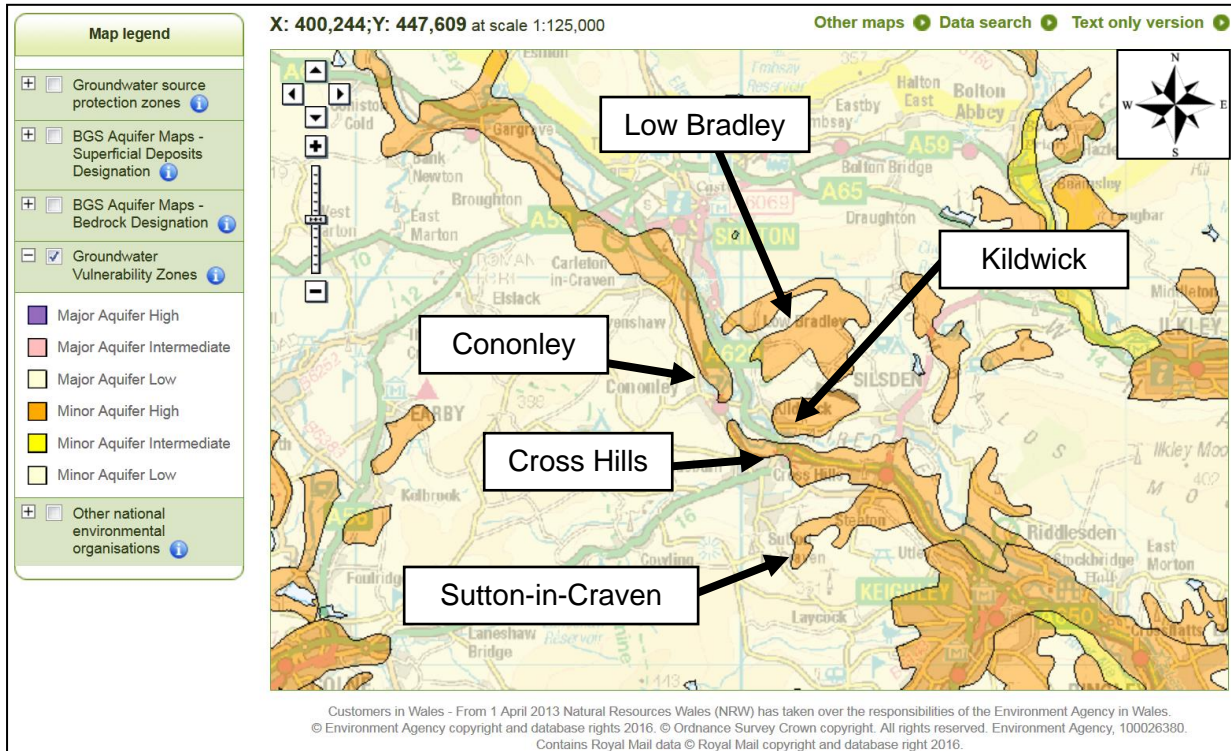


Figure 2.10 Hydrogeology in South Craven¹⁵

2.8 Airedale Drainage Board

Some of the South Craven area falls within the drainage district for Airedale drainage board¹⁶. The board operates as the Land Drainage Authority within their district and is responsible for the management of water levels in respect of Flood Risk Management within their drainage district. The Board is also directly responsible for the maintenance of a number of small watercourses in the close vicinity of the River Aire, as shown in Figure 2.11.

These watercourses are: 6–Top Dyke, 7–Middle Dyke, 8–Bottom Dyke, 9–Unnamed, 10–Unnamed and 11–Unnamed. None of these watercourses were reported to have influenced the Boxing Day flood event.

¹⁵ Environment Agency Groundwater mapping

¹⁶ Airedale Drainage Board Map

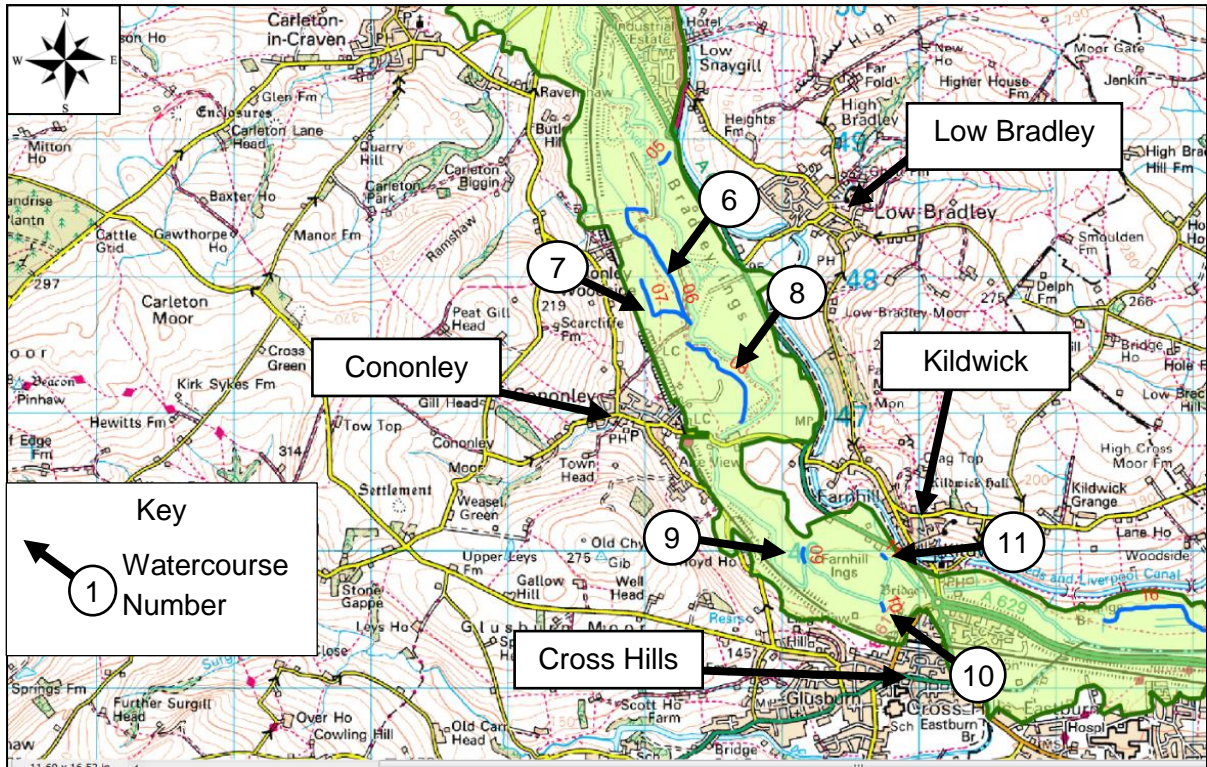


Figure 2.11 Airedale Drainage Board map¹⁶

3 Flood Event

3.1 Antecedent conditions

3.1.1 November Rainfall

The Nation Climate Information Centre (NCIC) has produced a dataset of aggregated climate data that shows November 2015 in the rankings for wettest month, as shown in Table 2.2. In the wettest catchments, November 2015 rainfall exceeded 200% of the long term average (LTA). The data shows that the Aire catchment had the second wettest November on record and indicates that the ground was already saturated from rainfall in November, prior to the exceptionally wet December¹⁷.

Catchment	Ranked Rainfall Total Wettest since 1909 November 2015	% LTA for the period November 2015
Yorkshire Area	5	191
Aire	2	234

Table 2.2 NCIC ranked rainfall total wettest since 1909 and percentage of LTA

3.1.2 December Rainfall

Before the event the northern and western catchments of Yorkshire had generally received more than the LTA rainfall for December, as shown in Table 2.3, particularly in the upper catchments. This particularly wet December following an exceptionally wet November, meant that catchments were saturated before the rainfall event of Christmas Day and Boxing Day¹⁷.

Catchment	Gauge Name	Location	Rainfall (mm) 1 st to 24 th December 2015	December LTA (mm)	Rainfall 1 st to 24 th December 2015 as % of December LTA
	Malham Tarn	Malham	301.4	162	186%
Aire	Lower Laithe	Keighley	178.2	132	135%
	Farnely Hall	Leeds	102	69.7	146%

Table 2.3 Total rainfall and percentage of LTA for 1st to 24th December 2015

The locations of the Tipping Bucket Rain gauge (TBR) sites that relate to South Craven within the Aire Catchment are shown in Table 2.3 and Figure 2.12.

¹⁷ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

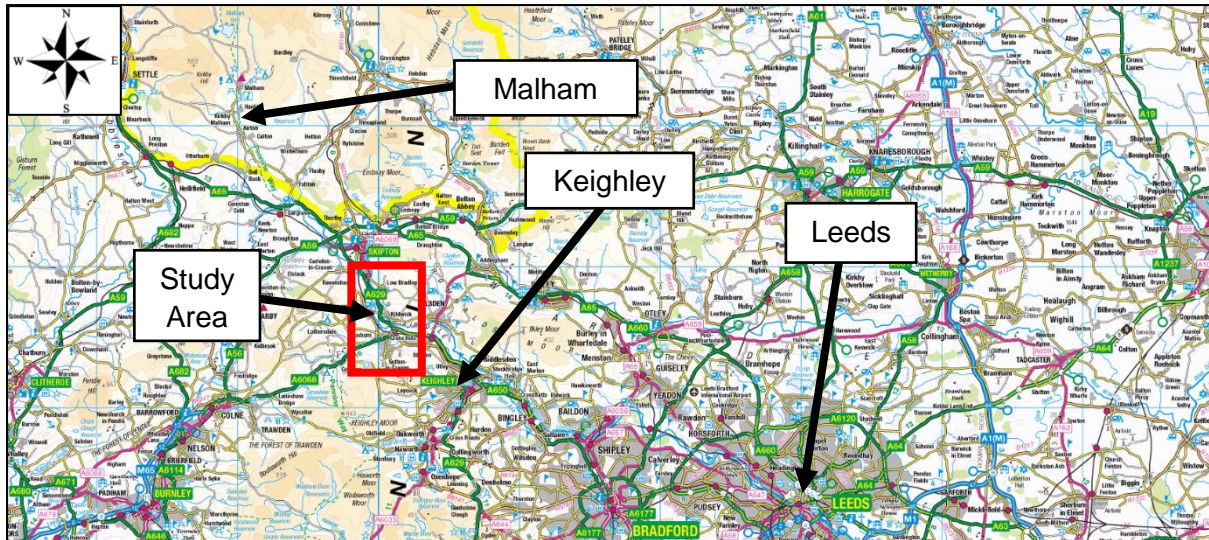


Figure 2.12 Aire Tipping bucket raingauge sites in relation to South Craven area.

3.1.3 Soil Moisture Deficit

At the beginning of October the ridge of the Pennine Hills is reported as having zero available storage and the nature of the rainfall ensured the ground remained fully saturated leading up to Christmas. From the beginning of December the ground was fully saturated, soil moisture defect levels for the week of 22nd December 2015 are shown in Figure 2.13¹⁸.

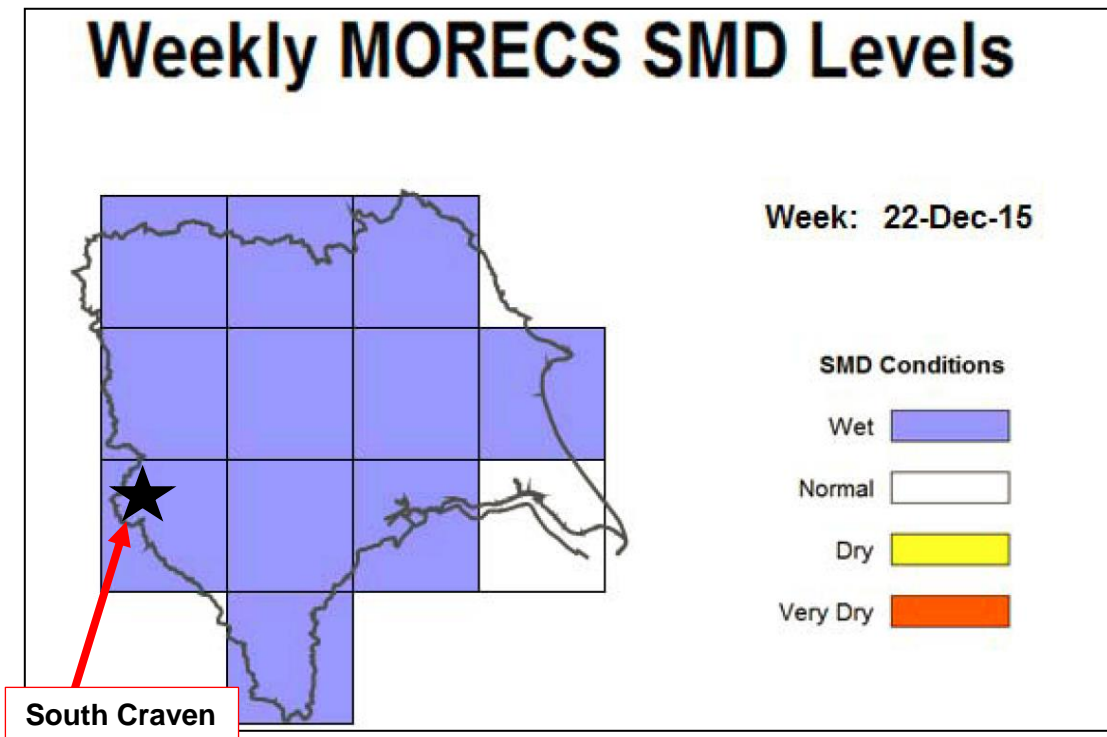
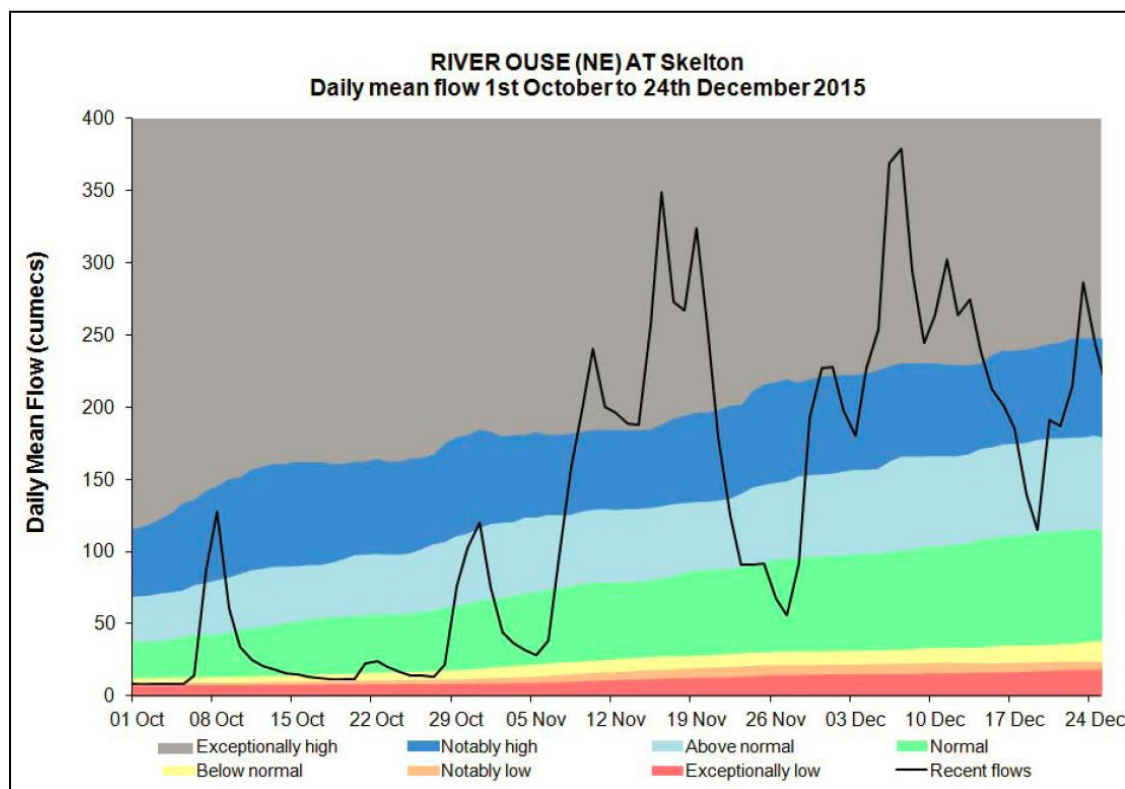


Figure 2.13 Antecedent Soil Moisture Deficit (EA)

¹⁸ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

3.1.4 River Flows

According to EA records, low river flows dominated the late spring and early autumn of 2015. Flows increased well above normal in November, as shown in Figure 2.14. Near continuous wet weather from November falling on already saturated ground ensured flows increased between “above normal” to “exceptionally high”. Immediately before Christmas Day. The Yorkshire Rivers were notably “high” or “exceptionally high¹⁷” as illustrated by levels on the River Ouse at Skelton, downstream of the confluences with the Swale, Ure and Nidd (seen Figure 2.14.)



2.14 Antecedent river flow as demonstrated by Skelton Flow Gauge, River Ouse, North Yorkshire¹⁹

3.1.5 Meteorological Conditions

The event was characterised by a slow moving low pressure system and warm frontal zone that immediately followed behind Storm Eva, moving across the region from the west. Storm Eva brought high winds and a band of rain which spread across the country on 23rd & 24th December. The rainfall which caused the flooding was brought by a weaker low pressure system which came through on 25th & 26th December following Storm Eva¹⁹.

A warm frontal zone passed over the UK during the morning of 25th December, bringing scattered showers with it, and by midday there was a blanket of rainfall covering Yorkshire, as shown in Figure 2.15. During the evening an occluded front had set over the northwest and northeast and it was this front which produced the more intense storms. There were two main pulses of heavy rainfall that led to the

¹⁹ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

flooding experience over Yorkshire. The first pulse occurred once the occluded front had formed during Christmas Day afternoon and evening, although the rainfall eased by midnight. During this time the rain was mainly confined to the upper catchment of the Aire, Calder, Wharfe and Swale²⁰.

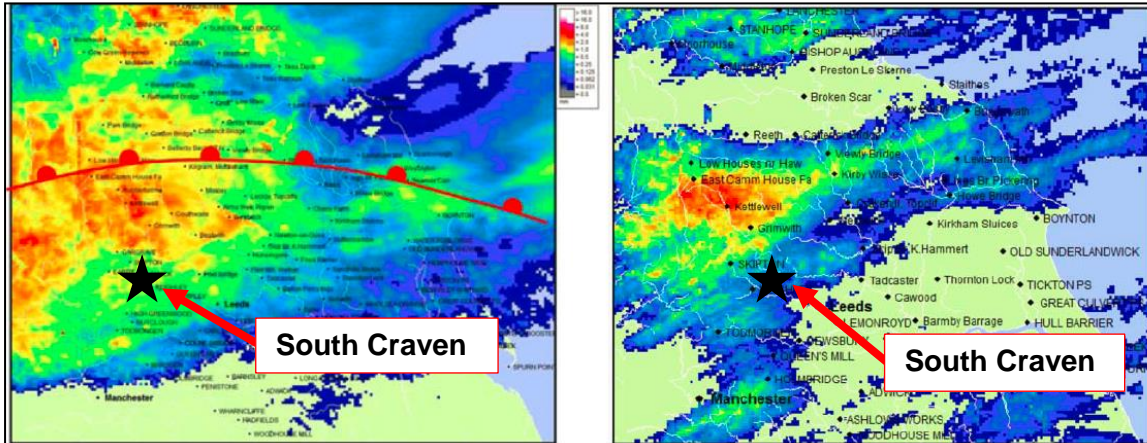


Figure 2.15 Radar image with overlaid front as of 18:00 on 25th December (left) and 01:00 on 26th December (Right) Copyright Meteorological Office

3.2 Rainfall – December 25th/29th

Widespread and substantial rainfall fell over West and North Yorkshire. The total rainfall for 25 – 29 December shows that the largest rainfall totals occurred over the Pennine Hills of West and North Yorkshire, as shown in Figure 2.16²⁰.

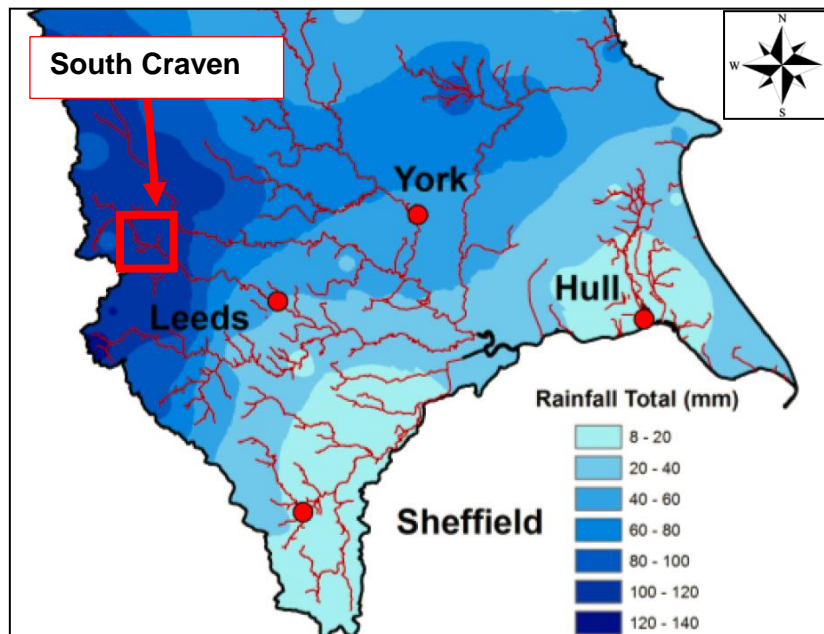


Figure 2.16 Total rainfall (mm) between 25th and 29th December 2015

²⁰ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

3.2.1 Peak Rainfall Analysis - 25th to 29th December

Rainfall data recorded by the tipping bucket rain gauge (TBR) network was analysed for a range of durations. A selection of peak rainfall accumulations for different durations, their rainfall return periods, and the rainfall as a percentage of the December LTA are shown in Table 2.4²¹.

	Aire				
Peak rainfall	Malham Tarn	Embsay	Skipton Snaygill	Thornton Moor	Farnley
Distance from Study area	25km north	8.2k m north	4.5k m north	12.7k m south	28km south east
Accumulation (mm)					
6 hour total	22.4	28	28.8	38	18.6
12 hour total	36.4	49.8	48.4	62.2	25.8
18 hour total	52.6	70.4	68	86.2	34.8
24 hour total	67.4	89.8	90.4	104	46.4
36 hour total	89.6	100	101.4	113.4	48.4
48 hour total	91.8	100.4	102.8	113.6	48.4
Return period (years)					
Peak 6 hour total	1	3	4	7	1
Peak 12 hour total	2	10	10	18	1
Peak 18 hour total	3	23	24	40	2
Peak 24 hour total	6	45	56	63	4
Peak 36 hour total	12	43	61	54	3
Peak 48 hour total	8	29	45	37	2
% LTA					
Peak 6 hour total	14	26	29	30	27
Peak 12 hour total	23	47	49	49	37
Peak 18 hour total	33	66	68	68	50
Peak 24 hour total	42	84	91	83	67
Peak 36 hour total	55	94	102	90	69
Peak 48 hour total	57	94	103	90	69
December Total as % LTA	240	230	273	245	211
Peak rainfall = return periods of 20 yrs and above are highlighted in red and percentage LTA of 50% and over are highlighted blue . December total = percentage LTA of 250% and over are highlighted purple					

Table 2.4 catchment rainfall

²¹ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

There was a sustained rainfall event with peak intensity occurring over the 24 hour to 36 hour period. The Aire catchment experienced the most unusual rainfall during the event, with the highest periods and greatest percentage of LTA. In many locations in the Aire catchment the total rainfall in December is in excess of 200% of the expected average for December rainfall. In particular the rainfall exceeds 100mm depth in 36 hours, and reaches 2.7 times the LTA for December. The intensity of the rainfall significantly reduced the storage.

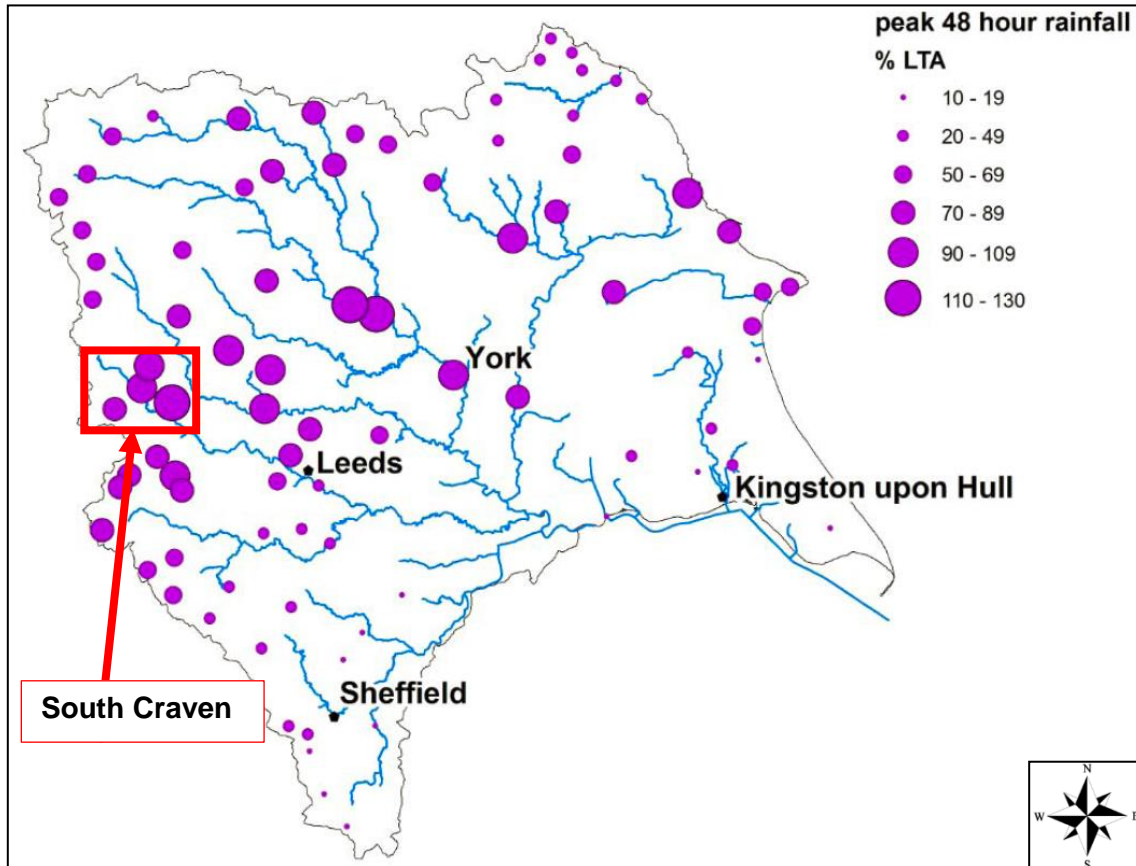


Figure 2.17 Peak 48 hour rainfall 25th to 29th December as a percentage of December LTA (Source: EA)

3.2.2 Radar Rainfall

Data was available from Hyrad UKPP 1km 1hour accumulation radar in addition to recording of actual rainfall from the TBR network. All of data is copyright of the

	Embsay	Aire Skipton Snaygill	Thornton Moor
TBR (mm)	100.4	102.8	113.6
Radar (mm)	104.4	100.5	84.8
<i>Difference (mm)</i>	<i>4.0</i>	<i>-2.3</i>	<i>-28.8</i>
% Difference	4	-2	-25

Meteorological Office.

Table 2.5 AMAX 25th to 29th December 2015

Comparison of Hyrad and TBR data show reasonable correspondence between the two rainfall datasets, as shown in Table 2.5. There is sufficient confidence to be able to use radar data as a guide to the finer scale distribution of rainfall during the event. This is important to help understand the scale of rainfall experienced where TBR sites are remote from flooded locations.

3.2.3 South Craven Rainfall

Yorkshire Water Services Ltd (YWS) has provided rainfall radar data for the rainfall event in Sutton-in-Craven (grid reference: SE 00500 44500). This rainfall data shows three significant events in three days, as shown in Table 2.6. The peak rainfall fell on Boxing Day producing a rainfall depth of 48.2mm in 12 hours²².

Date	Start of event	Duration of event	Total rainfall depth (mm)
24/12/2015	08:20	00:30	3.92
25/12/2015	15:00	07:40	28.02
26/12/2015	01:05	11:55	48.23

Table 2.6 Showing the YWSL rainfall data for Sutton-in-Craven

Environment Agency TBR data has been provided for three locations with close proximity to the study area²³, as shown in Table 2.7. The sites are:

- Skipton Snaygill- 2.5km northwest of Low Bradley
- Proctor Heights - 5.5km west of Cononley
- Silsden – 3km east of Kildwick

Date	Rainfall (mm)		
	Skipton Gill	Proctor Heights	Silsden
24/12/2015	4	2.6	3.4
25/12/2015	31.8	28	36.2
26/12/2015	47.4	52.4	52.6

Table 2.7 Rainfall from EA TBRs

The rainfall depth data from the TBRs shows a good match with the radar data, the depths for the TBR are marginally greater than that of the radar data, but this is expected as radar data generally under predicts depths¹⁸. The times of the rainfall events are also very similar between the two data sets, as can be seen by the comparison on Figure 2.18 with the times in Table 2.7.

²² Rainfall Radar Data, YWS

²³ South Craven Hydrometric Data, Environment Agency

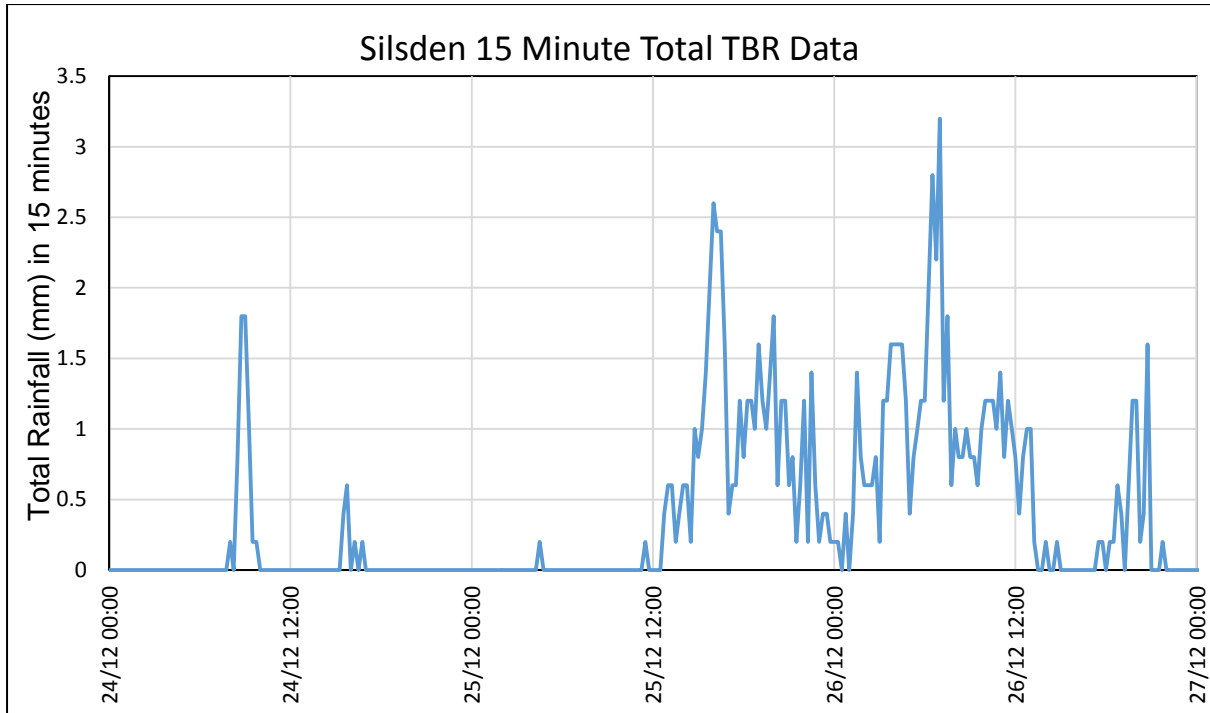


Figure 2.18 TBR 15 minute total data from Silsden

3.3 River Levels

Peak river levels for this event are presented using an annual maximum (AMAX) rank order for EA gauging stations. AMAX is the highest level recorded in each water year, which runs from October to September¹⁸. The rank 1 means the level recorded was the highest recorded AMAX within the duration of the record.

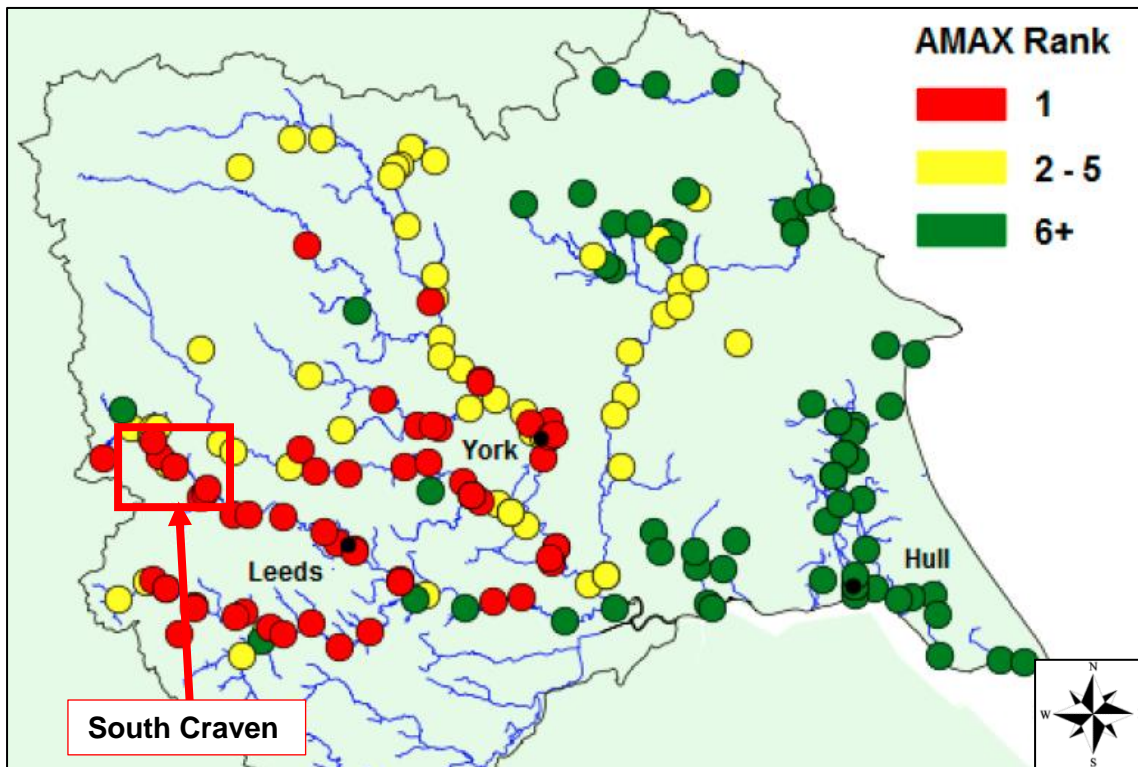


Figure 2.19 AMAX rank 25th to 29th December

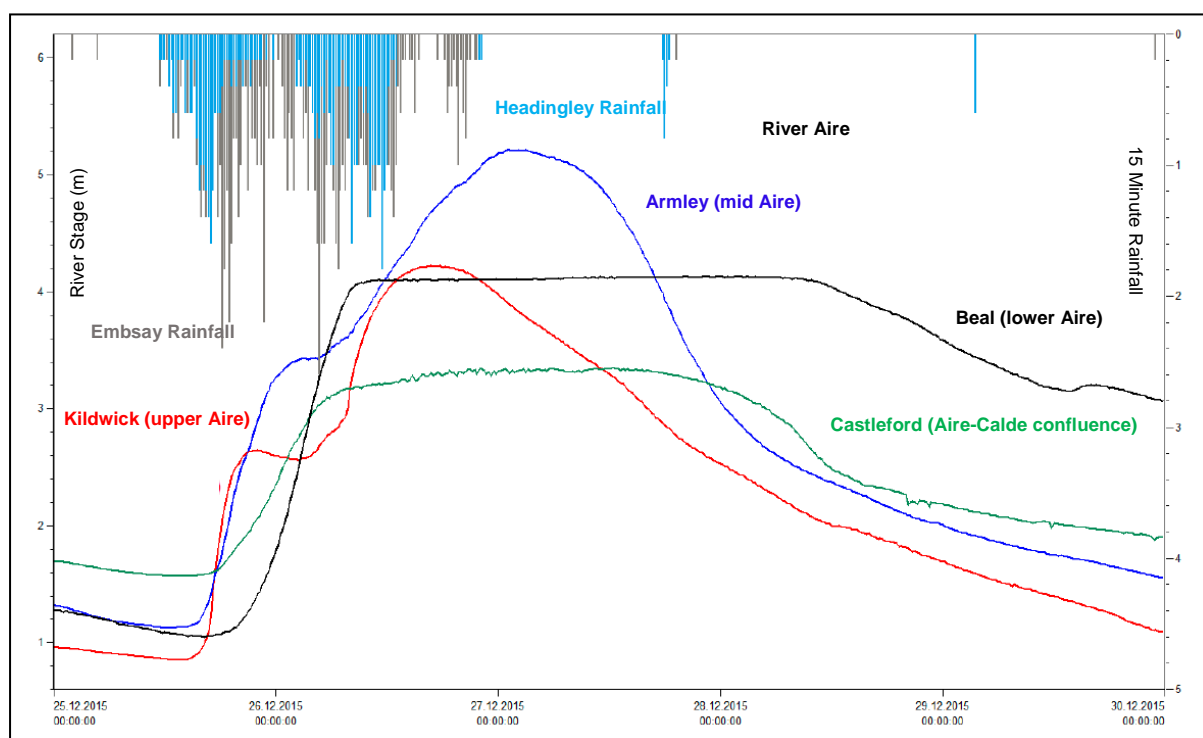
Figure 2.19 and Table 2.8 show record peak levels along the West Pennine catchments, with near record peaks tracking northeast over North Yorkshire. The response of the West Yorkshire Rivers (Aire & Calder) were driven from the uppermost catchments, whilst many of the North Yorkshire (Wharfe, Nidd, Ure) river peaks occurred in the middle and lower reaches of catchment²⁴. The AMAX results show record high river levels in the Aire catchment at numerous locations.

Catchment	Gauge name	Peak stage (m)	Time and Date	Rank (in record)	Record Length	Current or Previous highest
Aire	Kildwick	4.219	17:45 26 Dec	2	37yrs	4.222 Autumn 2000
Aire	Armley	5.214	02:15 27 Dec	1	45yrs	4.025 Autumn 2000
Aire	Beal	4.13	23:45 27 Dec	1	24yrs	4.116 Autumn 2000

Table 2.8 AMAX level for key gauges

3.4.1 River Aire Catchment Response

The river levels on the upper and middle catchment show a quick sharp reaction, changing to a longer drawn out response in the lower reaches. There are waves of rainfall evident as water levels rise quickly with initial peak being observed in the late evening of Christmas Day in the upper catchment. The water levels here rise quickly again during the morning of Boxing Day. As the flows progressed downstream, the water levels rose less quickly and sustained peak levels over a longer period due to the effects of washlands filling and emptying in the lower catchment, as shown in Figure 2.20²⁵.



²⁴ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

²⁵ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

Figure 2.20 River response in the Aire Catchment (Source: EA)

EA analysis has revealed that wash lands at Cononley have been shown to limit the flows measured at Armley in Leeds, when flood flows are driven from the upper Aire. The slight reduction in river levels at Kildwick late on Christmas Day, is likely due to the filling of the Cononley Washlands. These appear to have provided additional capacity in the system before the effects of second pulse of rainfall were realised.

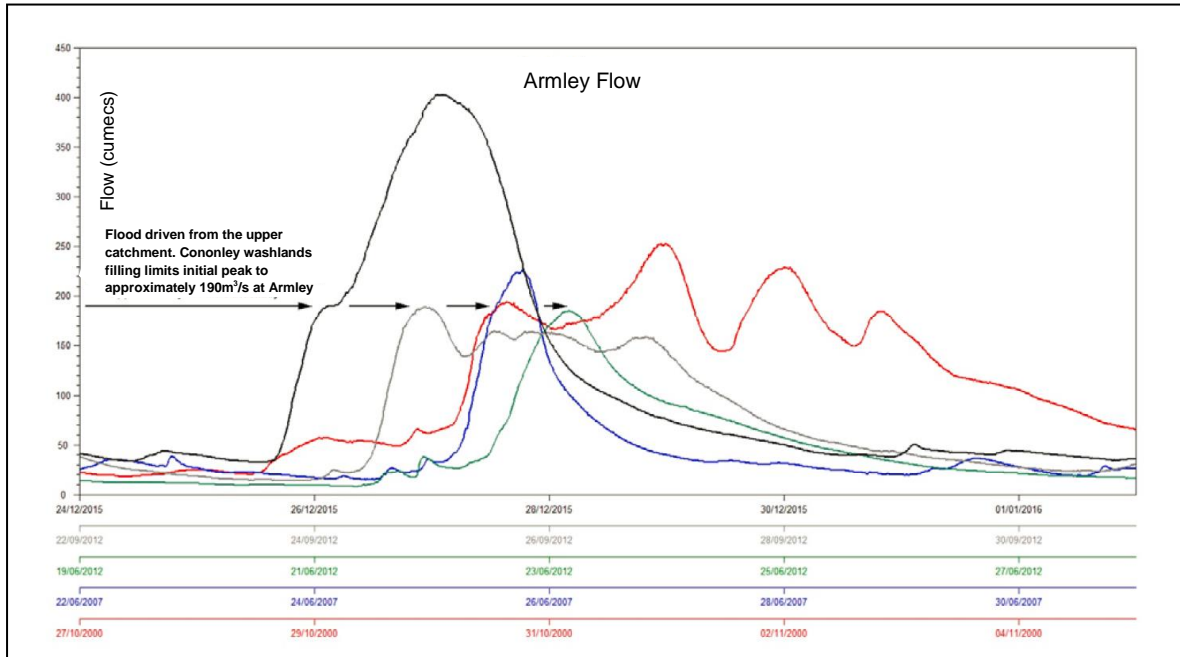


Figure 2.21 Effects of Cononley washlands

In June 2007 flood event it can be seen how the flows at Armley quickly exceeded 190m³/s because the event was driven by rainfall in the mid catchment, downstream of the Cononley Washlands. This indicates water levels in the lower catchment can be managed by implementing flood attenuation and storage in the upper catchment¹⁶.

Fluvial gauges on the River Aire down to its tidal limit at Chapel Huddersley recorded the highest or near highest levels on record in December 2015²⁶.

3.4.2 River Flows & Return periods

River flows are measured in cubic metres per second (m³/s). Flow measurements becomes increasingly uncertain at higher flows, and hence can limit the number of sites for which flow frequency calculations can be made.

The EA have adapted a four category system to indicate accuracy of the sites, as shown in Table 2.9. Based on these there are some sites that are unlikely an accurate flow estimate can be calculated.

Not applicable to high flows Flow estimate has been extrapolated beyond the calibrated range for the gauge; or a site is not

²⁶ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

	designed, or is unable to be used, to calculate high flows
Rating review required to calculate flows	Rating is currently not able to be used to calculate flow for this event without further review
Acceptable at high flows, with caution	Rating can be used to calculate high flows but may not be applicable or may need additional information for this event
Good at high flows	Rating can be used to calculate flows for this event.

Table 2.9 EA system for determining the accuracy of flow estimation

River flow estimates have been made for site where the flow estimates are considered significantly robust to determine using the Flood Estimation Handbook (FEH) methods. These estimated return periods are provided with comment regarding data quality.

Gauge name	Peak stage (m)	Highest check gauging (m)	Rating equation status	Peak Flow (m ³ /s)	Comment
Gargrave	1.163	0.9	Rating review required to calculate flows	70.4	Looks suspicious – problem recording peak/ peak missed?
Kildwick	4.219	3.21	Acceptable at high flows, with caution	163.2	Medium to high flows affected by upstream washlands and therefore the rating needs reviewing
Cross Hills (Eastburn Beck)	1.763	0.72	Acceptable at high flows, with caution	54.4	Silt is a major issue
Armley	5.214	3.5	Rating review required to calculate flows	350 - 400	Top end of rating potentially over estimating flows by approximately 50 m ³ /s

Table 2.10 December 2015 flow and data quality for the River Aire

Table 2.10 shows the reliability of peak flow analysis for the Aire catchment. It can be seen that flows calculated for Kildwick and Cross Hills are acceptable for high flows, however may not be applicable or need additional information for this event. Taking this into account it has been identified that peak flows at Kildwick and Armley

on the Aire were the highest recorded and have estimated return periods of 80-100 and over 200 years respectively.

Although peak rainfall accumulation varied over the Yorkshire area, this rain fell onto a saturated ground and into rivers that were already high. The subsequent peak flow return period estimates are considerably higher than compared to the rainfall return period estimates and illustrate the significant role of antecedent conditions in this event²⁷.

Catchment	Gauge Name	Peak Flow (m³/s)	Time and Date	Rank in record	Return period (years)
Aire	Kildwick	163	17:45 26 Dec	1	80 - 100
	Armley	350	02:15 27 Dec	1	200 +

Table 2.11 December 2015 flow return period estimates

²⁷ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

4 Low Bradley

4.1 Location

Low Bradley (Grid Reference: SE 00329 48385) is located to the 800m East of the A629 and approximately 3.5km south of Skipton, as shown in Figure 4.1¹. Perched on the hillside adjacent to the River Aire Low Bradley, along with its neighbour high Bradley are collectively known as Bradleys Both. The village lies within the district of Craven and Bradleys are within the County Council electoral division of North Yorkshire. The villages have a combined population of 1260 according to the 2011 Census. Bradley historically supplied slate and stone for building materials and villagers were engaged in hand looming and wool combing, before industrial development occurred in the form of spinning and weaving mills. The key locations in Low Bradley are shown in Figure 4.1.

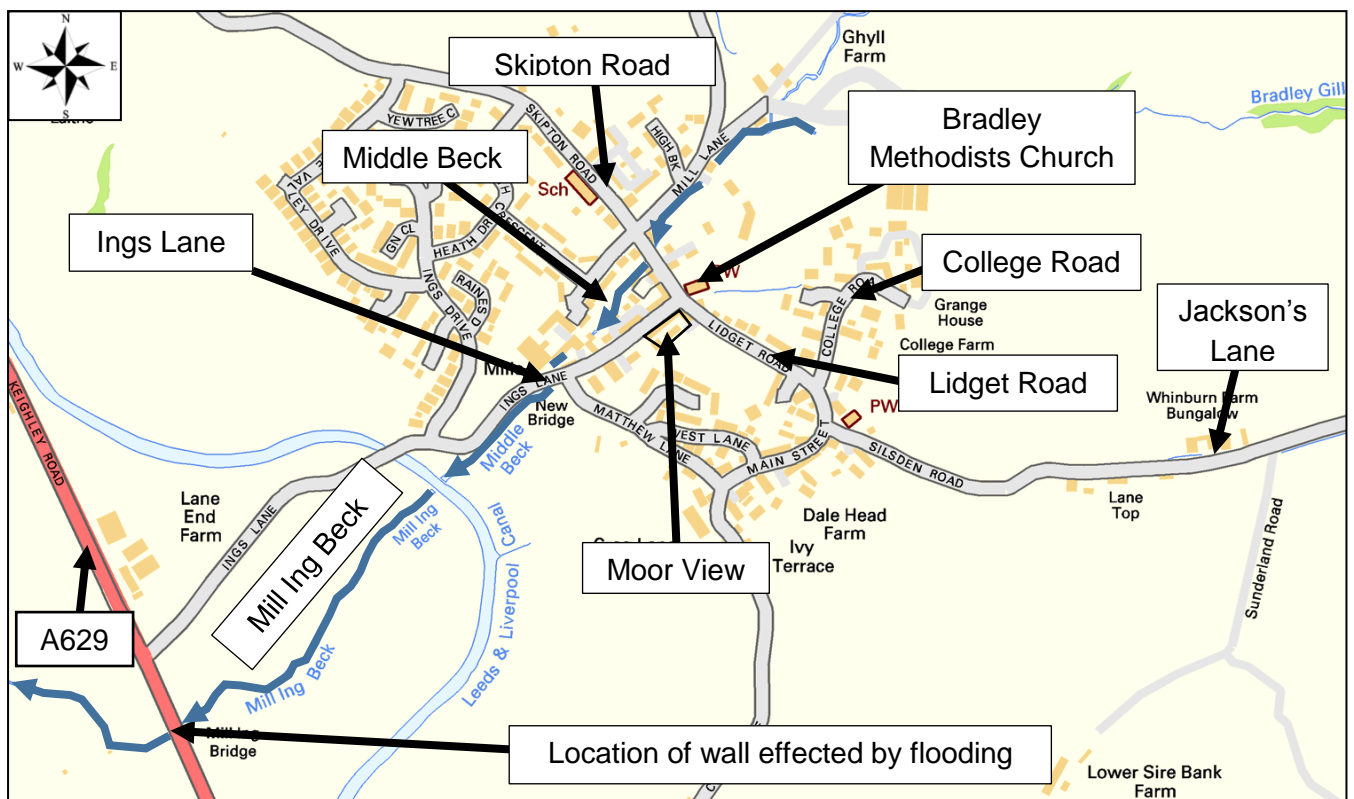
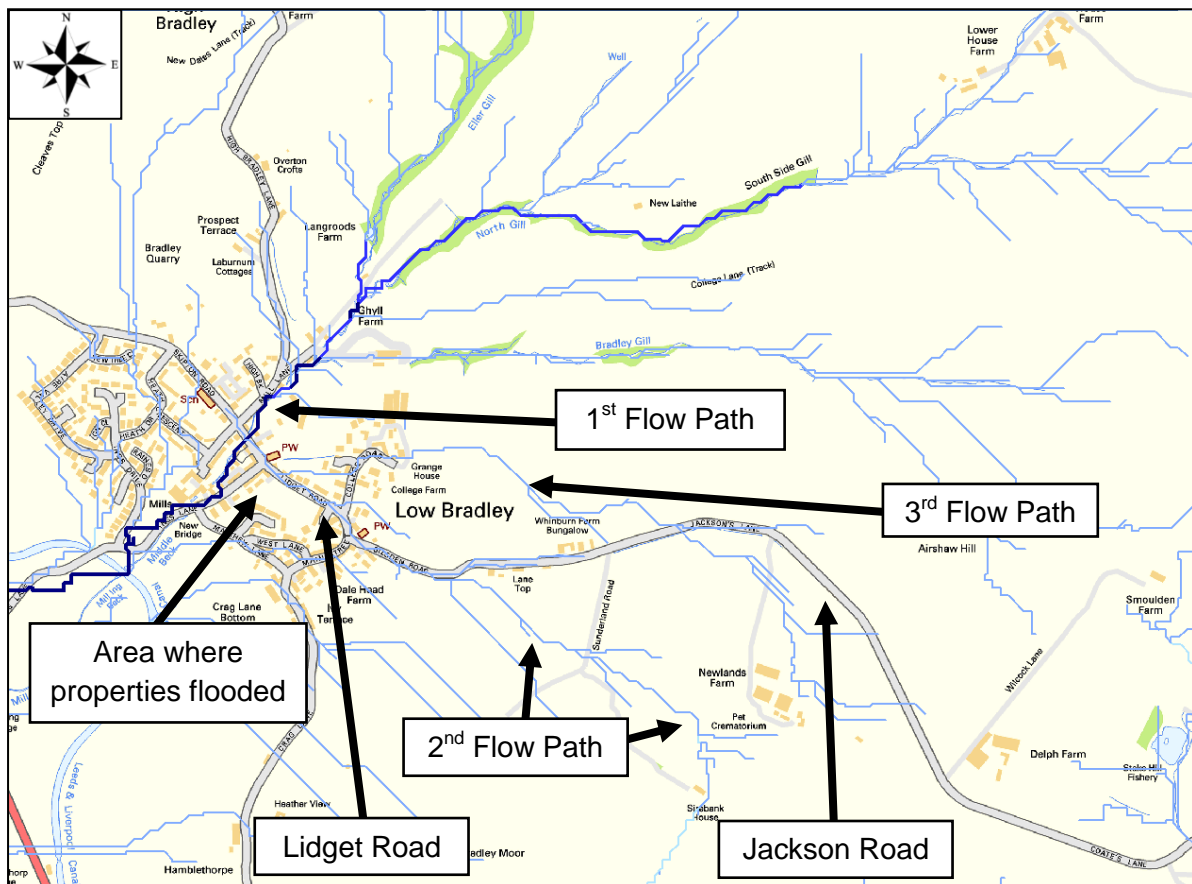


Figure 4.1 Bradley study area map (NYCC)

4.2 Water Environment

Low Bradley is surrounded by elevated moorland from which run a by a number of small watercourses, some of which are culverted, which feed into Middle Beck. Middle Beck runs through the centre of the village, and becomes Mill Ing Beck, passing under both the Leeds & Liverpool Canal and the A629 (Keighley Road) before joining the Aire at Bradley Ings. Low Bradley is situated in a valley, as such after a rainfall event the surface water flows towards the centre of the village, as shown in Figure 4.2²⁸. There are watercourses and significant flow paths to the north of Low Bradley that converge to create the Middle Beck upstream of the village. Lidget Road has a steep gradient falling towards Middle Beck in the centre of the village. There is a second significant flow path that comes off Low Bradley Moor, entering the village via the western end of Silsden Road which continues on to flow down Lidget Road, entering the Middle Beck via Ings Lane and Skipton Road. The third flow path of interest collects surface water north of Jackson Lane and enters the water course that is culverted under Bradley Methodist church. The flow paths shown to the south of Jackson Lane are likely to enter the highway ditch and travel down the side of Jackson Lane.



²⁸ NYCC Rolling Ball Analysis – identifying indicative overland flow route

Figure 4.2 Rolling ball analysis showing key flow paths to Low Bradley from surrounding land

The EA surface water flood map, shown in Figure 4.3, shows the area closest to the Middle Beck to be at the greatest risk of surface water flooding. The map also shows a lower risk at a number of locations including Moor View, as shown in Figure 4.4.

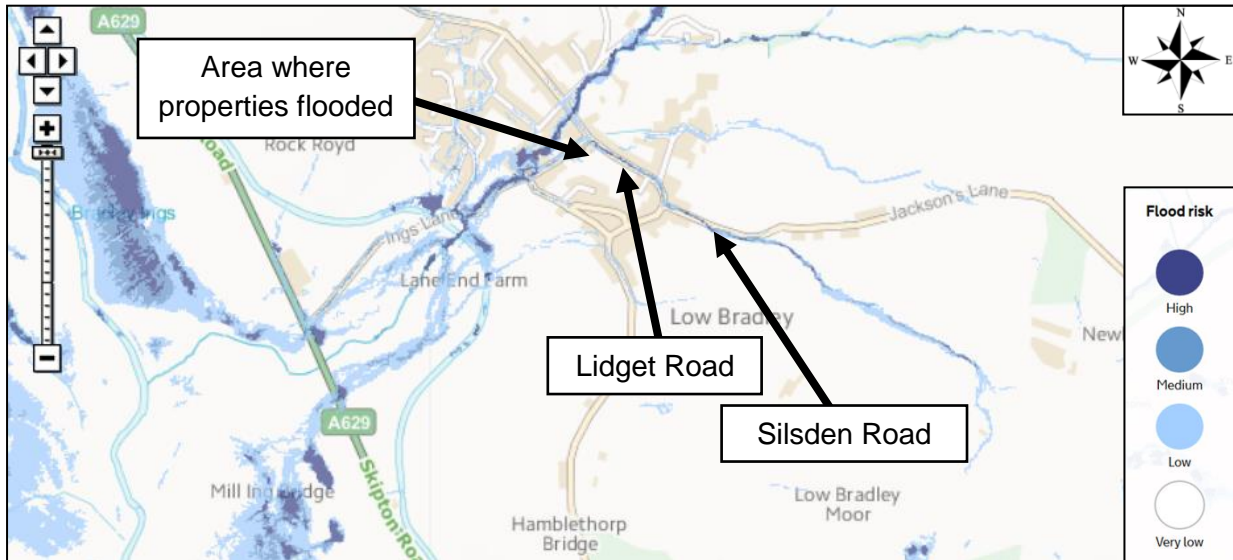


Figure 4.3 Environment Agency surface water flooding map (Source: EA)

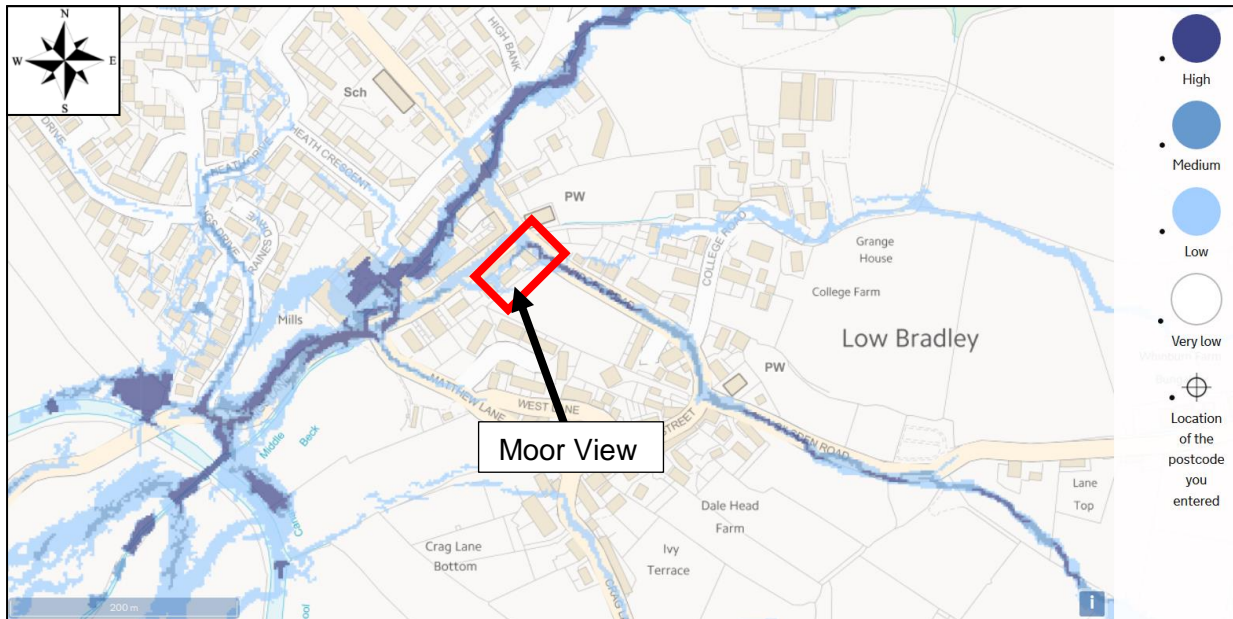


Figure 4.4 Surface water Flood Risk at Moor View

4.3 Flood Event

Nine properties in Low Bradley experienced internal damage associated with the flood event with eight of these being located at Moor View²⁹. Flooding occurred in Low Bradley as a result of the November and December rainfall levels and the significant precipitation event on Boxing Day 2015.

The properties at Moor View have frontages onto Ings Lane and Lidget Road, there is access to the courtyard through an archway on Lidget Road, as shown in Figure 4.5.

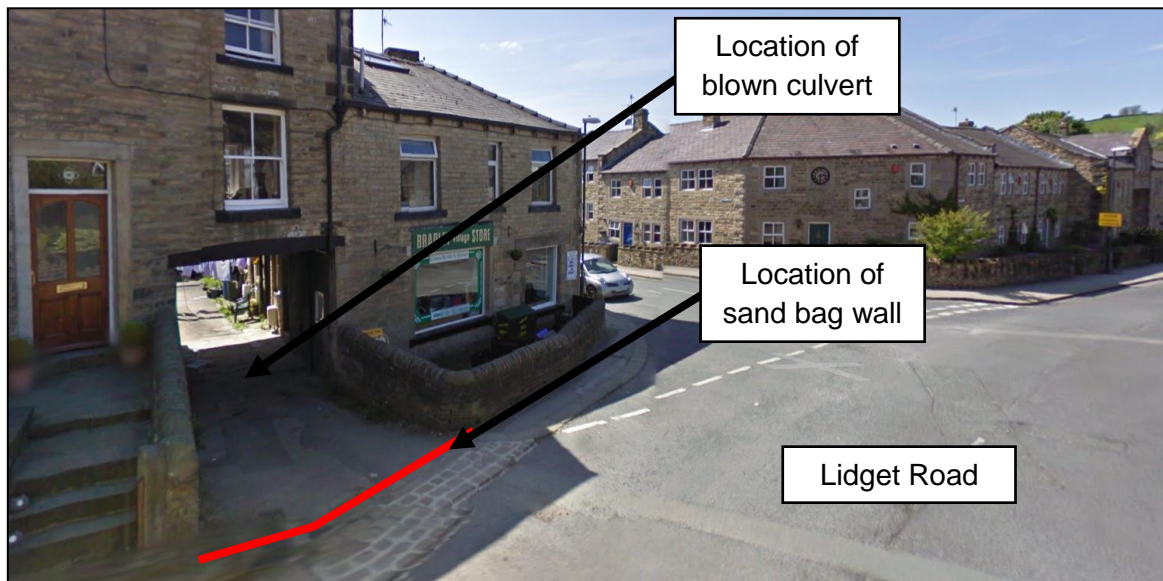


Figure 4.5 Moor View Courtyard access from Lidget Road (Source: Google Maps)

²⁹ Reports of flooding map, NYCC

The following is an account of a Local Resident:

Flooding at Moor View occurred in the early morning of the 26th of December 2015.

1. The rainfall event on the 25th December resulted in surface water flowing down Lidget Road from Low Bradley Moor. The residents built a wall out of sandbags at the entrance to the courtyard, to stop surface water entering the courtyard from Lidget Road, as shown in Figure 4.5.
2. In the early morning, approximately 4am, on the 26th of December residents were woken by the sound of water flowing in the Moor View courtyard. The water at the back of the properties had risen to approximately 300mm in depth.
3. The residents attempted to stop the water flowing off Lidget Road, but found that more water was entering the courtyard from a blown culvert located under the archway entrance, as shown in Figure 4.6 (C).
4. The water continued to rise in the courtyard due to its layout. The courtyard slopes away from Lidget Road and the location of the blown culvert, caused the water to flow into the courtyard. At the far end of the courtyard there was a boundary wall that acted as a dam, shown in Figure 4.6 (D), which held the water in the courtyard.
5. The water then entered the basements of the properties on the southeast of Moor View through the basement windows, which are at ground level, as shown in Figure 4.6 (B). The water continued to rise entering properties on the northwest of Moor View, overtopping the slot demountable door guards, as shown in Figure 3.4(A).

With the help of the fire brigade the residents created a hole in the wall at the end of the courtyard, as shown in Figure 4.6(D), allowing the water to dissipate.

One Moor View resident described the water level having reached an approximate depth of 300mm by 4am and to a max depth of 600mm, at Moor View on Boxing Day 2015.

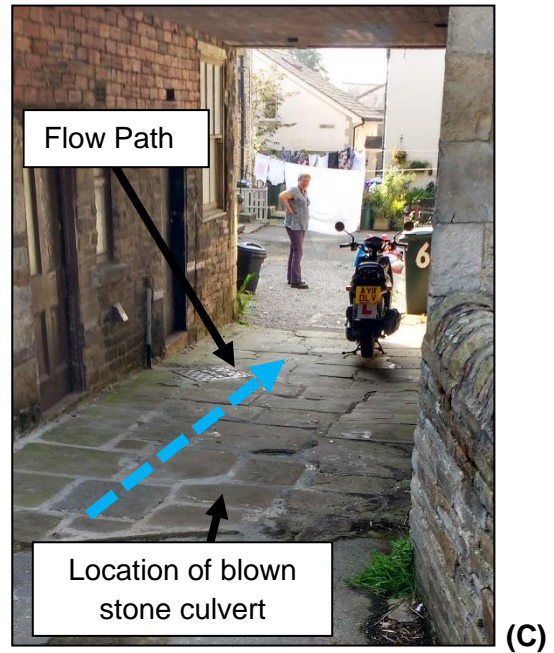
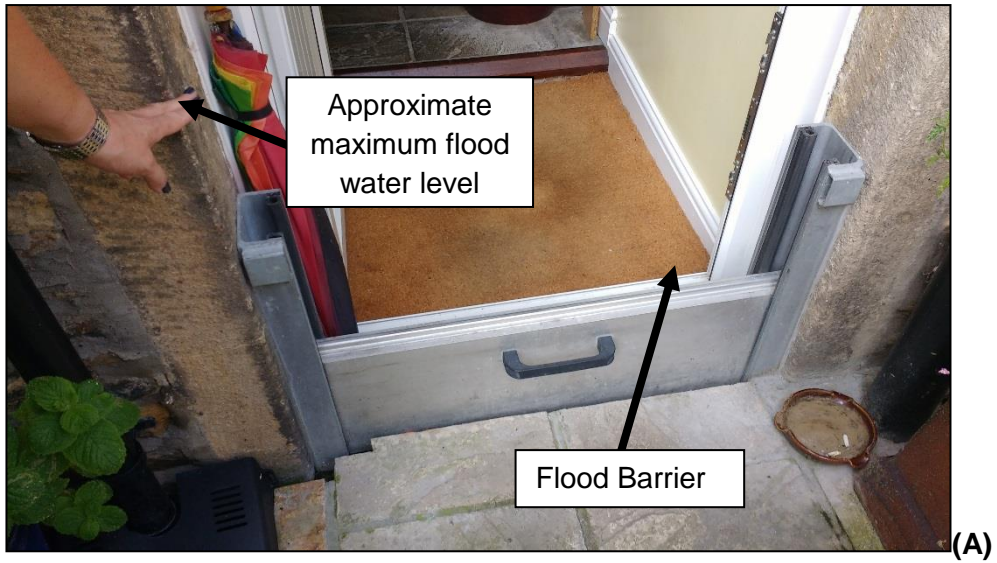


Figure 4.5 Photographs of Moor View

According to records provided by the EA for Silsden, the rainfall event that caused the Boxing Day flood started at 12:45 on the 25th December and finished at 13:15pm on the 26th December, as shown in Section 3.3. There were two distinct pulses of rainfall, with the intensity peaking at 16:45 on the 25th and 07:00 on the 26th December.

Local residents described how the water pressure in the masonry culvert lifted the large stone culvert cap, so they were affected by flows from this culvert in addition to the surface water flows on Lidget Road.

Analysis undertaken by the EA as part of a view of the weather event across Yorkshire has been used to derive data for this investigation. An analysis of this and information from other sources has shown:

1. Prior to the rainfall on the 25th and 26th December 2015 the Aire catchment had experienced its 2nd wettest November on record. In Keighley, 9km from Low Bradley, 135% of Decembers LTA fell from the 1st to 24th December. Hence the ground was fully saturated prior to Christmas Day. As such any following precipitation would almost entirely be converted in to surface runoff³⁰.
2. The rainfall can be seen to have two distinct pulses, the first between 12:45 and 11:30 of the 25th and the second between 00:30 and 13:15 on the 26th December³.
3. The steep catchment was saturated and produced rapid surface water runoff.
4. The water level in the Middle Beck began to rise due to receiving surface water from the surrounding catchment.
5. The culvert on Lidget Road is known to take discharges from the highway drainage¹⁰. The highway drainage system collected a large amount of the surface water travelling down from Low Bradley Moor (second flowpath) and the highway drains were overwhelmed.
6. High water levels in the local watercourses into which the surface water and highway drainage systems flow will have seriously restricted the ability of these systems to discharge
7. The water level in the Middle Beck exceeded the outflow level of Lidget Road Culvert, causing the culvert to back up.
8. The culvert backing up was exacerbated by the flows from the culvert behind the Bradley Methodist church (third flow path) which is believed to enter the same system between Moor View and Middle Beck although the exactly position of this join is not known..
9. The water in the Lidget Road Culvert continued to back up, exacerbated by the steep gradient of the surrounding land and the head of pressure increased significantly to the point where the stone slab forming the roof of the culvert

³⁰ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

under the archway entrance to Moor View was lifted in the early hours of Boxing Day.

The anecdotal evidence states that there were very large flows exiting the blown culvert, this indicates that much of the surface water from the flow path off Low Bradley Moor is finding its way into the culvert system. It is unlikely to be just from or via the highway drainage system. It is likely there are more direct connections as the Lidget Road culvert continues in the direction of Low Bradley Moor and College Road.

In addition the culvert was observed to be flowing in dry weather when the CCTV inspection was carried out in the summer of 2016. This suggests that this may be more of a culverted watercourse being fed from a larger catchment area rather than a local drain. This is supported by OS Mapping where it can be seen that there is a watercourse running down Jackson’s Road which is culverted under the road and then disappears from the map, as shown in Figure 4.6. It is suggested that this could be connected into the Historic culvert system. The significant surface water flows overwhelmed the highway drainage resulting in the excess surface water flowing down Lidget Road as well as that being delivered underground by the culvert.

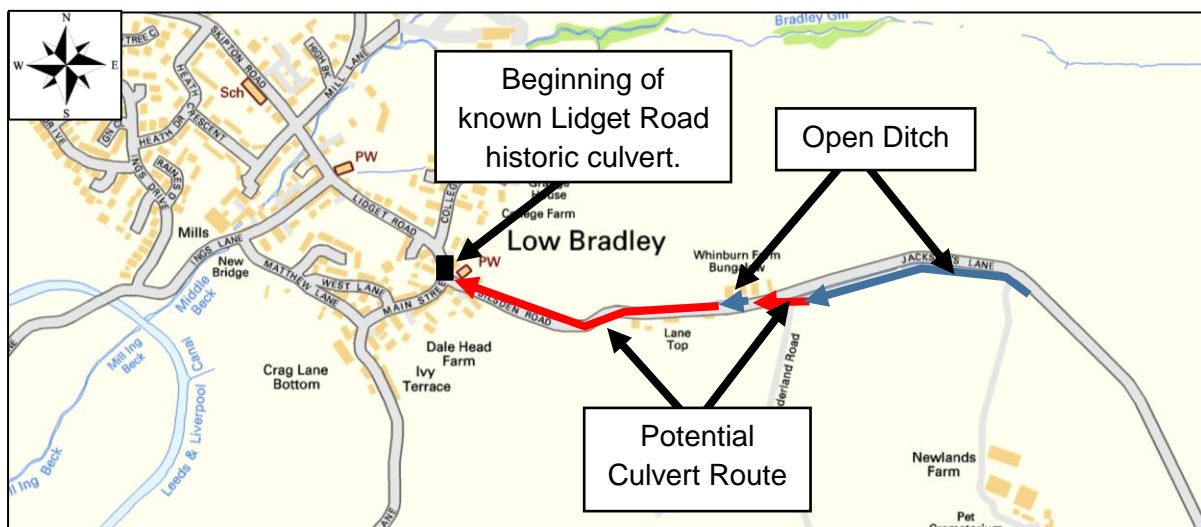


Figure 4.6 Watercourse running down Jackson Road

The flood waters from Low Bradley and the surrounding catchment entered the Middle Beck and the Mill Ing Beck. As the flood waters progressed downstream they overtopped the banks of Mill Ing Beck, this combined with highway surface water resulted in flooding of the A629. The fire brigade removed the A629 wall to alleviate the flood waters. During the site inspection a significant amount of debris was observed in the channel under the Leeds and Liverpool Canal³¹, as shown in Figure 4.7. It cannot be determined how much of this accumulated during the December 2015 event, however the significant build-up of debris under the canal has the potential to restrict the Mill Ing Beck syphon, which would:

³¹ Site Inspection

- Increase the restriction to flow for Mill Ing Beck and Middle Beck;
- Cause more extensive flooding, in the immediate vicinity and in Low Bradley;
- Potentially damage the structural integrity of the canal.



Figure 4.7 Photograph showing deposits in canal

5 Cononley

5.1 Location

Cononley (Grid Reference: SD 99060 46968) is located to the West of the A629 and approximately 5.5km south of Skipton. Cononley is located in a valley with the River Aire flowing through the western side of the village and the Cononley Beck through its centre, approximately west to east, as shown in Figure 5.1. The village lies within the district of Craven and within the County Council electoral division of North Yorkshire. The village has a population of 1200 according to the 2011 Census. Cononley has an industrial history based in lead mining and hand loom weaving and later textile mills.

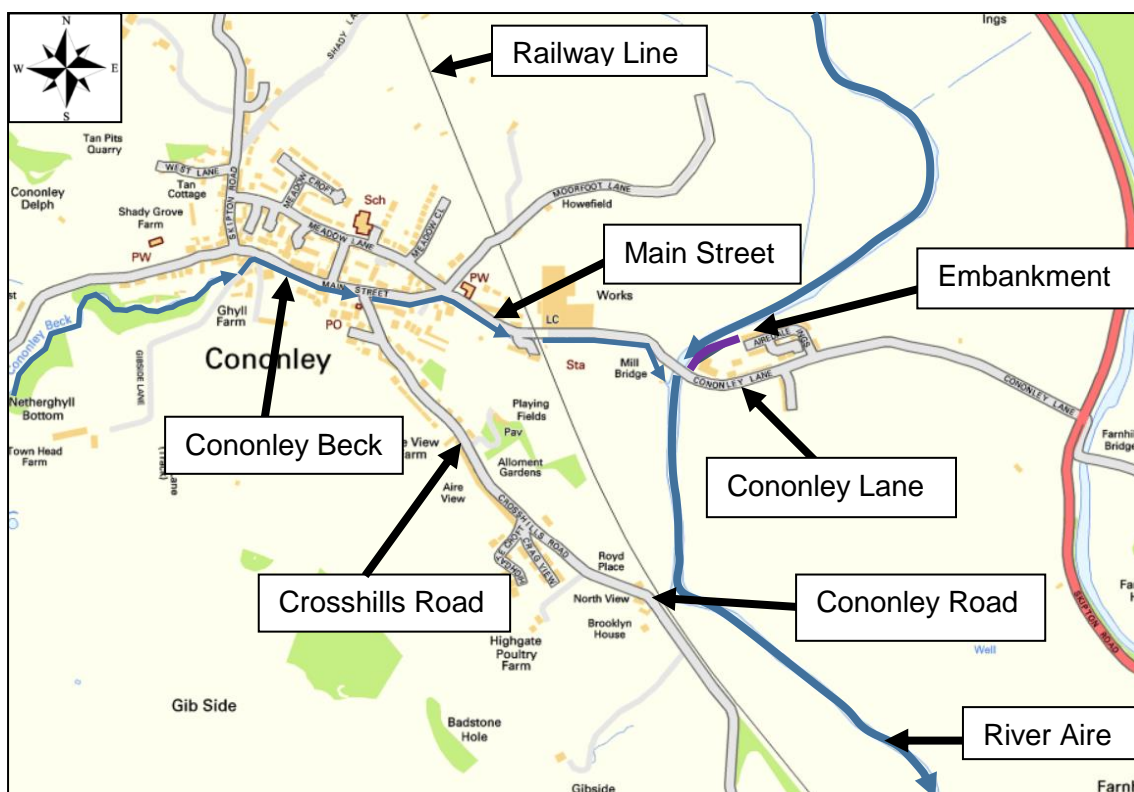


Figure 5.1 Cononley study area map (NYCC)

5.2 Water Environment

Cononley is situated in a valley that has steep agricultural land surrounding its western side and the flat River Aire flood plain on its eastern side, as shown in Figure 5.2. Due to the shape of the surrounding land after a rainfall event surface water will flow towards the village centre, Crosshills Road and Cononley Road, as shown in Figure 5.3.³² The surface water flood map, shown in Figure 5.4 shows properties in close proximity to the Cononley Beck and a large area immediately west of the railway line are at high risk to surface water flooding.

³² NYCC Rolling Ball Analysis – identifying indicative overland flow route

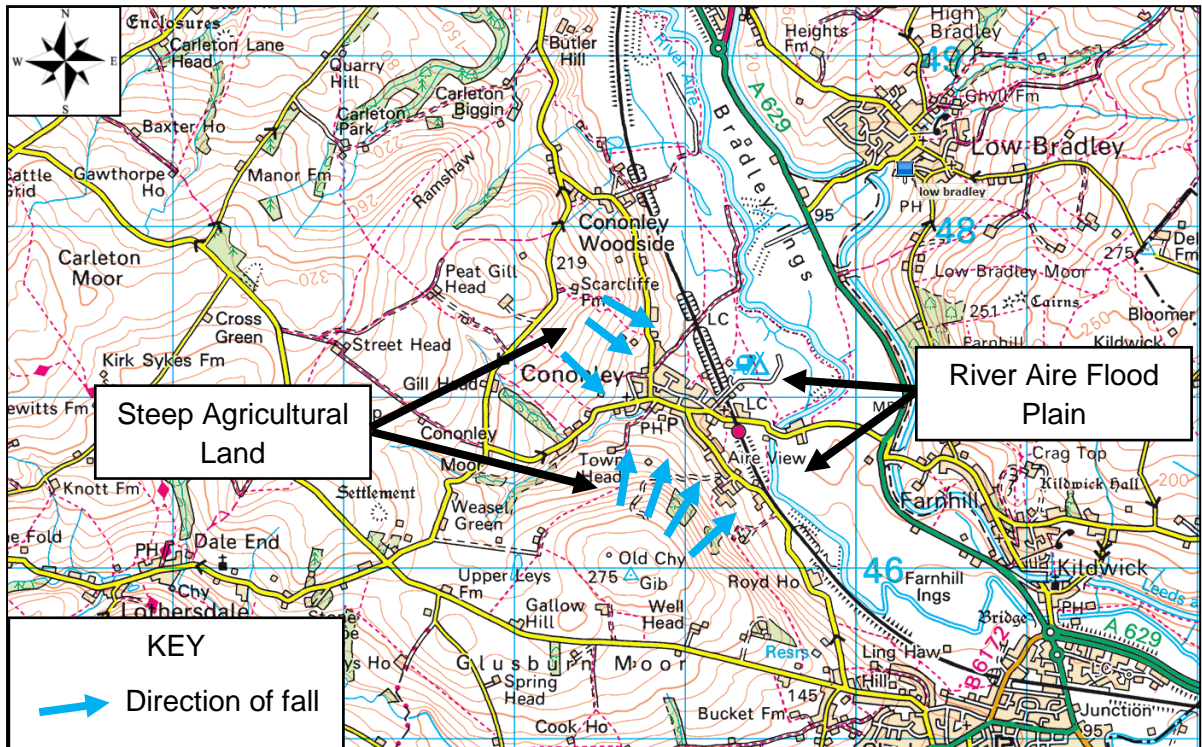


Figure 5.2 Cononley Topography (Source: NYCC)

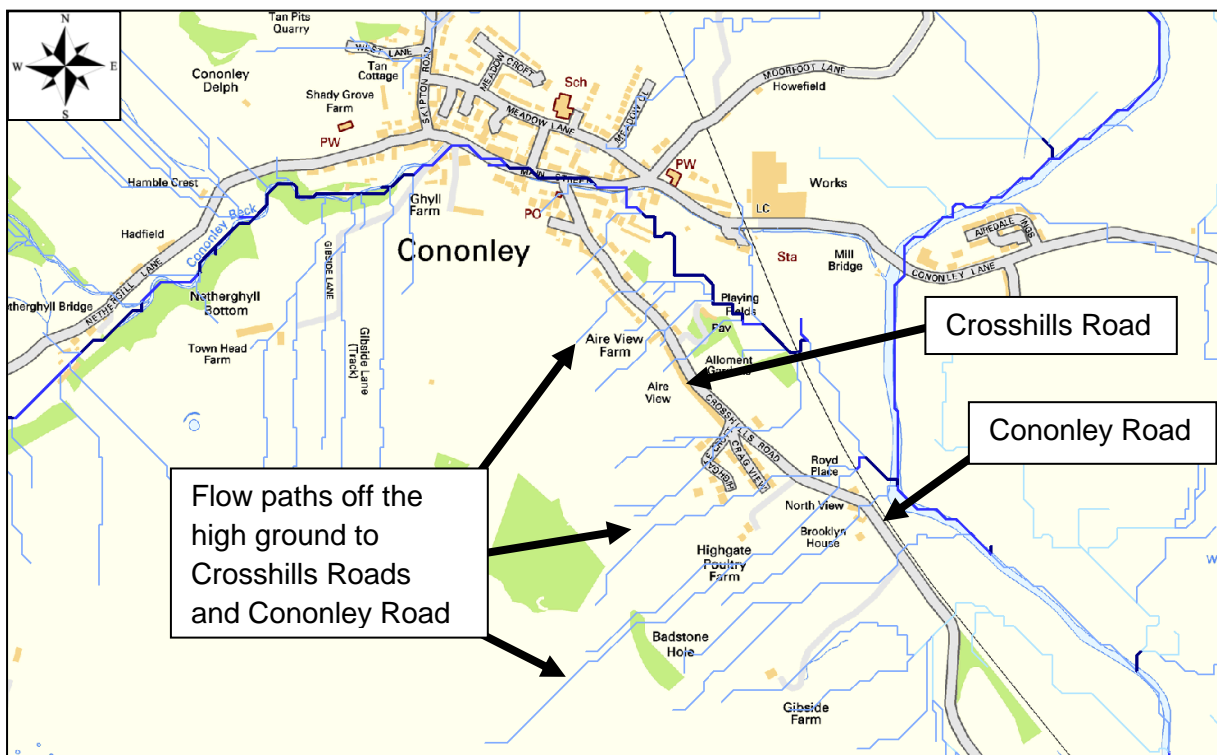


Figure 5.3 Rolling Ball Analysis for Cononley (Source: NYCC)

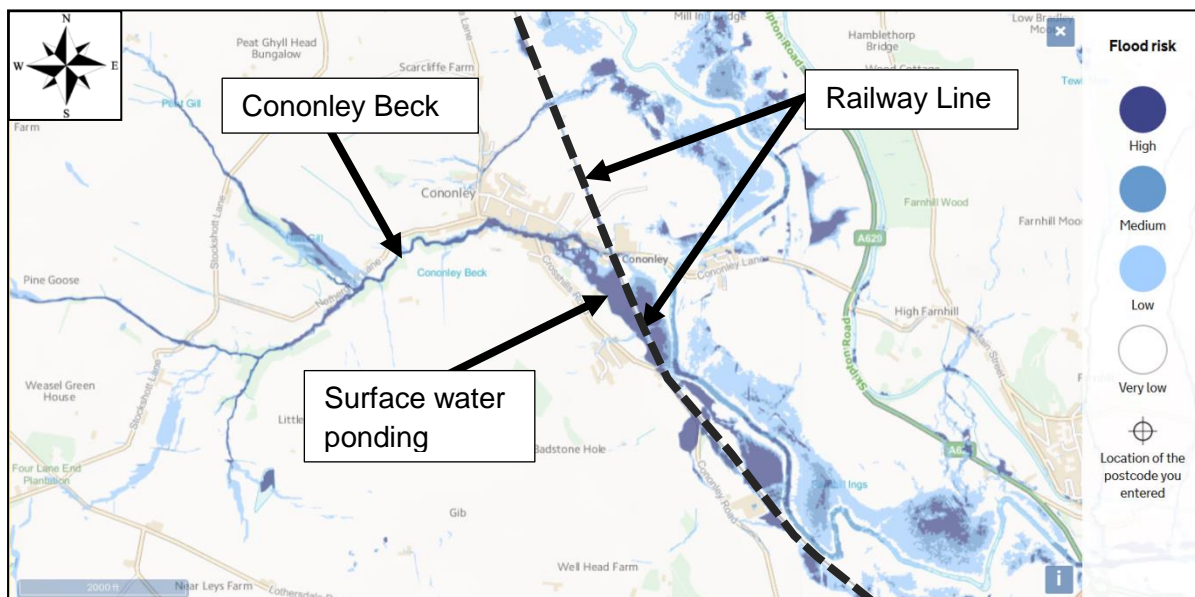


Figure 5.4 Environment Agency surface water flooding map (Source: EA)

The River Aire passes through Cononley in close proximity to properties, its bed level is approximately 89m above sea level at the EA river gauge site³³ (Grid Reference: SD9973046925). Cononley Beck flows through the centre of the village in close proximity to properties and is culverted in a number of places, an example of the channel is shown in Figure 5.5. The EA river flooding map, as shown in Figure 5.6, shows a large area close to the River Aire is at risk of river flooding. Properties in close proximity to the Cononley Beck and a large area immediately west of the railway line are also at risk of river flooding from Cononley Beck.

³³ Flood Information Service, Environment Agency

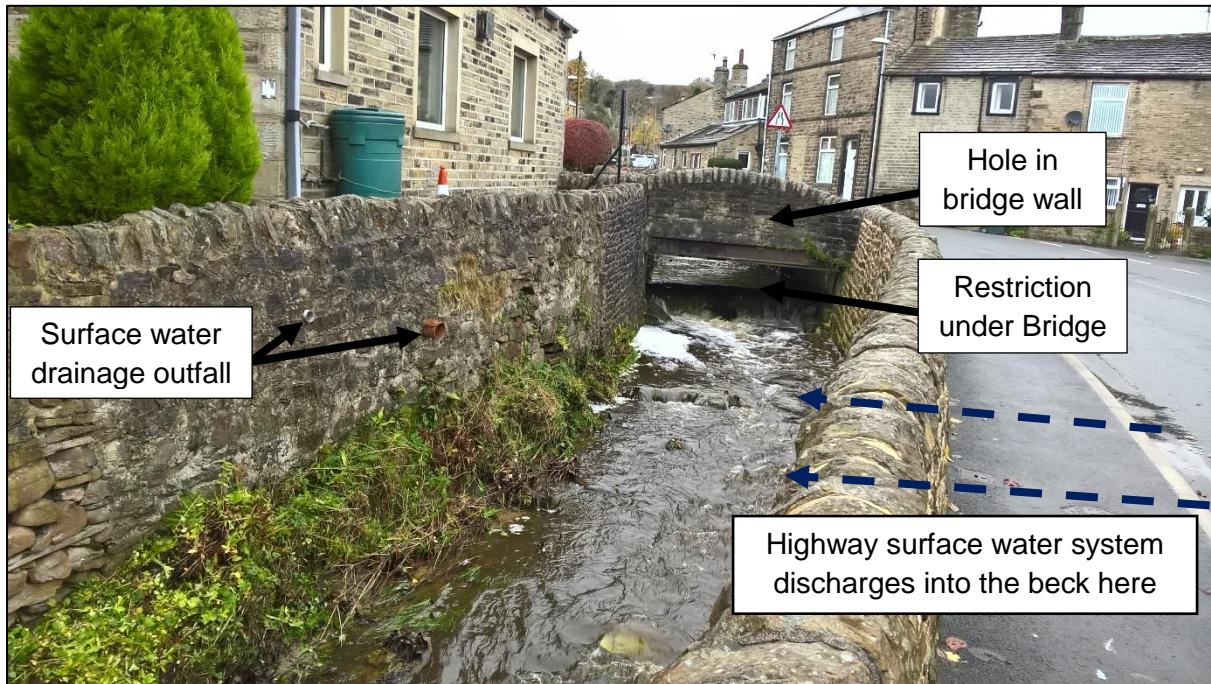


Figure 5.5 Photograph showing an example of the Cononley Beck channel

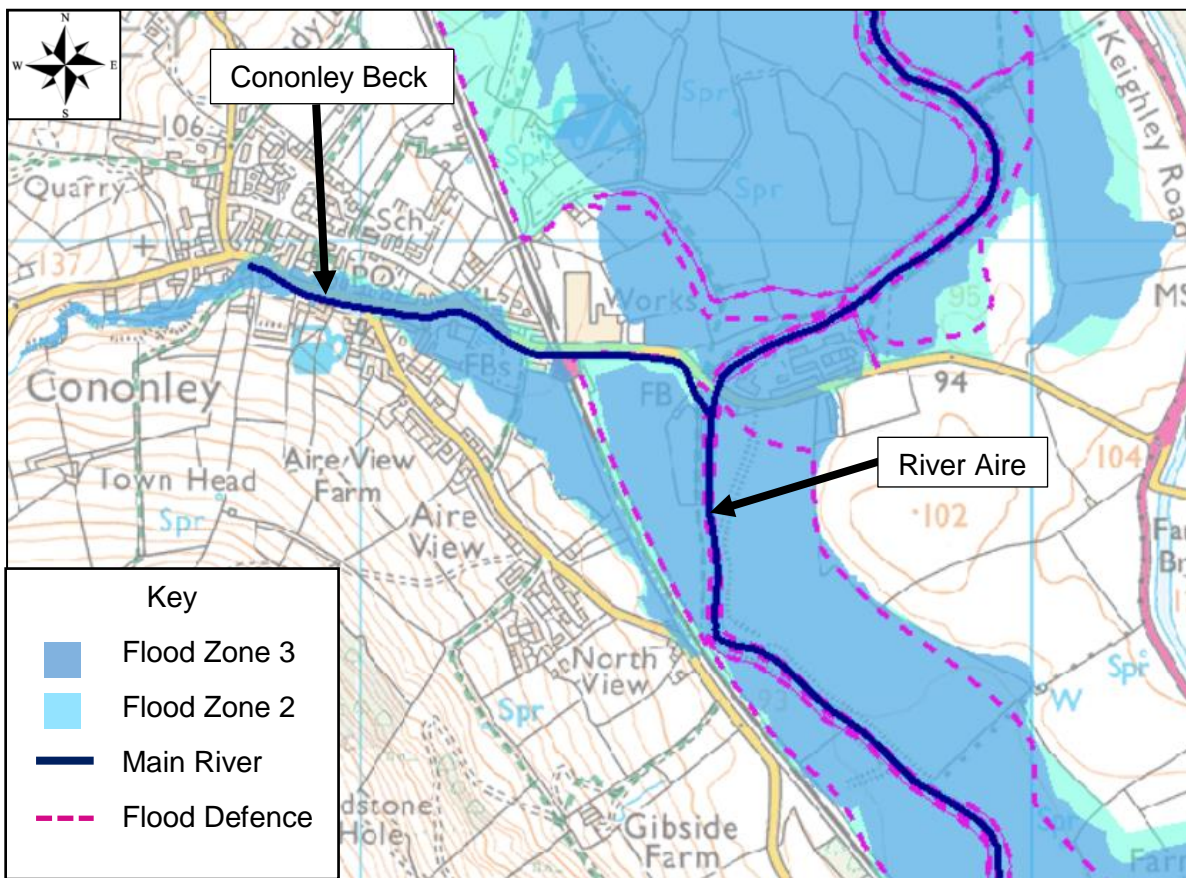


Figure 5.6 Environment Agency river flooding map (Source: EA)

5.3 Flood Event

Cononley has a history of flooding³⁴. 18 properties in Cononley experienced internal flooding associated with the Boxing Day 2015 event, ten properties located on Cononley Lane, six properties on Crosshills Road and Cononley Road, and one on Main Street²⁰. Flooding occurred in Cononley as a result of the November and December rainfall levels and the significant rainfall event on Christmas and Boxing Day 2015.

5.3.1 Cononley Lane

The flooded properties on Cononley Lane are located within 85m of the River Aire, as shown in Figure 5.7, Cononley Lane elevations in this area are between 93m and 95m above sea level.



Figure 5.7 Photograph showing properties on Cononley Lane (Source: Google Maps)

Analysis undertaken by the EA as part of a view of the weather event across Yorkshire has been used to derive data for this investigation. An analysis of this and information from other sources has shown:

1. The Catchment in the whole of Yorkshire had experience high levels of rainfall in November and December leading up to the flooding event. The Aire catchment had its 2nd wettest November on record. In Keighley, 9km from Cononley, 135% of Decembers LTA fell from the 1st to 24th December³⁵. The EA hydrology report on the event stated that the ground was fully saturated

³⁴ Historic Flooding Data, NYCC

³⁵ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

- prior to Christmas Day. As such any following precipitation would almost entirely be converted in to surface runoff.
2. The rainfall event started at 12:45 on the 25th and continued until 13:15 on the 26th December. The rainfall can be seen to have two distinct pulses the first between 12:45 and 23:30 on the 25th and the second between 00:30 and 13:15 on the 26th December⁴.
 3. The River Aire levels at Cononley show a quick sharp reaction, as shown in Figure 5.8. The two pulses of heavy rainfall were evident within the catchment as water levels rose quickly with the initial peak being observed on the evening of Christmas Day then rising quickly to peak again on Boxing Day.

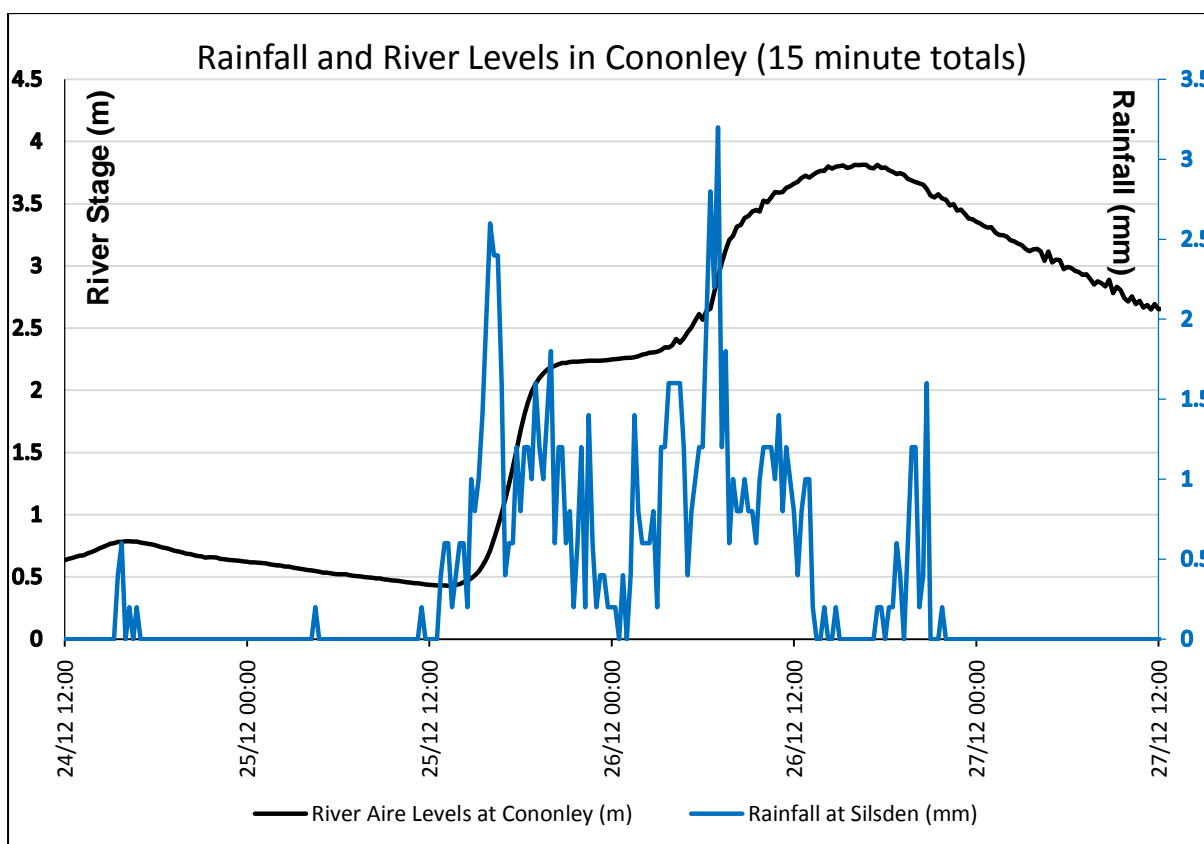


Figure 5.8 Comparison of local rainfall and River Aire levels at Cononley.

4. The EA issued a flood warning for Cononley Business Park on Cononley Lane and Aireside Avenue at 21:49 on the 25th December³⁶.
5. The River Aire levels rose to the threshold required to overtop the flood defence embankment located between properties on Cononley Lane and the River Aire, as shown in Figure 5.1. The River Aire at Cononley reached a maximum level of 3.81m¹⁸ (92.81AOD) at 16:45 on the 26th December.
6. The flood water overtopping the embankment propagated towards the residential properties on Cononley Lane and business properties in the

³⁶ Flood Warning Information, Environment Agency

business park resulting in internal flooding from the rear, the extents of River Aire flooding on Boxing Day 2015 are shown in Figure 5.9 and Figure 5.10.

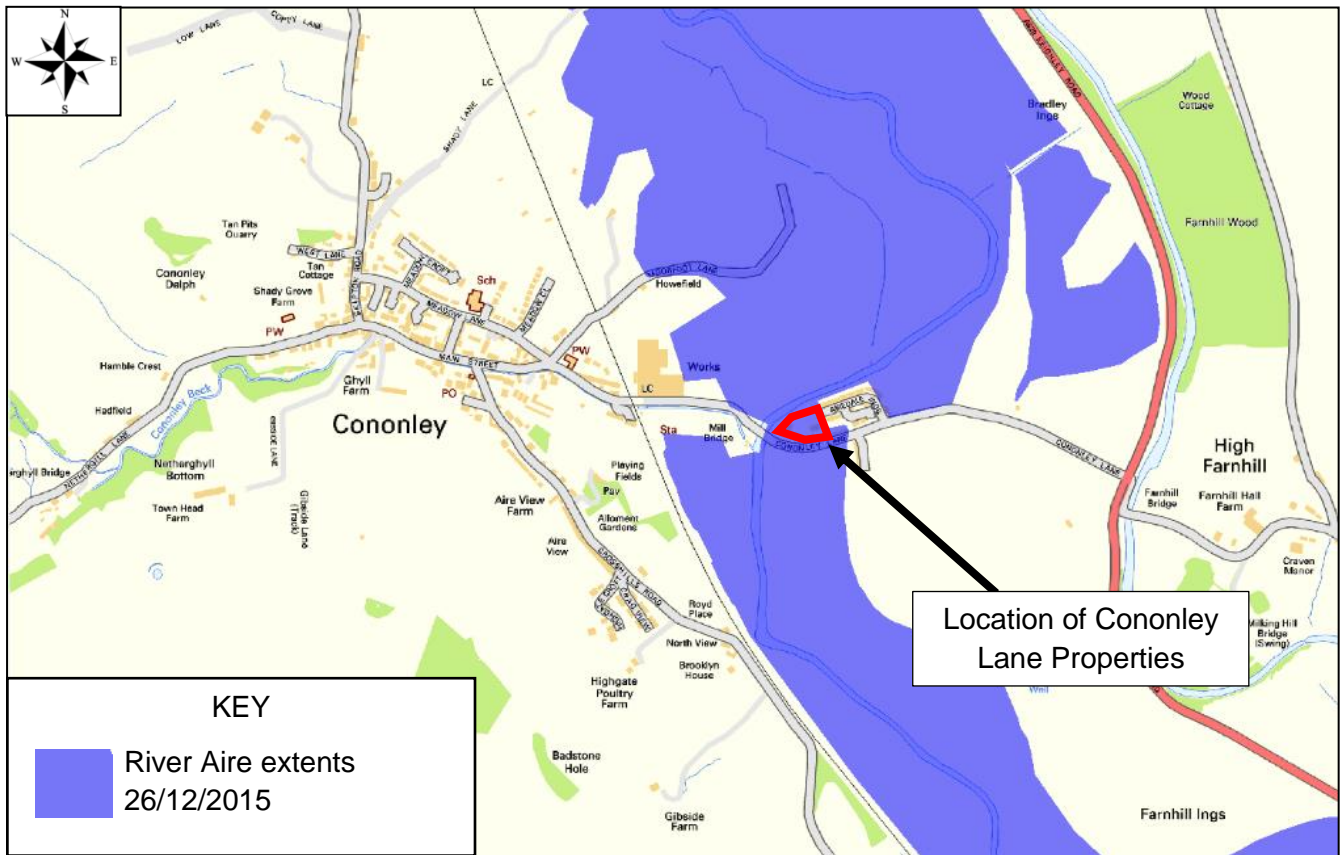


Figure 5.9 River Aire flood extents for Cononley 26th December 2015.



Figure 5.10 Photograph showing the extent of flooding in Cononley on the 26th December 2015

5.3.2 Cross Hills Road and Cononley Road and Main Street

The River Aire flood extents for the Boxing Day flood were held to the east of the railway embankment (Figure 5.9 above), hence the properties to the west of the railway embankment do not appear to have been directly related to River Aire flooding³⁷.

Analysis undertaken by the EA as part of a view of the weather event across Yorkshire has been used to derive data for this investigation. An analysis of this and information from other sources has shown:

1. The steep agricultural catchment to the west of Cononley was saturated due to rainfall prior to the 25th December 2015³⁸.
2. Heavy rainfall on the 25th and 26th produced a large amount of surface water.
3. Due to the topography of the surrounding land, the surface water from the land in close proximity to Cononley flowed towards the village, Crosshills Road and Cononley Road. Surface water further up the catchment entered the Cononley Beck, resulting in increase in water levels.
4. The surface water followed the gradient of the land toward the properties on Cross Hills Road. This water gradually built up in depth as the rainfall event continued, resulting in the flooding of properties along Crosshills Road.
5. The Highway drainage along Crosshills Road became overwhelmed by surface water from the surrounding agricultural land.
6. High water levels in the local watercourses into which the surface water and highway drainage systems flow will have seriously restricted the ability of these systems to discharge
7. Surface water from the agricultural land north of Cononley Road discharged directly onto the highway.
8. Surface water from Crosshills Road and Cononley road flowed south towards the railway line where it built up in the lowest point, increasing in depth and flooding two properties on Cononley Road.
9. A property on Kings Street, in close proximity to the junction of Cross Hills Road and Main Street, was flooded from water coming up through the floor of the property. The water in the property was 25mm deep at 7am on Boxing Day. The resident, supported by other members of the community, was able to minimise the damage by installing sandbags. The source was later investigated by Yorkshire Water Services, and found to be a non YWS culvert that had silted up³⁹.
10. The surface water on the local highways overwhelmed the highway drainage systems and created a flow path down Main Street.

³⁷ River Aire Flooding Extents Data, 26th December 2015, Environment Agency

³⁸ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

³⁹ YWSL records & Discussion with Cononley Resident

11. The levels of water in the Cononley Beck increased almost resulting in overtopping through the holes in the bridge wall, shown in Figure 5.11. There have been no reports of the Cononley Beck over topping its banks.



Figure 5.11 photograph showing Cononley Beck Bridge wall

12. It is believed that the another property in Cononley flooded due to the surface water system being unable to discharge to the Cononley Beck, as a result of high river levels.

6 Kildwick

6.1 Location

Kildwick (Grid Reference: SE 00884 46161) is located to the north and west of the A629 and 6.1km south of Skipton. The village lies within the district council of Craven and within the County Council electoral division of North Yorkshire. The village has a population of 200 according to the 2011 Census. The Leeds and Liverpool Canal passes through the south of Kildwick and the Aire borders its southern most point. The key characteristics and locations are shown in Figure 6.1.

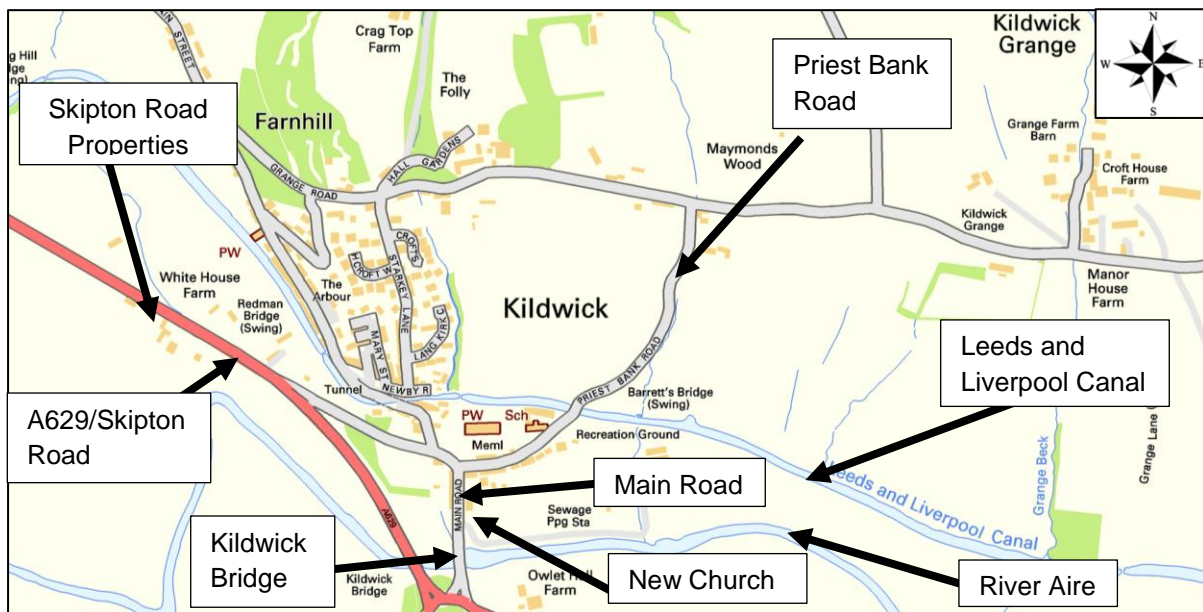


Figure 6.1 Kildwick study area map (NYCC)

6.2 Water Environment

Kildwick sits in a low lying area in relation to the surrounding land, as indicated in the contour lines shown in Figure 6.2. Steep agricultural land surrounds Kildwick from the northwest to the east. Kildwick is partially separated from the River Aire flood plain to the south by the A629 and the Leeds and Liverpool Canal.



Figure 6.2 Kildwick topography map

Water levels on the River Aire are gauged at Kildwick (Grid Reference: SE0110645684), where the bed level is 87.28m above sea level. There is a small watercourse running through the centre of Kildwick (Central Watercourse) that passes under the Leeds and Liverpool Canal, through a long culverted section before discharging into the Aire on the upstream side of Kildwick Bridge. Another small watercourse passes through the eastern part of Kildwick (Eastern Watercourse), passes under the Leeds and Liverpool Canal and discharges into the River Aire. The majority of the surface water from the steep agricultural land feeds into these small watercourses identified in Figure 6.3⁴⁰

⁴⁰ Flood Map for Surface Water, Environment Agency

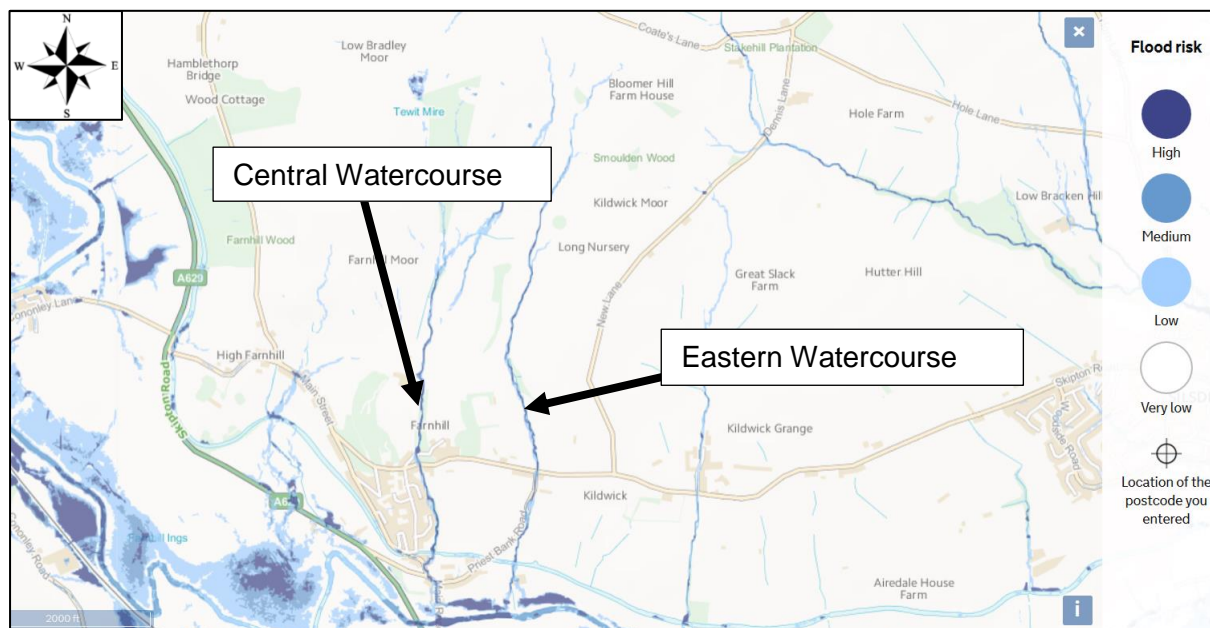


Figure 6.3 Watercourses and flow paths off steep agricultural land

6.3 Flood Event

Ten Properties in Kildwick are reported to have experienced internal flooding associated with the Boxing Day event, four on Main Road, four on Skipton Road and two on the outskirts of the village⁴¹. Flooding occurred in Kildwick as a result of the November and December rainfall levels and the significant precipitation event on Christmas Day and Boxing Day 2015.

The cause of the flooding in this location was a combination of river flooding and surface water flooding.

6.3.1 River Aire

The properties located on Skipton Road and Main Road are between 80m and 180m from the River Aire. The Skipton Road properties are situated on flat land between the River Aire and the A629.

Analysis undertaken by the EA as part of a review of the weather event across Yorkshire has been used to derive data for this investigation. This has shown:

1. In the October prior to the Boxing Day flood the members of the New Church moved belongings from the ground floor to the first floor⁴².
2. The whole of Yorkshire had experienced high levels of rainfall in November and December leading up to the flooding event. The Aire catchment had its 2nd wettest November on record. In Keighley, 7km from Kildwick, 135% of Decembers LTA fell from the 1st to 24th December. The EA hydrology report on the event stated that the ground was fully saturated prior to Christmas Day. As such any following precipitation was almost entirely surface runoff⁴³.

⁴¹ NYCC reports of flooding , 26th December 2015

⁴² Discussions with a Kildwick Resident

⁴³ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

3. The rainfall event started at 12:45 on the 25th and continued until 13:15 on the 26th December. The rainfall can be seen to have two distinct pulses the first between 12:45 and 11:30 of the 25th and the second between 00:30 and 13:15 on the 26th December⁴⁴.
4. The River Aire levels at Kildwick show a rapid reaction to the rainfall as shown in Figure 6.4. The two pulses of heavy rainfall were evident within the catchment as water levels rose quickly with the initial peak being observed on the evening of Christmas Day then rising quickly to peak again on Boxing Day.

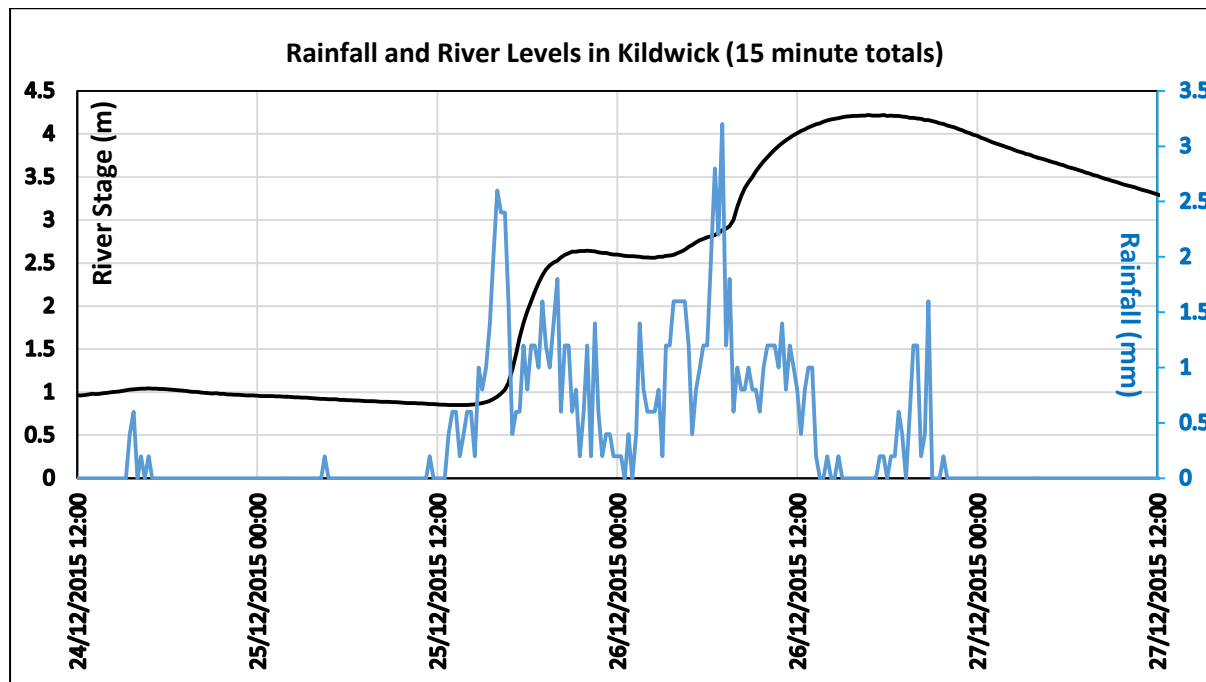


Figure 6.4 Comparison of local rainfall and River Aire levels at Kildwick.

5. A flood warning was issued from the Environment Agency at 06:46 on the 26th December⁴⁴. (River Aire at Skipton Road, Kildwick – Ref 123FWFR108)
6. The River Aire levels continued to rise resulting in the banks being overtopped downstream of the Main Street Bridge the water flowed on to the flood plain and back towards Main Street, as shown in Figure 6.5.

⁴⁴ Flood Warning Time line, Environment Agency

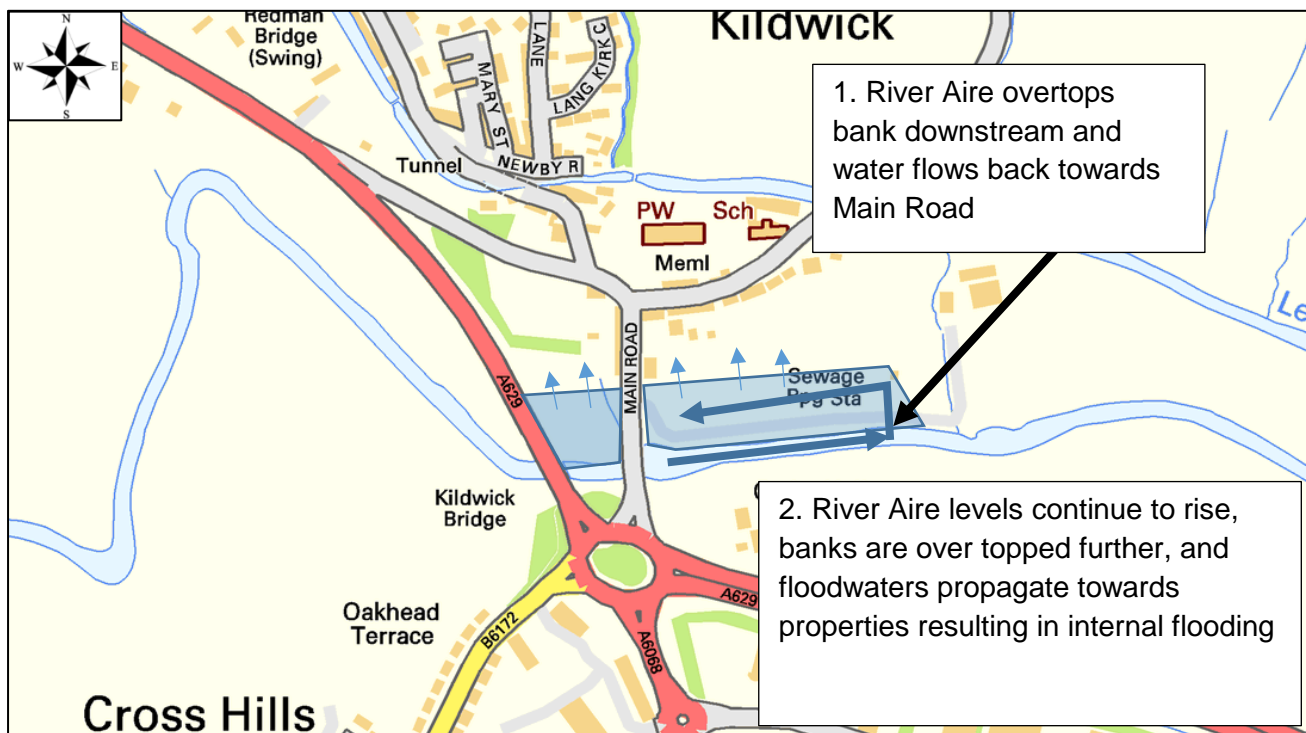


Figure 6.5 River Aire flooding at Kildwick

7. The river levels continued to rise flooding the properties on Main Street and Skipton Road, the River Aire levels rose to half the height of the New Church’s ground floor door⁴⁵.
8. The River Aire Levels downstream and upstream of Main Street can be seen in Figure 6.6 and 6.7.
9. The River Aire rose to a maximum level of 4.22m at 17:45 on the 26th December, the extent of the flood water can be seen in Figure 6.8.

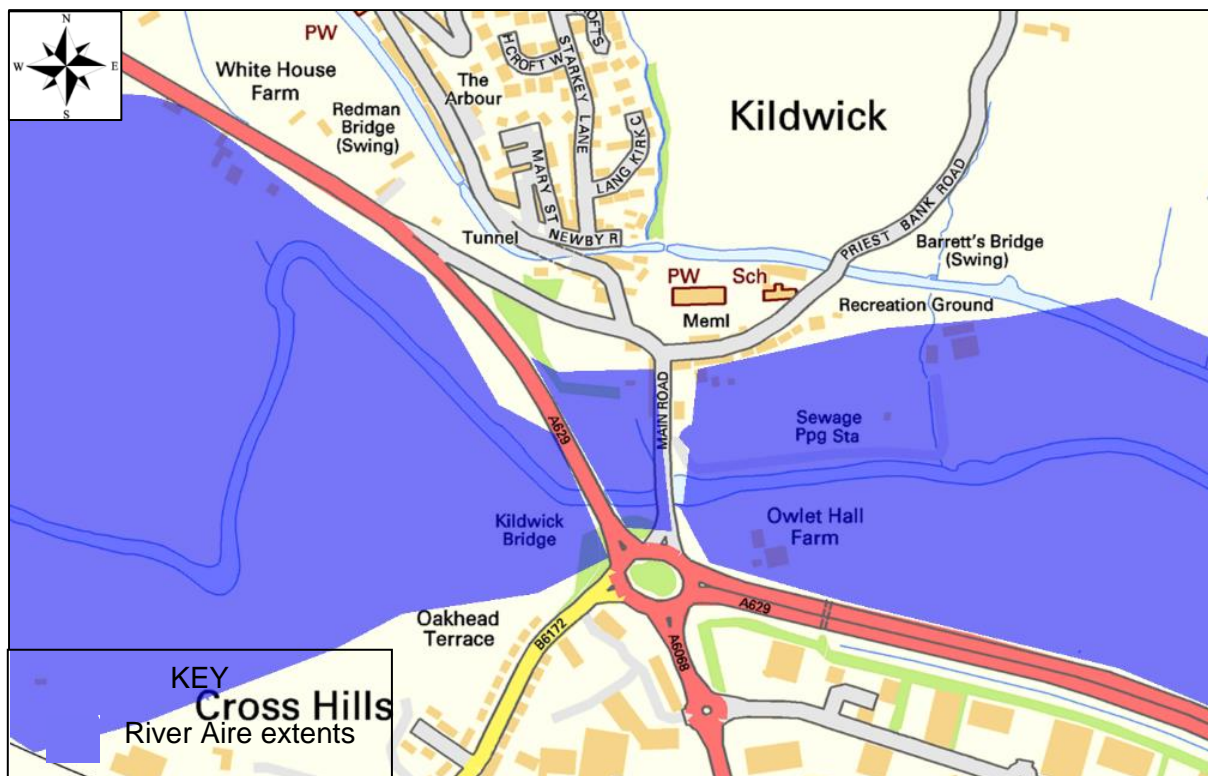
⁴⁵ Discussion with local Resident



Figure 6.6 Photograph showing the River Aire at Kildwick on the 26th December 2015



Figure 6.7 Photograph showing the depth of flood water against the Kildwick Bridge



(Sutton-in-craven village website)

Figure 6.8 River Aire flood extents for Kildwick 26th December 2015.

6.3.2 Surface Water

The White Lion on Main Street did not flood from the River Aire.

An analysis of EA weather event and information from other sources has shown:

1. The steep agricultural catchment to the north of Kildwick was saturated due to rainfall prior to the 25th December 2015⁴⁶.
2. The rainfall events of the 25th and 26th created a large volume of surface water on the steep agricultural land to the north of Kildwick.
3. The majority of the surface water flowed towards the town via the two watercourses discussed in Section 6.2.
4. The Eastern Watercourse flows in close proximity to Priest Bank Road, it is culverted under Grange Road, and a property south of Grange Road.
5. It is possible that part of the water conveyed by the Eastern watercourse overflowed onto Priest Bank Road, and this is considered to be the most probable source of flows which ultimately impacted The White Lion.

⁴⁶ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

6. There is no formal highway drainage system on Priest Bank Road and due to the stone walls on either side the majority of surface water is contained and flows down the road.
7. The surface water travelled down Priest Bank Road to the Leeds and Liverpool Canal where a proportion entered the canal, the remaining water continued over the bridge downhill to its junction with Main Road.
8. The surface water flowing down Priest Bank Road has a combination of sources highway surface water; runoff from agricultural land; property surface water and potentially the Eastern Watercourse draining land to the North of Grange Road.
9. The surface water then entered the cellar of the property via an entry hatch close to the road, as shown in Figure 6.9.
10. A highway gully outside this property was the collection point for all surface water flows coming down Priest Bank Road. However, the speed and the volume of flow is likely to have overwhelmed the capacity of both the surface gully grate and the underlying drainage system. Surcharge at this point added to the flooding of the property through the cellar hatch adjacent to the road.

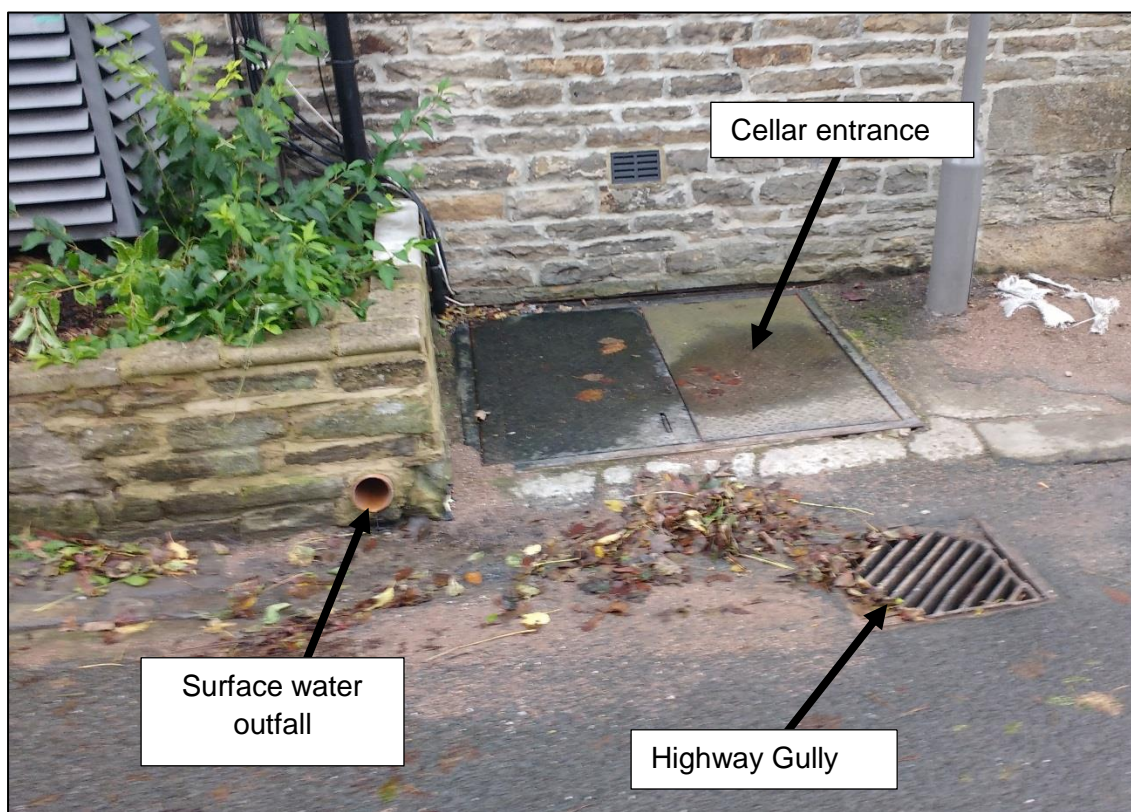


Figure 6.9 Photograph showing the point of entry of the surface water

7 Cross Hills

7.1 Location

Cross Hills (Grid Reference: SE 00870 45069) is located to the south of the A629, the River Aire, and 7.5km south of Skipton and 6.5km northwest of Keighley. Cross Hills is part of the Glusburn Civil Parish in the district of Craven. The village has a population of 7600 according to the 2011 Census. The key locations and rivers are shown in Figure 7.1.

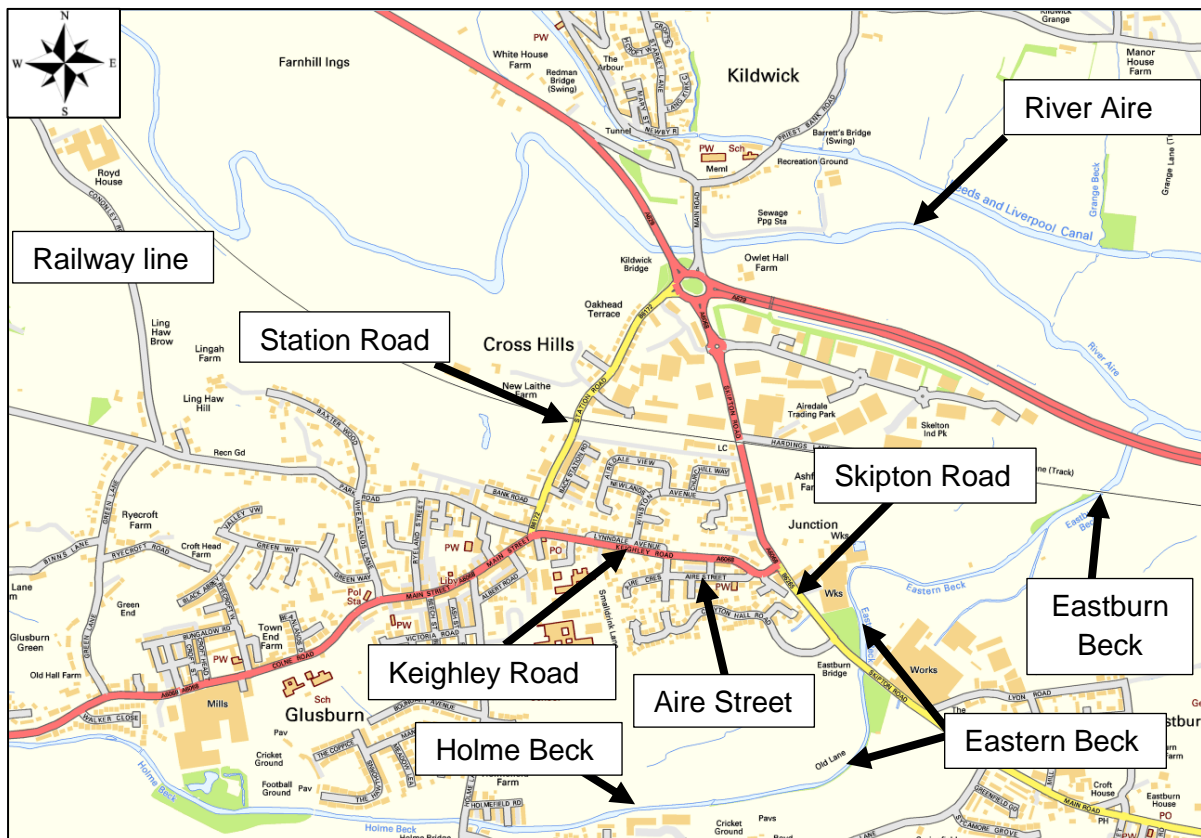


Figure 7.1 Cross Hills study area map (NYCC)

7.2 Water Environment

Much of Cross Hills is located in flat low lying land, in close proximity to two main rivers, and surrounded by urban, industrial and agricultural land. The River Aire flows west to east to the north of Cross Hills. Another main river flows to the south of Cross Hills and then along the eastern boundary. It has different names along its length, which from west to east are: Holme Beck; Eastern Beak; and Eastburn Beak. Cross Hills is at risk of flooding from both the main rivers, as shown in Figure 7.2. Flood Zone 2 represents land assessed as having between a 1 in 100 and 1 in 1,000 annual probability of river flooding (1% – 0.1%); Flood Zone 3 a probability of 1 in

100 or greater annual probability of river flooding (>1%). It can also be seen from this that some of the area already benefits from Flood defences⁴⁷.

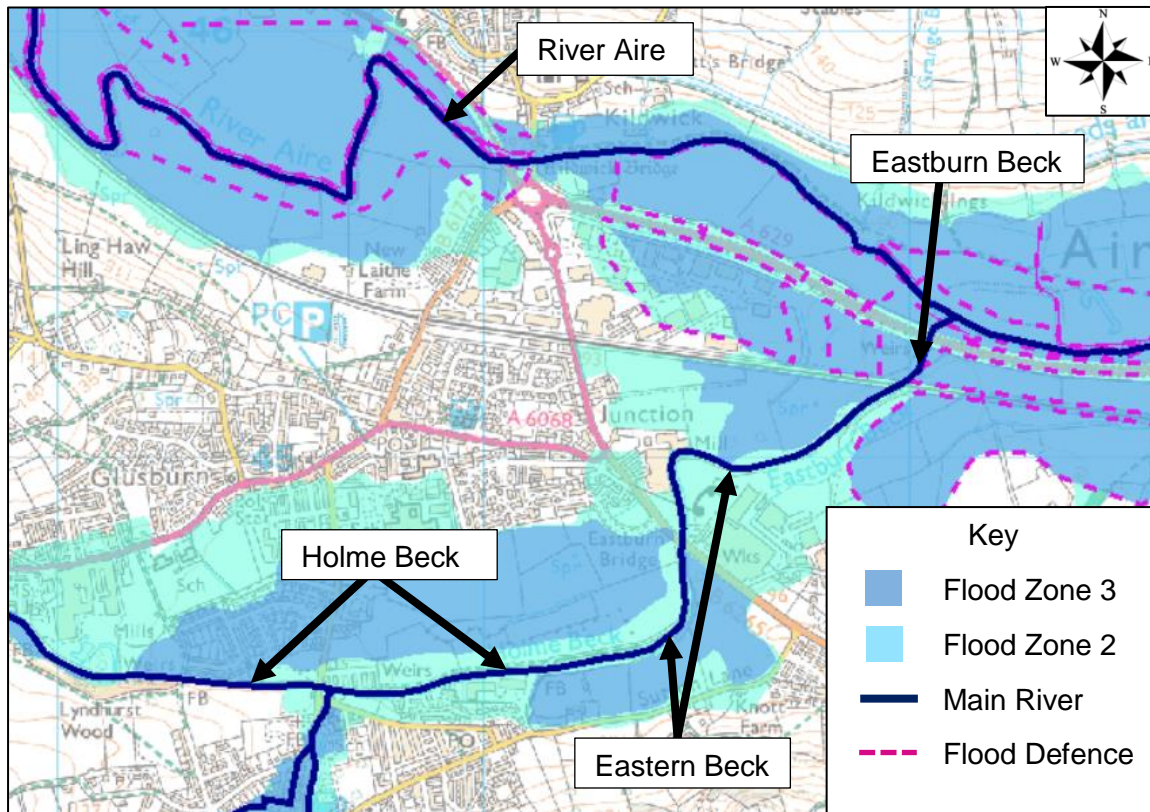


Figure 7.2 EA river flood risk map for Cross Hills

⁴⁷River Flood Risk Map, Environment Agency

Cross Hills is also at risk from surface water flooding with the area close to the Holme Beck, Eastern Beck and Eastburn Beck at greatest risk⁴⁸, as shown in Figure 7.3.

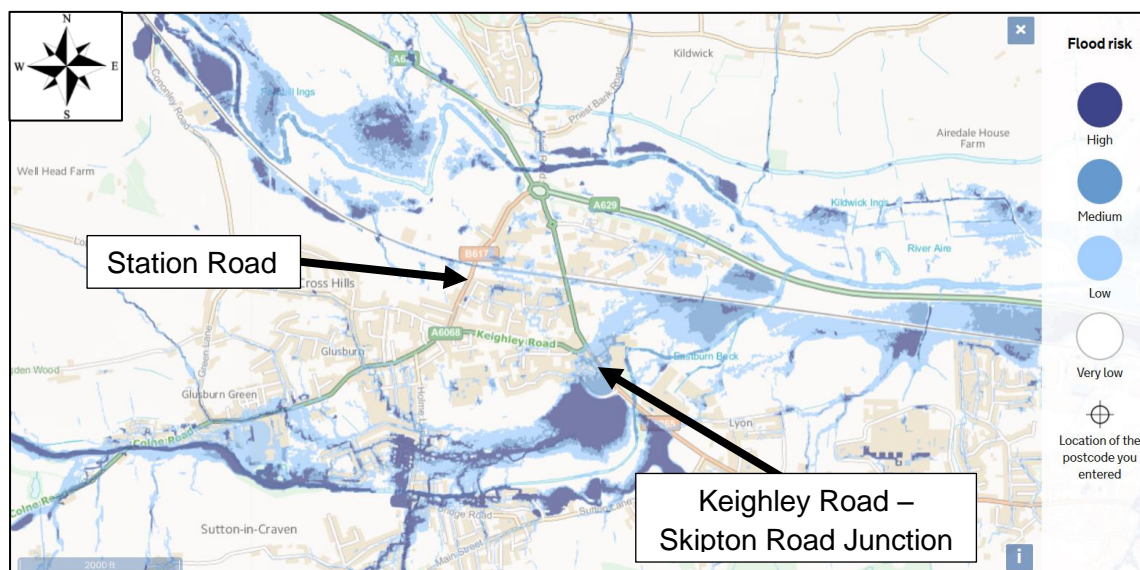


Figure 7.3 EA Surface water flood risk map for Cross Hills

As some areas are at high risk of flooding from both rivers and surface water it may not be possible to distinguish and quantify the effects of each source during an event.

7.3 Flood event

Nineteen properties in Cross Hills experienced internal flooding associated with the flood event, eleven in the vicinity of Station Road, north of the railway embankment, and eight in the vicinity of Keighley Road and its junction with Skipton Road. Flooding occurred in Cross Hills as a result of the significant rainfall event on Boxing Day 2015 falling on a catchment that was completely saturated following high November and December rainfall.

The EA river flooding map shows that the properties in the vicinity of the Keighley Road - Skipton Road junction are at medium risk of flooding from the Eastern Beck. The properties in the vicinity of Station Road are at risk of flooding from the River Aire.

In the vicinity of the junction of Keighley Road and Skipton Road there are significant numbers of properties at risk of surface water flooding, as shown in Figure 7.4. In the Station road area there are properties and adjacent land at risk from surface water flooding, as shown in Figure 7.4³.

⁴⁸ Surface Water Flood Risk Map, Environment Agency

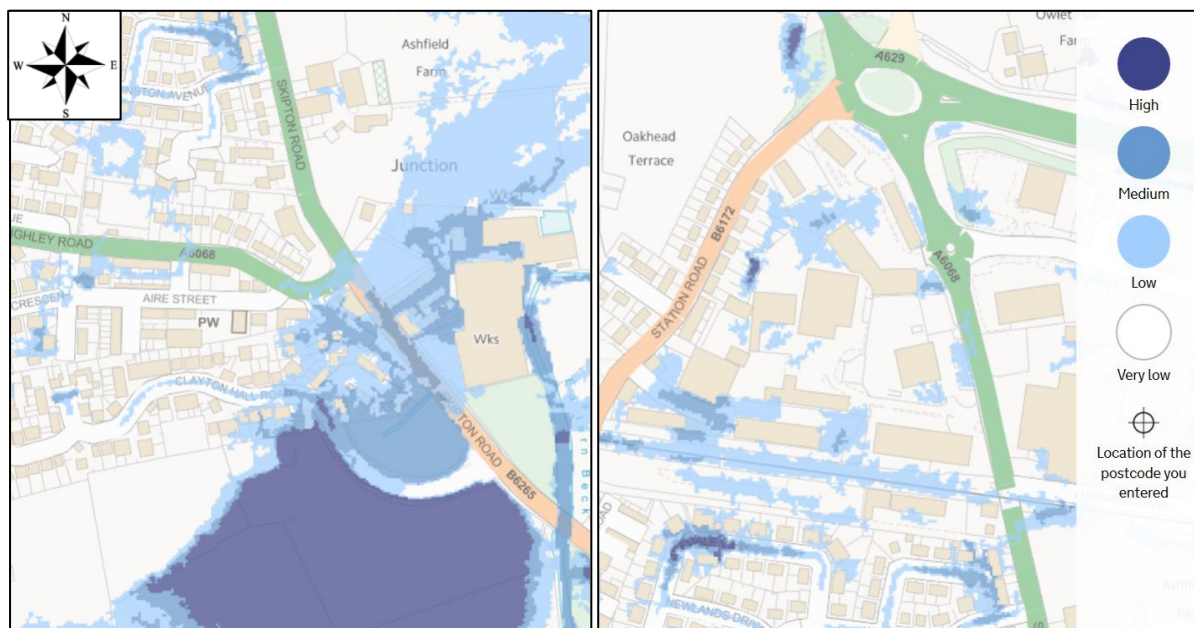


Figure 7.4 Surface water flood risk on Station Road

7.3.1 Station Road

Analysis undertaken by the EA as part of a view of the weather event across Yorkshire has been used to derive data for this investigation. An analysis of this and information from other sources has shown:

1. The whole of Yorkshire had experience high levels of rainfall in November and December leading up to the flooding event. The Aire catchment had its 2nd wettest November on record. In Keighley, 6.25km from Cross Hills, 135% of Decembers LTA fell from the 1st to 24th December. The EA hydrology report on the event stated that the ground was fully saturated prior to Christmas Day. As such any following rain would almost entirely be seen as to surface runoff⁴⁹.
2. The rainfall event started at 12:45 on the 25th and continued until 13:15 on the 26th December. The rainfall can be seen to have two distinct pulses the first between 12:45 and 11:30 of the 25th and the second between 00:30 and 13:15 on the 26th December³.
3. The River Aire levels at the Kildwick river level gauge, the closest to Cross Hills, show a rapid reaction as shown in Figure 7.5 The two pulses of heavy rainfall were evident within the catchment as water levels rose quickly with the initial peak being observed on the evening of Christmas Day then rising quickly to peak again on Boxing Day.

⁴⁹ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

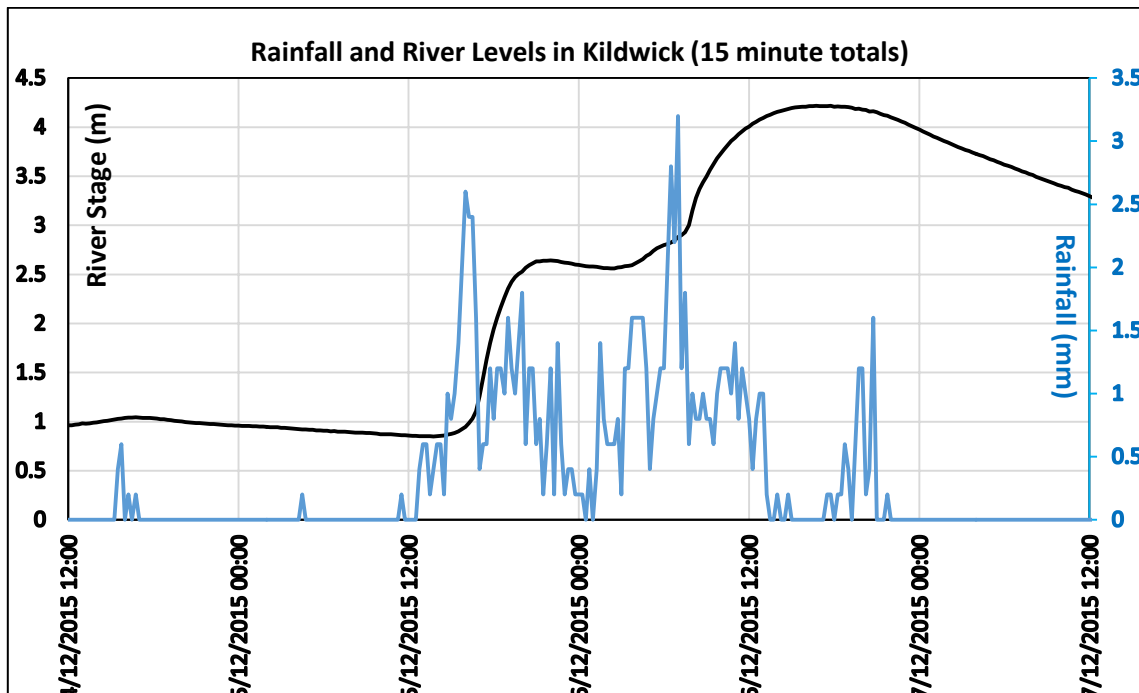


Figure 7.5 Comparison of local rainfall and River Aire levels at Kildwick.

4. A flood warning for Cross Hills was issued from the Environment Agency at 06:46 on the 26th December⁵⁰.
5. The River Aire levels continued to rise, resulting in river water overtopping its banks and flowing towards Station Road. The extents of the River Aire on the 26th December 2015 are shown in Figure 7.6.



⁵⁰ Flood Warning Time line, Environment Agency

Figure 7.6 Observed River Aire flood extent on the 26th December 2015⁵¹

6. The river water spilled onto Station Road and increased in depth resulting in the closure of station road⁵².
7. The water flowed to the lowest point, the rear gardens of Saint Andrews terrace, from here the water propagated towards the industrial area, as shown in Figure 7.7. The water depth increased in depth resulting in the flooding of six properties in the industrial area, as shown in Figure 7.8, and four residential properties via the rear gardens⁶.



Figure 7.7 Mechanism of flooding on Station Road

⁵¹ Environment Agency

⁵² Discussions with Cross Hills Residents



Figure 7.8 Photograph showing the flooding of Station Road Industrial Properties on Boxing Day 2015

7.3.2 Aire Street, Hargreaves Street and Mill

1. The rainfall event on the 25th and 26th December resulted in a large volume of surface water in the surrounding area and the rise in river levels in the Eastern Beck and Holme Beck.
2. High water levels in the local watercourses into which the surface water and highway drainage systems flow will have seriously restricted the ability of these systems to discharge.
3. The surface water discharging onto the highway overwhelmed the highway drainage in the vicinity of the Keighley Road and Skipton Road junction.
4. The surface water increased in depth on both roads resulting in the flooding of one property on Keighley road and one on Skipton Road, were flooded via the cellar, as shown in Figure 7.9.
5. It appears that property flooded on Keighley Road due to the combination of roof drainage and surface water.
6. The surface water from Skipton Road flowed down Hargreaves Street, the surface water increased in depth and resulted in the flooding of properties the surface water most likely entered over the low thresholds.

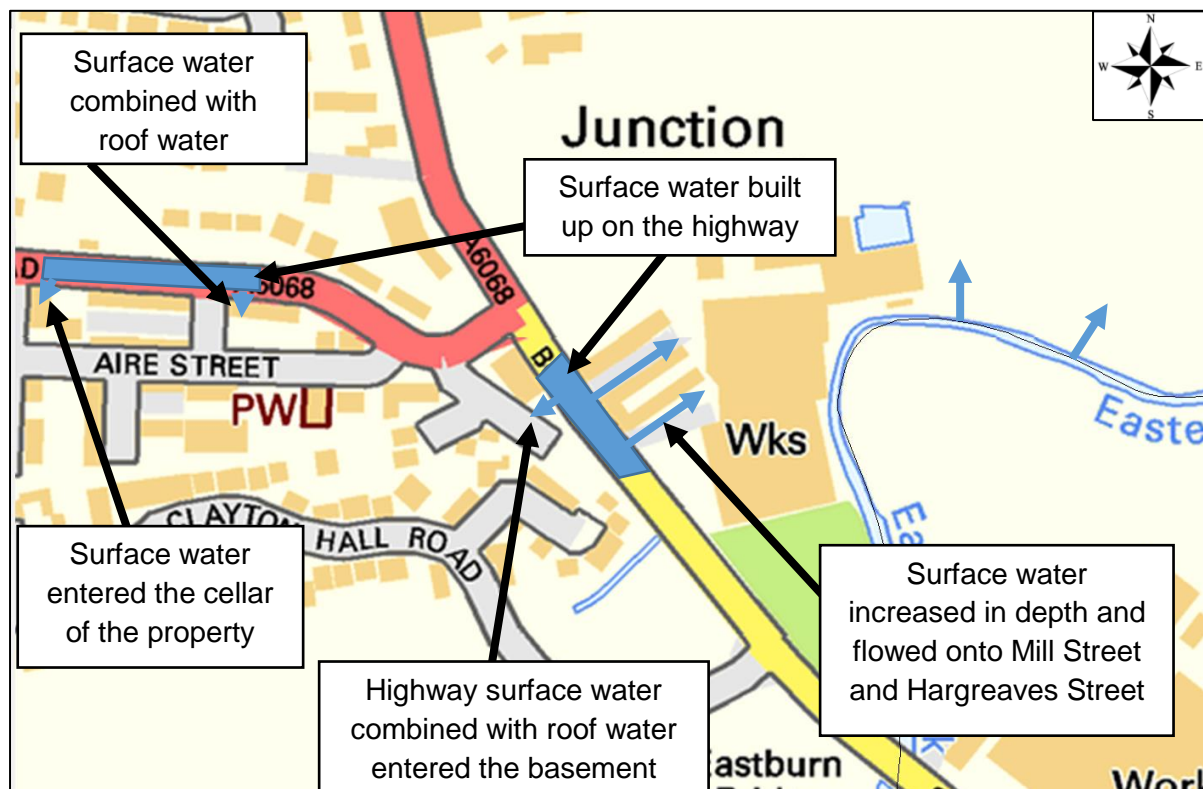


Figure 7.9 Plan demonstrating connection of flood plain to area of flooded properties

7. The flooding of the Mill building could have been from surface water, but due to its close proximity to the Eastern Beck, which reached a record level on the 26th December⁵³, it is likely to be a combination of both, the river levels of the Eastburn Beck are shown in Figure 7.10, which reached a peak level at 1.76m at 09:00 on the 26th December.

⁵³ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

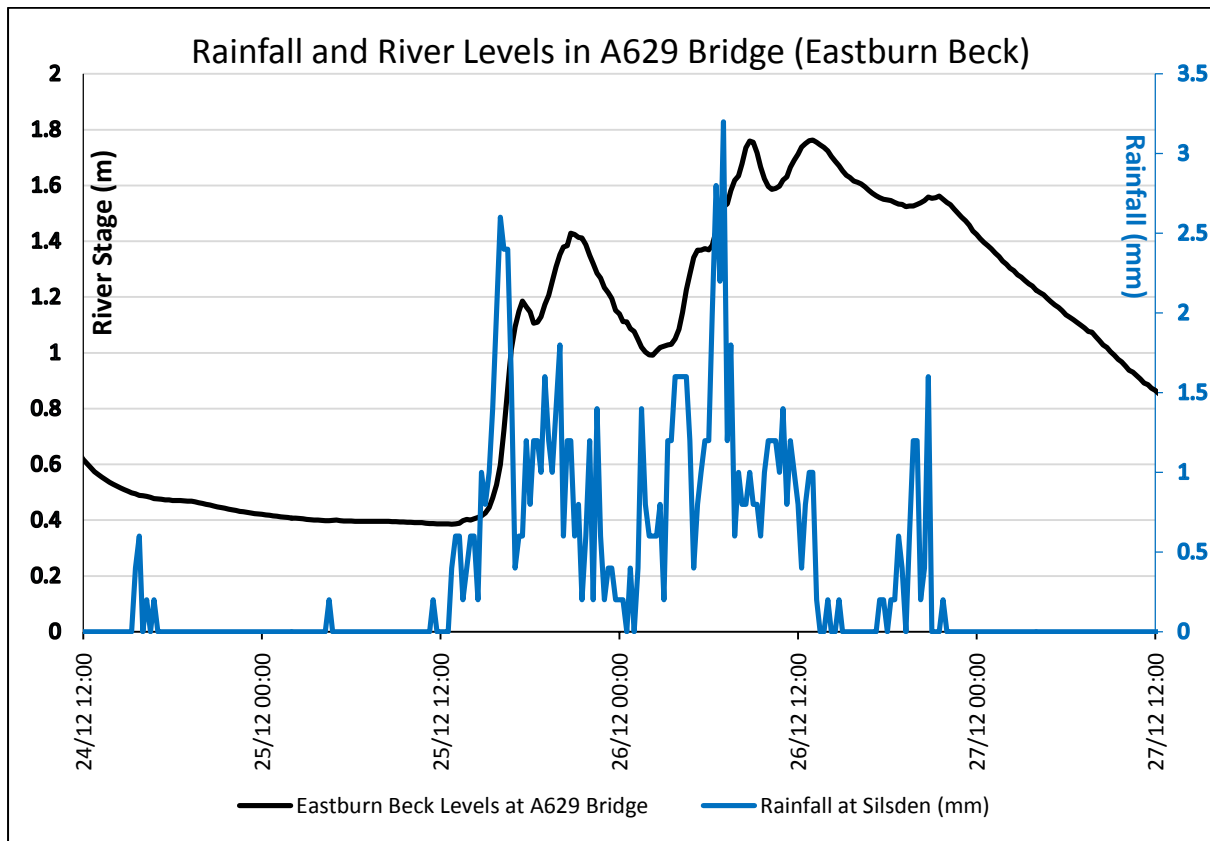


Figure 7.10 River levels in Eastburn Beck

8. In addition there is also a flow path shown in the rolling ball analysis from Sutton-in-Craven which could have contributed to the water flowing into this location. From the site inspection there was a visible connection from the flood plain to the Eastern Beck in close proximity to properties, as shown in Figure 7.11.

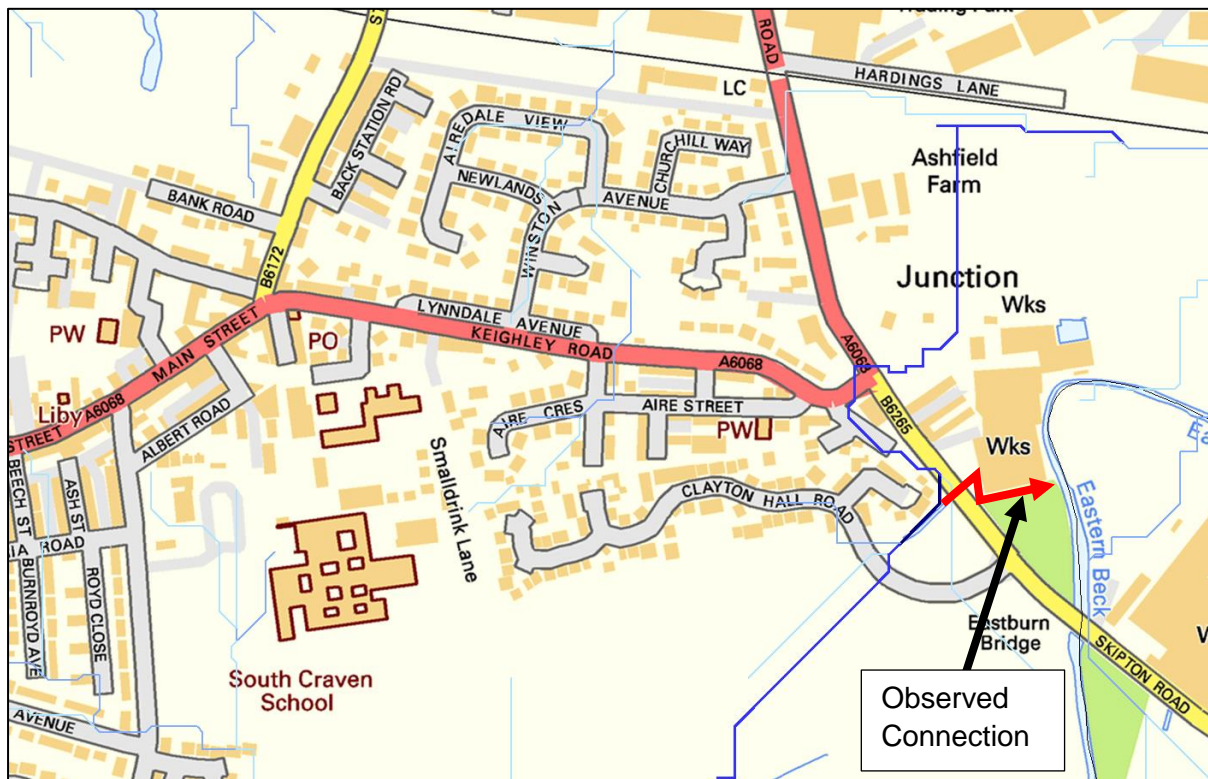


Figure 7.11 Rolling Ball analysis for Cross Hills⁵⁴

⁵⁴ NYCC Rolling Ball Analysis – identifying indicative overland flow route

8 Glusburn

8.1 Location

Glusburn (Grid Reference: SE 00575 44616) is a village situated on the A6068, 6.5km south of Skipton, adjacent to the Holme Beck and the village of Sutton-in-Craven. The village lies within Craven district within the County Council electoral division of North Yorkshire. The village has a population of 4000 according to the 2011 Census. Glusburn was historically a farming community with villagers also engaging in spinning and weaving, as transport links progressed the textile industry became the dominant employer in the area, resulting in a number of mills and adjustments to the river system.

The key locations and rivers are shown in Figure 8.1.

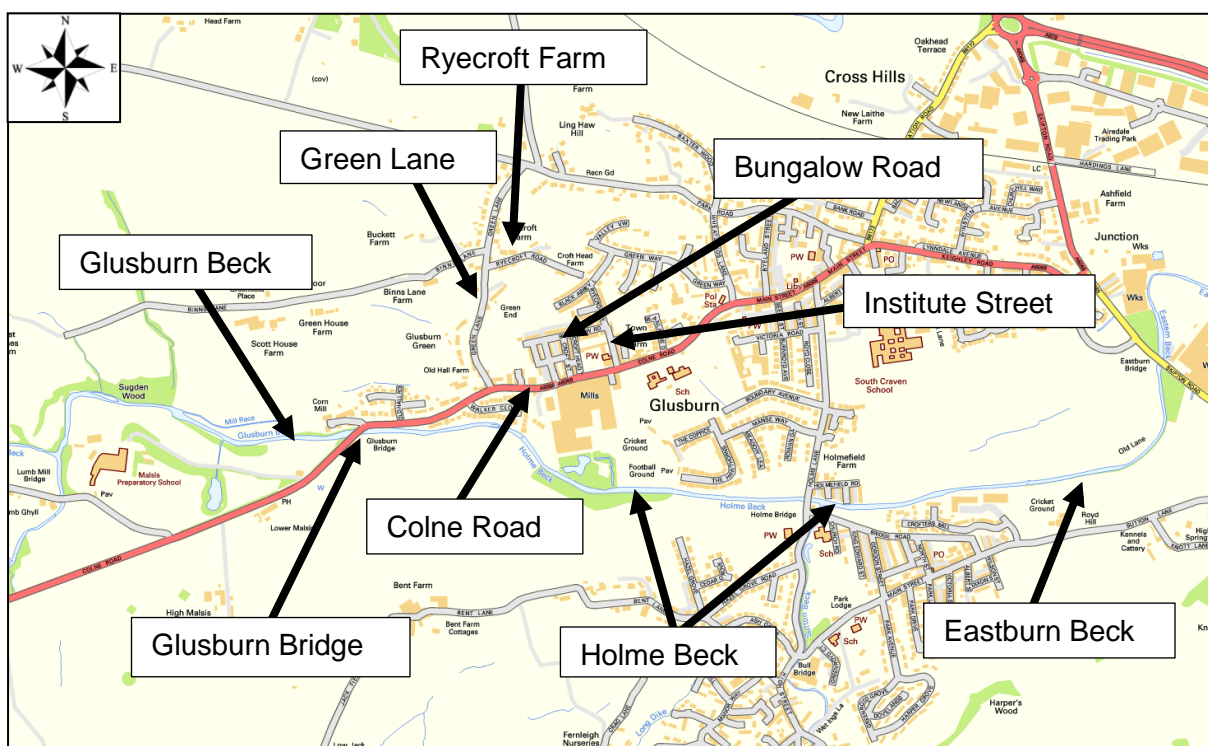


Figure 8.1 Glusburn study area map (NYCC)

8.2 Water Environment

Glusburn is located in flat low lying land with steep agricultural land rising to the northwest. Glusburn Beck and Holme Beck run from west to east, south of the village¹. Areas of Glusburn to the south of, and in the vicinity of, Colne Road are at medium risk of river flooding from the Glusburn Beck and Holme Beck, as shown in Figure 8.2: Flood Zone 2 represents land assessed as having between a 1 in 100 and 1 in 1,000 annual probability of river flooding (1% – 0.1%); Flood Zone 3 a probability of 1 in 100 or greater annual probability of river flooding (>1%)⁵⁵.

⁵⁵ River Flood Risk Map, Environment Agency

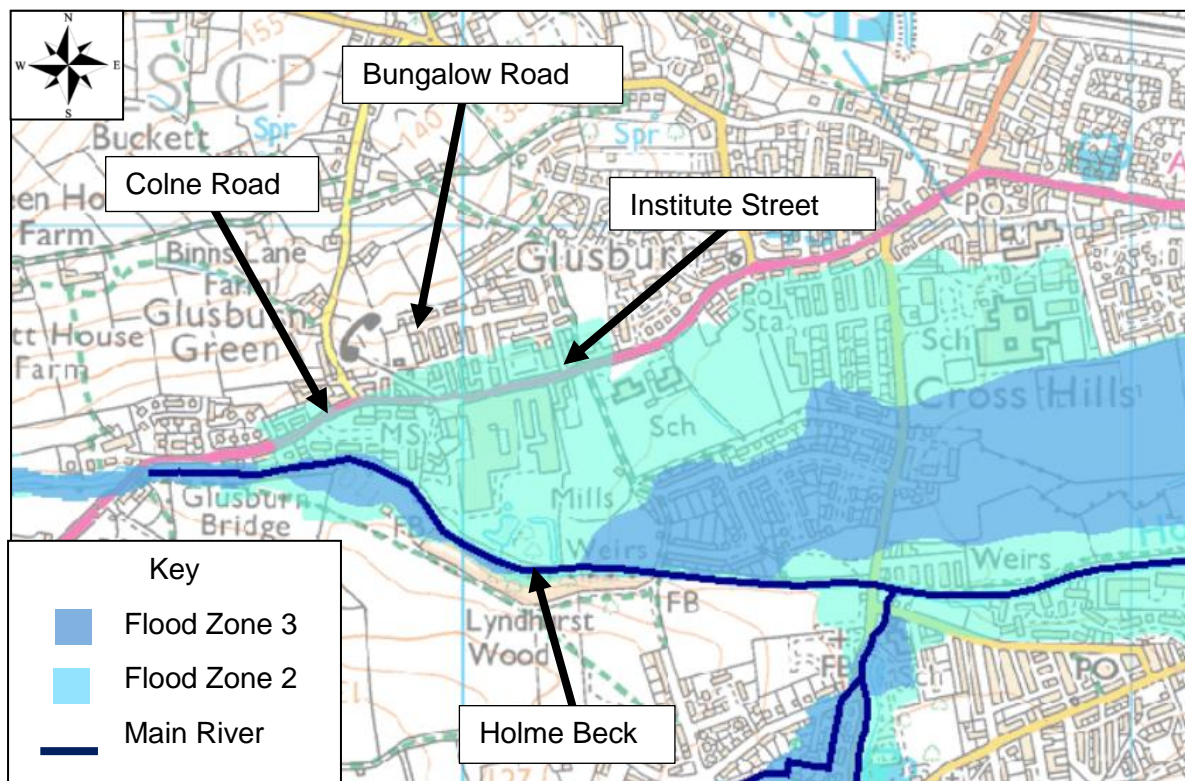


Figure 8.2 EA river flood risk map for Glusburn¹

Due to the topography of the surrounding land surface water from the north is channelled towards the centre of the village⁵⁶. A large area of Glusburn is at risk from surface water flooding, as shown in Figure 8.3.

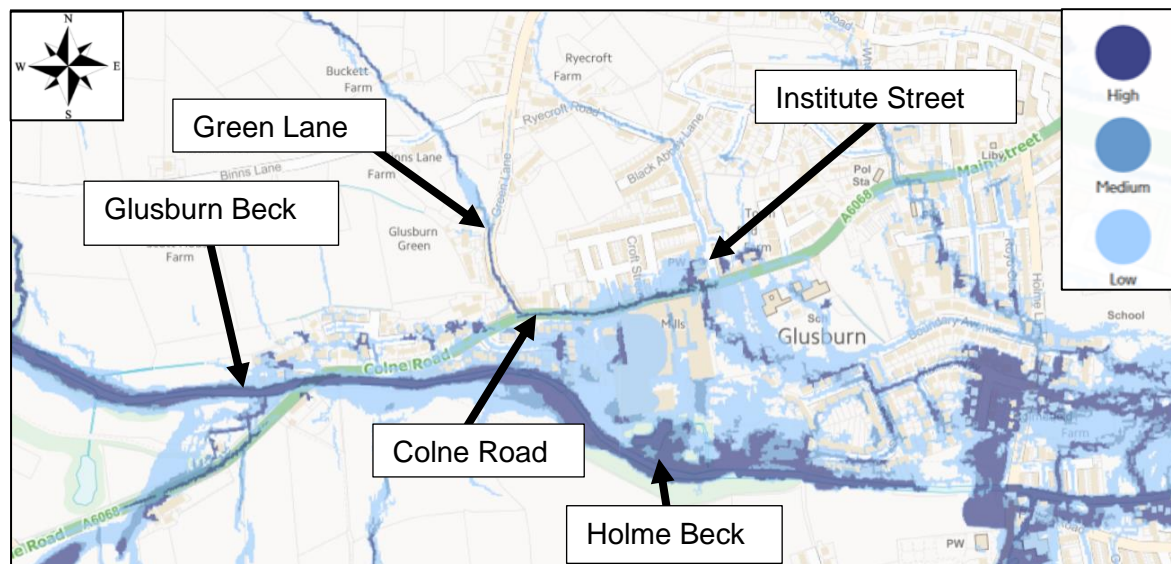


Figure 8.3 EA Surface water flood risk map for Glusburn

The high risk of surface water flooding is to the south of and in the vicinity of Colne Road. There is a significant flow path originating from the steep agricultural land to the north east, this flows onto Green Lane 115m from its junction with Colne Road, as shown in Figure 8.4.

⁵⁶ Surface Water Flood Risk Map, Environment Agency

There is a second significant flow path originating from the northwest of Ryecroft Farm, flowing to Colne Road, as shown in Figure 8.4.

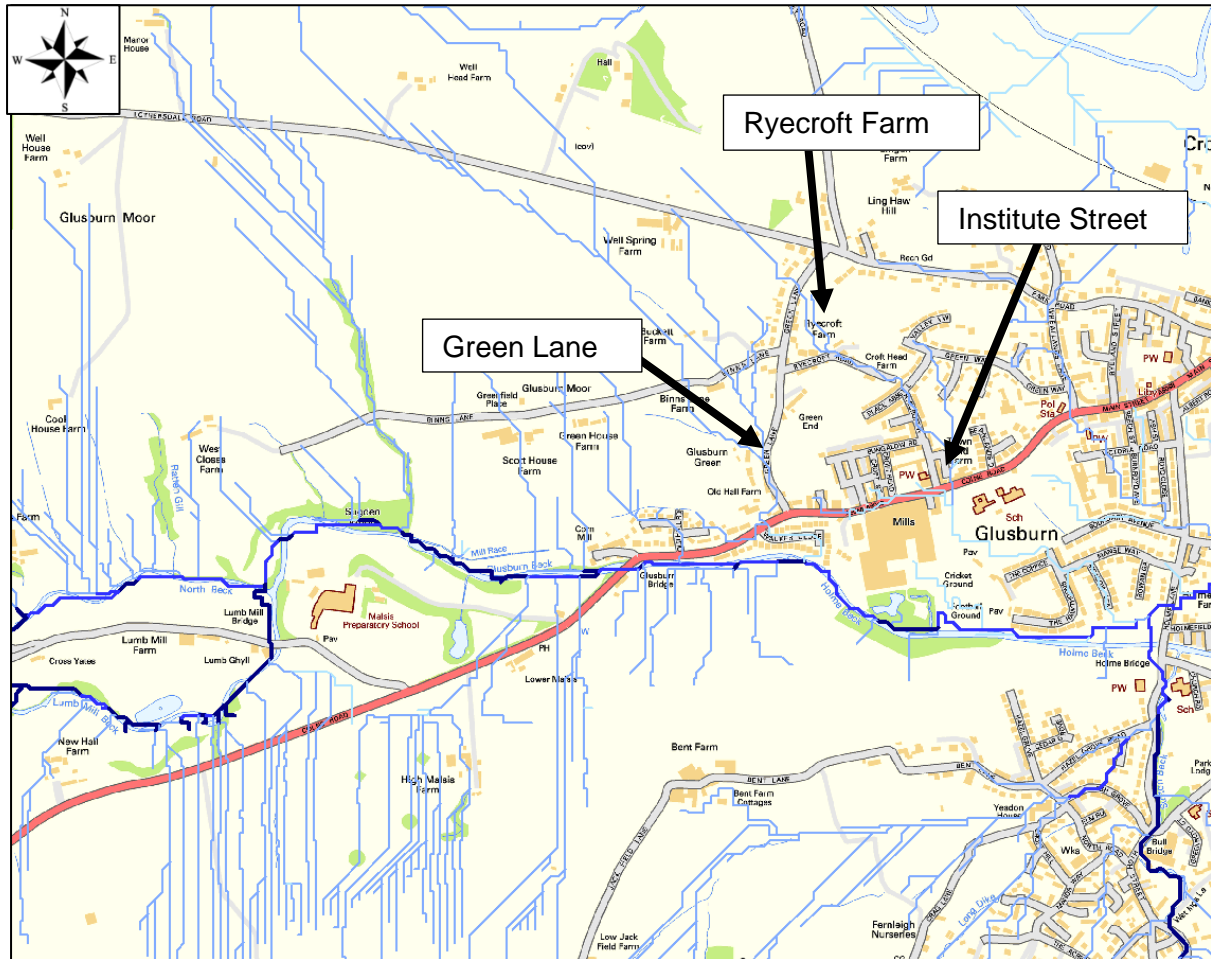


Figure 8.4 Rolling Ball analysis for Glusburn showing indicative overland flow routes⁵⁷

8.3 Flood event

Eight Properties in Glusburn experienced internal damage associated with the flood event, five in close vicinity to Colne Road, two on Green Lane and one on Bungalow Road. Flooding occurred in Glusburn as a result of the significant rainfall event on Boxing Day 2015 falling on a catchment that was completely saturated following high November and December rainfall level.

Analysis undertaken by the EA as part of a view of the weather event across Yorkshire has been used to derive data for this investigation. An analysis of this and information from other sources has shown:

⁵⁷ NYCC Rolling Ball Analysis – identifying indicative overland flow route

1. The rainfall event on the 25th and 26th December resulted in a large volume of surface water in the surrounding area and the rapid rise in river levels in the Glusburn Beck and Holme Beck⁵⁸.
2. The surface water from the steep agricultural land to the northwest flowed down hill towards the centre of the village through a number of different flow paths. The main flow paths are shown in Figure 8.5.

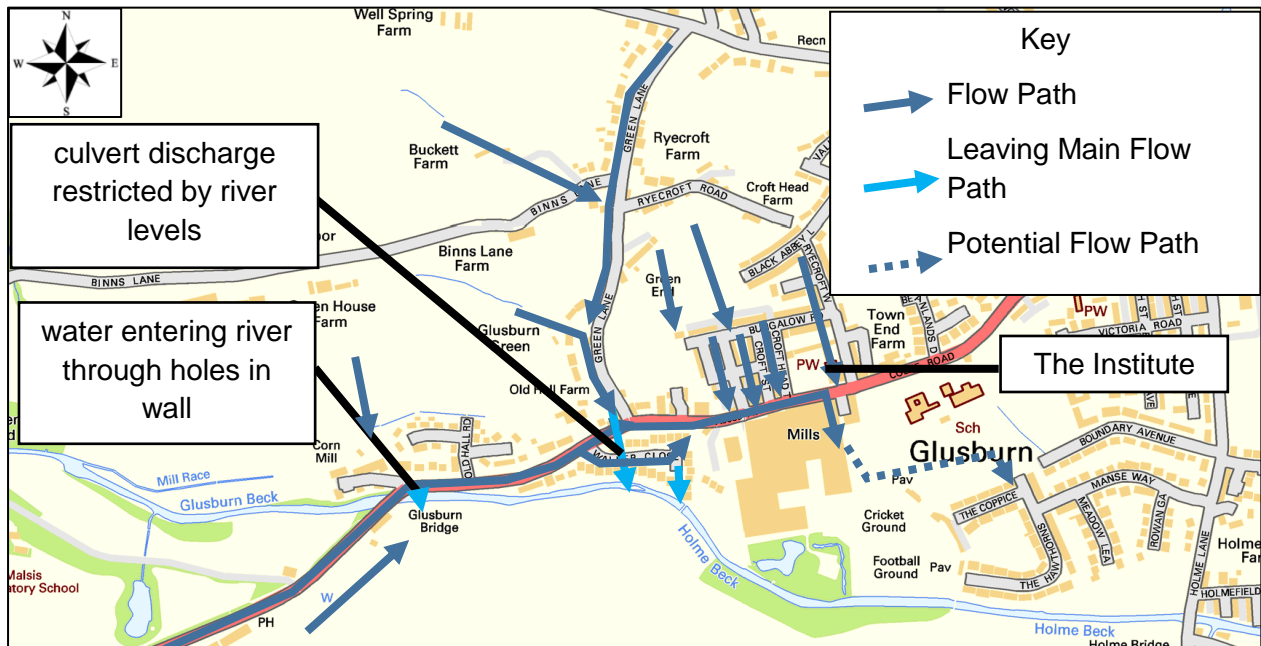


Figure 8.5 Surface water flow paths from residents' testimonies

3. Rainfall falling on, and surface water discharging onto the highways in the local area overwhelmed the highway drainage systems.
4. High water levels in the local watercourses into which the surface water and highway drainage systems flow will have seriously restricted the ability of these systems to discharge.
5. Surface water was flowing off the agricultural land to the north west of Green Lane via the historic culvert system. In addition to this, surface water flowing over ground to the North West was being directly discharged onto the highway.
6. The historic culvert, which under normal circumstances receives highway drainage reached full capacity, resulting in large volumes of excess surface water flowing down Green Lane, Figure 8.6 shows excess surface water flowing down Green Lane from a previous much smaller event.

⁵⁸ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency



Figure 8.6 Surface water on Green Lane from a smaller rainfall event

7. It is thought that due to the hydraulic pressure in the culverts water was forced up through the ground into two properties resulting in internal flooding. This could indicate that there is little cover to the culvert beneath the properties. It is also worth noticing that the condition of the culvert is at present unknown.
8. In the vicinity of The Old Corn Mill there is a footpath, which is believed to have a culverted watercourse running beneath it. It is unknown whether this watercourse impacted the flooding on Boxing Day. During the site visit a ridge was observed in the land which is thought to indicate the course of a historic culvert that channels flows from the agricultural land towards the Old Mill Building.
9. During the event the surface water flow from the agricultural land flowed along the course of the footpath, as shown in Figure 8.7. There are signs of significant erosion present on the footpath as water took an overland route.
10. Beyond the footpath the course of the historic culvert is uncertain. However two outfalls were observed on the northern bank of Glusburn Beck upstream of Glusburn Bridge. One was a small diameter outlet discharging through the wall, and the other was a larger diameter flapped outfall within a concrete outfall structure. If the historic culvert discharged to the smaller outlet it appears that the small diameter would restrict flow. YWSL have confirmed that the larger outfall is from the public surface water sewer system. Both outlets would become submerged during high flows and lead to backing up, although the flap on the public sewer will avoid river water egress into the system.
11. The water left the footpath and started to pond in the courtyard behind the buildings.



Figure 8.7 Mechanism of flooding at The Old Corn Mill

12. The surface water from the second flow path, discussed in Section 8.2, came over the agricultural land then through the rear boundary walls on Bungalow Road and Black Abbey Lane^{12, 13}. During the course of the event this resulted in the flooding of a property on Bungalow Road. The surface water then travelled to Colne Road, via Institute Street and four other streets (all private roads) to the west, causing damage to the road surfaces.
13. On the southern side of Holme Beck and to the west of Glusburn Bridge; surface water from agricultural land also flowed onto the A6068, this combined with the highway surface water and flowed along A6068 in an easterly direction.
14. In addition to the flow on the road, it has been reported that a significant flow of water could be seen in the field, flowing parallel and to the south of Colne Road. This is likely to have been generated by overland flow and springs on the crag above. It was reported that this water exited the field and joined the flow on the road somewhere between the entrance to High Malsis Farm and the Dog and Gun Inn.
15. The surface water on the A6068 crossed the Glusburn Bridge, south to north, and due to the camber of the road the majority of this flow missed the drainage system on the south side of the bridge and continued to flow over the bridge. Some of this water entered the Holme Beck on the east side of the bridge. However the remaining flows continued along Colne Road to combine with the surface water flows from Green Lane via Walker Place, as shown in Figure 8.5.

16. The flood waters from Colne Road, Green Lane, Bungalow Road and Institute Street combined outside of The Institute, causing extensive and deep flooding that over spilled onto Townend Place, to the south of Colne Road adjacent the Mills causing internal property flooding
17. A hole was made in a wall at the end of Townend Place to enable the flood water to flow onto the adjacent agricultural land.
18. It considered possible that some of the surface water from the Glusburn area is going on to affect properties in Sutton-in-Craven as can be seen from the rolling ball analysis, shows a flow path from Colne Road to The Coppice (Fig 8.4). Hence there appears there may be a hydraulic connection between Glusburn and Sutton-in Craven and any future studies should consider this hydrological connectivity.

9 Sutton-in-Craven

9.1 Location

Sutton-in-Craven (Grid Reference: SE 00576 43806) is located 1.7km south of the A629, 6.2km northwest of Keighley and 6.2km south of Skipton. The village lies within the district of Craven and is within the County Council electoral division of North Yorkshire. The village has a population of 3700 according to the 2011 Census. There are three main rivers passing through Sutton-in-Craven. The key locations are identified in Figure 9.1.

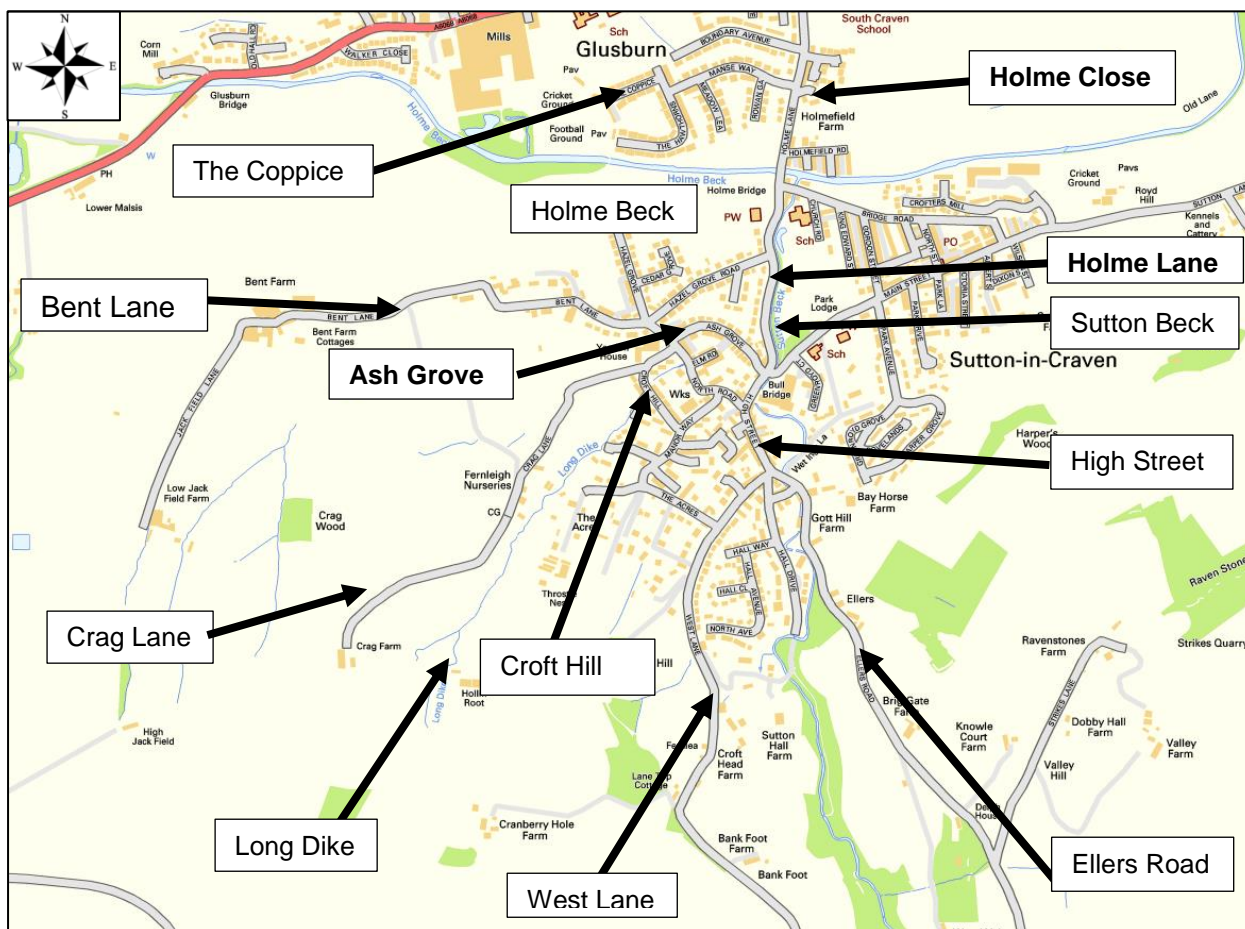


Figure 9.1 Sutton-in-Craven study area map (NYCC)

9.2 Water Environment

Sutton-in-Craven is situated in a valley surrounded by steep agricultural land that falls towards the village centre and Holme Beck, as shown in Figure 9.2. Due to the shape of the surrounding land after a rainfall event the surface water flows towards the village, the areas identified by the EA as at risk from surface water are shown in Figure 9.3.

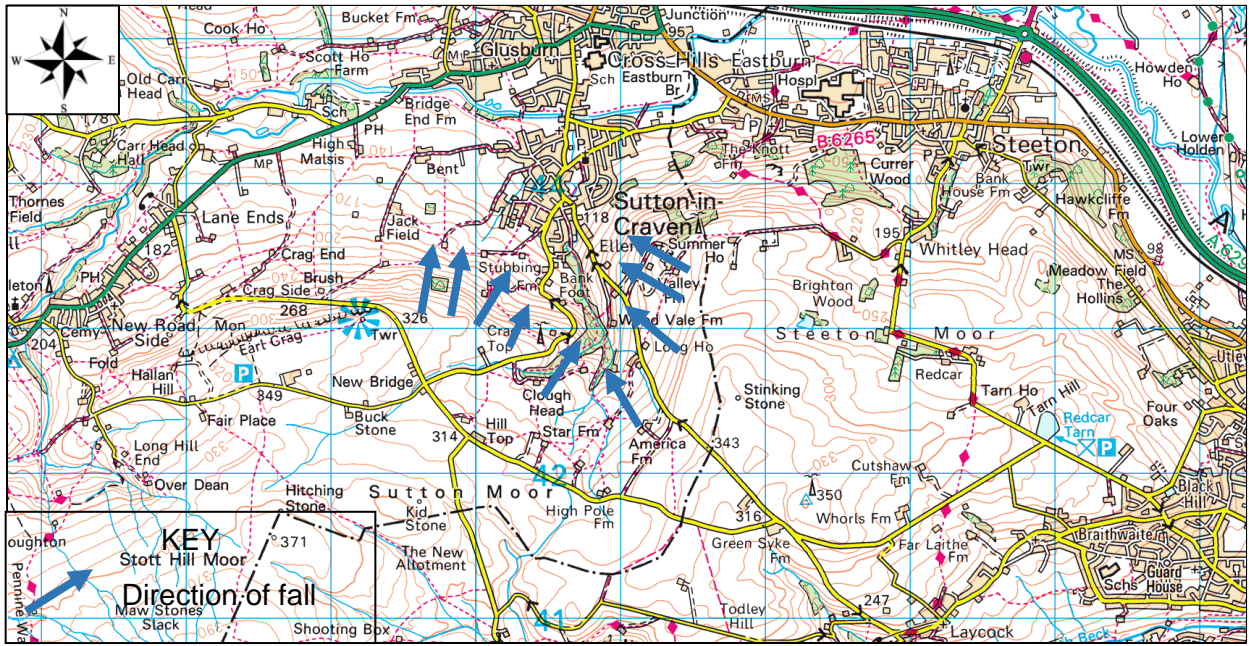


Figure 9.2 Sutton-in-Craven topography map

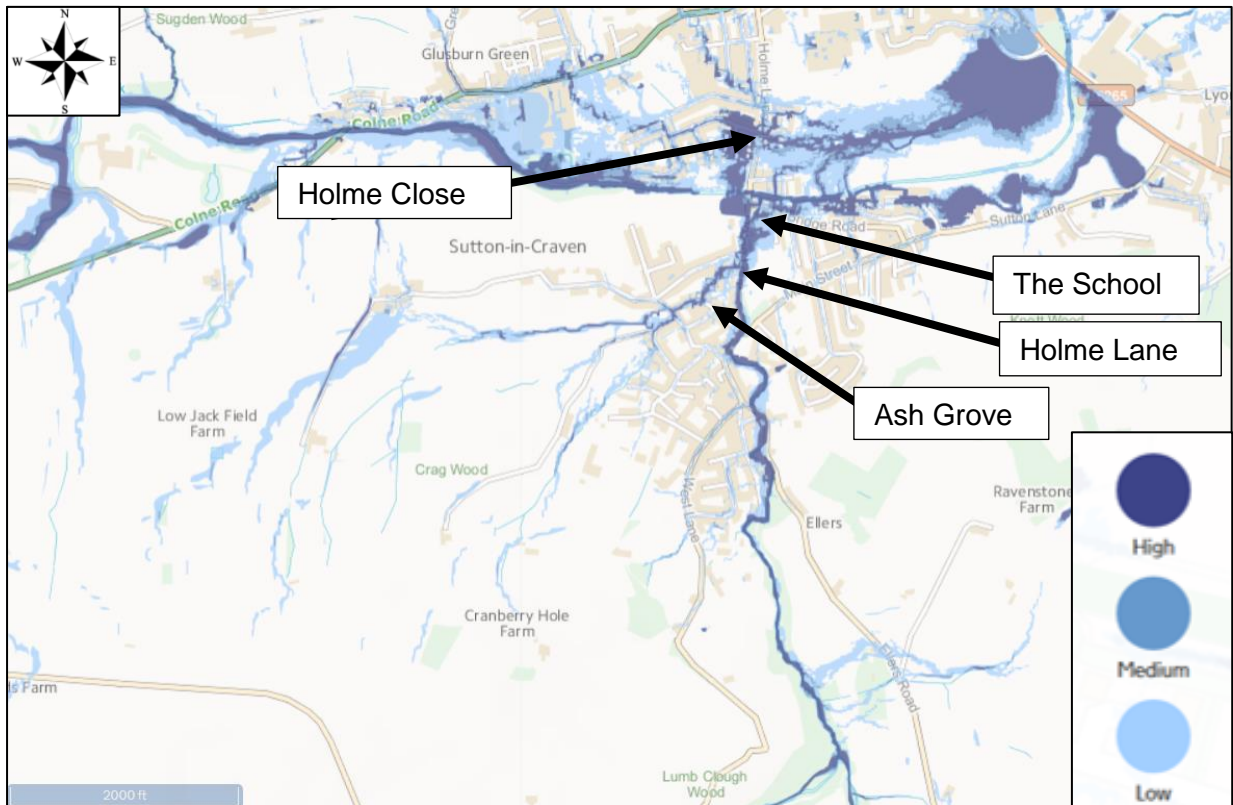


Figure 9.3 EA surface water flood risk map⁵⁹

The three main rivers are Holme Beck, Long Dike and Sutton Beck⁶⁰. Holme Beck is fed by a catchment of mainly agricultural land to the west (where it is called Glusburn

⁵⁹ Surface Water Flood Map, Environment Agency

⁶⁰ Main Rivers overlay, Environment Agency

Beck, west of the bridge). Long Dike and Sutton Beck are fed by a much smaller but steeper catchments to the south. The flood risk associated with these rivers is shown in Figure 9.4.⁶¹

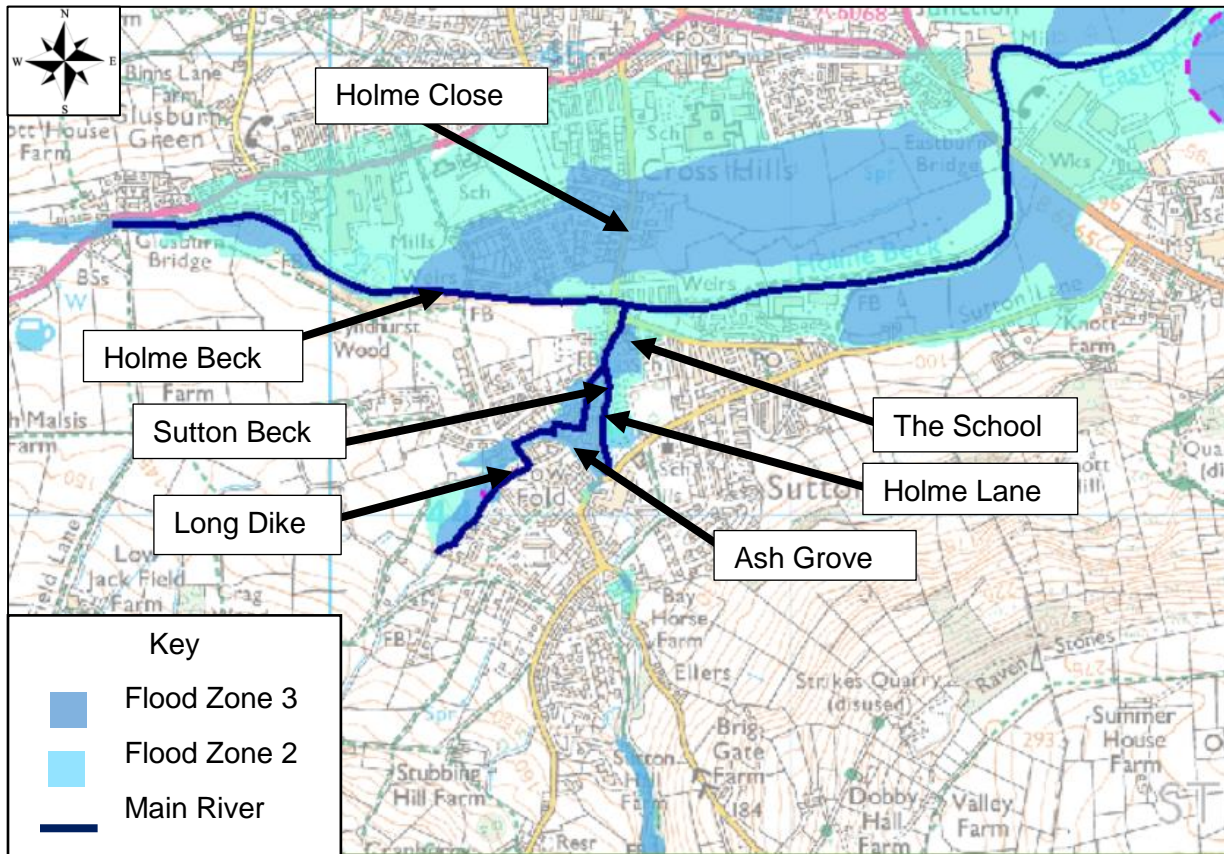


Figure 9.4 EA river flood risk map³

9.3 Event

Ten properties in Sutton-in-Craven experienced internal damage associated with the flood event, four on Holme Lane, three on Ash Grove, two on Holme Close and the Sutton-in-Craven Community Primary School (The School)⁶². Flooding occurred in Sutton-in-Craven as a result of the significant rainfall event on Boxing Day 2015 falling on a catchment that was completely saturated following high November and December rainfall levels.

9.3.1 Holme Close

Holme Close can be seen from the EA maps to be at a high risk from both river and surface water flooding (Figure 9.3 and 9.4 above). The river flooding is attributed to Holme Beck. There is a significant risk from surface water flooding at this location and a number of surface water sources which are shown in Figure 9.5.⁶³ This

⁶¹ River Flood Risk Map, Environment Agency

⁶² NYCC reports of flooding map, 26th December 2015

⁶³ NYCC Rolling Ball Analysis – identifying indicative overland flow route

indicates that there is a potential flow path from Colne Road, Glusburn to the affected areas.

In addition to the surface flows, the surface water sewer system runs from the north of the junction of Colne Road and Main Road in a southerly direction towards Sutton-in-Craven, as shown in Figure 9.6⁶⁴.

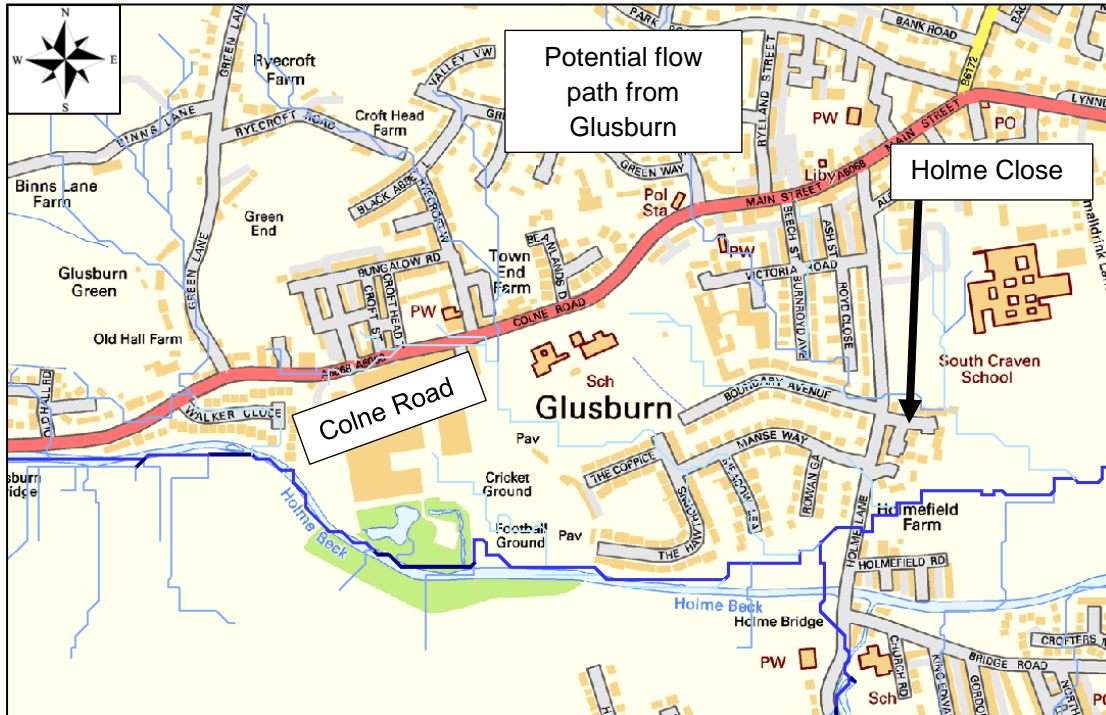


Figure 9.5 Rolling ball analysis for Holme Close area⁵

⁶⁴ Surface Water Sewer Maps, YWSL



Figure 9.6 Surface water system in Glusburn and Sutton-in-Craven

Analysis undertaken by the EA as part of a view of the weather event across Yorkshire has been used to derive data for this investigation. An analysis of this and information from other sources has shown:

1. The rainfall event on the 25th December 2015 resulted in a sharp rise in Holme Beck levels, as shown in Figure 9.7⁶⁵, the river was reported to almost come out of bank⁶⁶.

⁶⁵ Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

⁶⁶ Account of flooding from a local Councillor

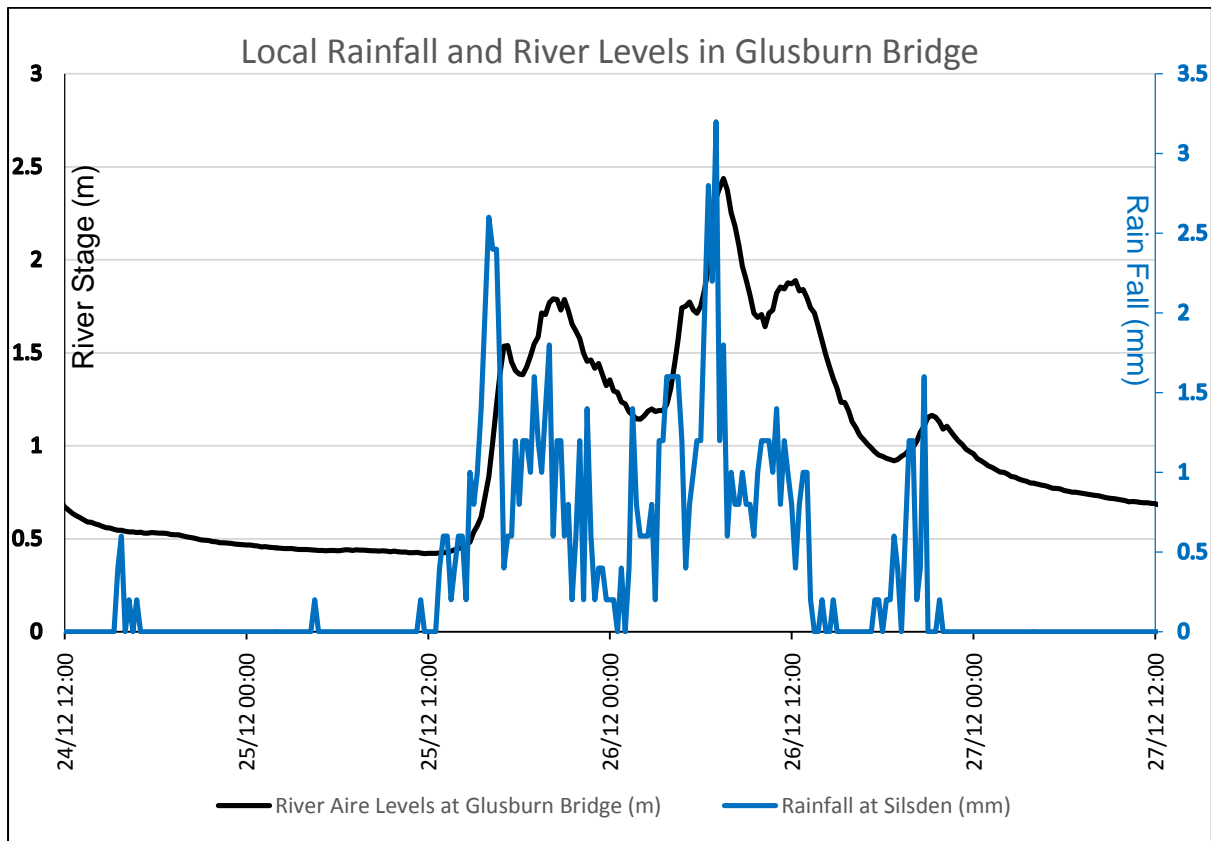


Figure 9.7 River levels at Glusburn Bridge

2. The second rainfall event on the 26th December caused Holme Beck levels to increase further resulting in the banks being overtopped and flows discharging onto the football pitch. The river flow in Holme Beck adjacent to the football pitch are shown in Figure 9.8.



Figure 9.8 Photograph showing river levels adjacent to football pitch

3. Surface water from Glusburn flowed down The Coppice and The Hawthorns. The volume of water getting on to the roads, the debris being carried in the flood water, and the sheer volume of surface water on the highways caused the highway drainage system to become overwhelmed⁶⁷.
4. In addition high water levels in the local watercourses into which the surface water and highway drainage systems flow will have seriously restricted the ability of these systems to discharge.
5. The flows from the football pitch and on the highways increased due to surface water from the highways and runoff from the land to the north of the Holme Beck.
6. Surface water flows brought a significant amount of material in the form of silt, gravel and woody debris which accumulated on the highway, blocking gully grills and drains. The residents on The Coppice and The Hawthorns cleared debris which maximised the ability of the systems to take flow and this, along with efforts with extensive sandbagging by residents doubtless prevented property flooding in this location.
7. Having exceeded the capacity of the existing highway and surface water systems, the surface water followed the gradient of the land, down Manse Way and onto Holme Close where flood waters internally flooded properties, as shown in Figure 9.9.

⁶⁷ Craven Herald

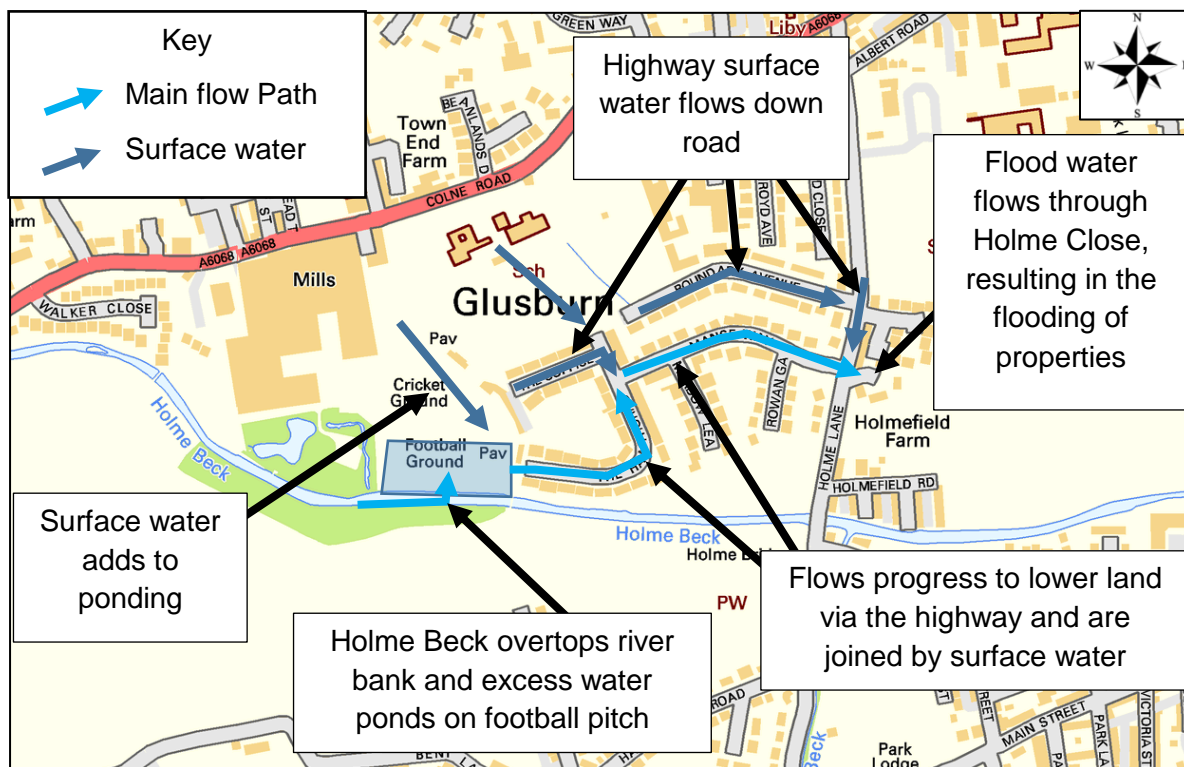


Figure 9.9 Flooding mechanism at Holme Close

There are reports that surface water sewers in this area were bubbling up and discharging additional water onto the highway. The surface water sewers in this area are reported to be connected to that in Glusburn⁶⁸, being the natural flowpath to the discharge point into Holme Beck (see Fig 9.6). The resulting flow from the Colne Road area added to the existing flow and overwhelmed the system, discharging onto the highways in areas of Sutton-in-Craven⁶⁹.

9.3.2 Ash Grove

Ash Grove can be seen to be at risk from river and surface water flooding from the EA maps (Figure 9.3 and 9.4). The river flooding is attributed to Long Dike, but only some properties on the Ash Grove are shown to be at risk by the modelling.

⁶⁸ Surface Water Sewer Maps, YWSL

⁶⁹ Discussion with local Resident

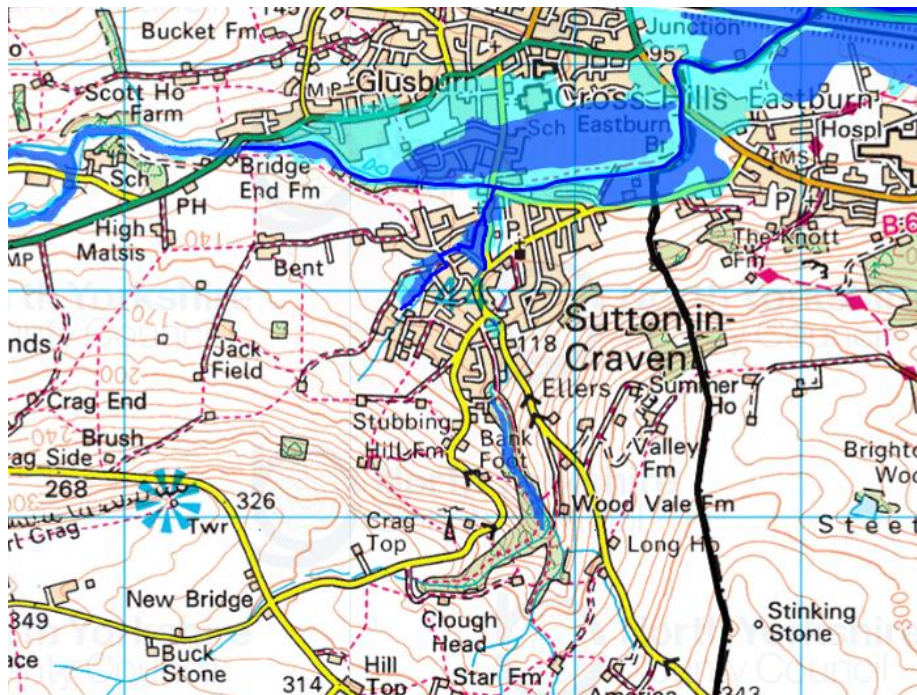


Figure 9.10 EA river flood risk map (Detail)⁷⁰

There is a significant risk of surface water flooding to a number of properties along Ash Grove due to the main flow path from the junction of Ash Grove and Bent Lane⁷¹. There are three significant flow paths converging on this location, as shown in Figure 9.10;

Flow Path 1 follows Long Dike from the agricultural land to the southwest, flowing in culvert under Croft Hill then Ash Grove;

Flow Path 2 flows down Crag Lane meeting Flow Path 1 on Croft Hill and proceeds to flow onto Ash Grove;

Flow Path 3 Follows the approximate path of the historic culvert discussed in Section 2.7.8, which drains the agricultural land to the west flowing into the Ash Grove system via the site of the former Yeadon House.

There is also a smaller flow path from Bent Lane flowing onto Ash Grove. Hence a number of flow routes drain a large, steep sided area, converge at the junction of Bent Lane and Ash Grove, both in culverts and, at times of heavy rainfall, above ground flows.

⁷⁰ River Flood Risk Map, Environment Agency

⁷¹ NYCC Rolling Ball Analysis – identifying indicative overland flow route

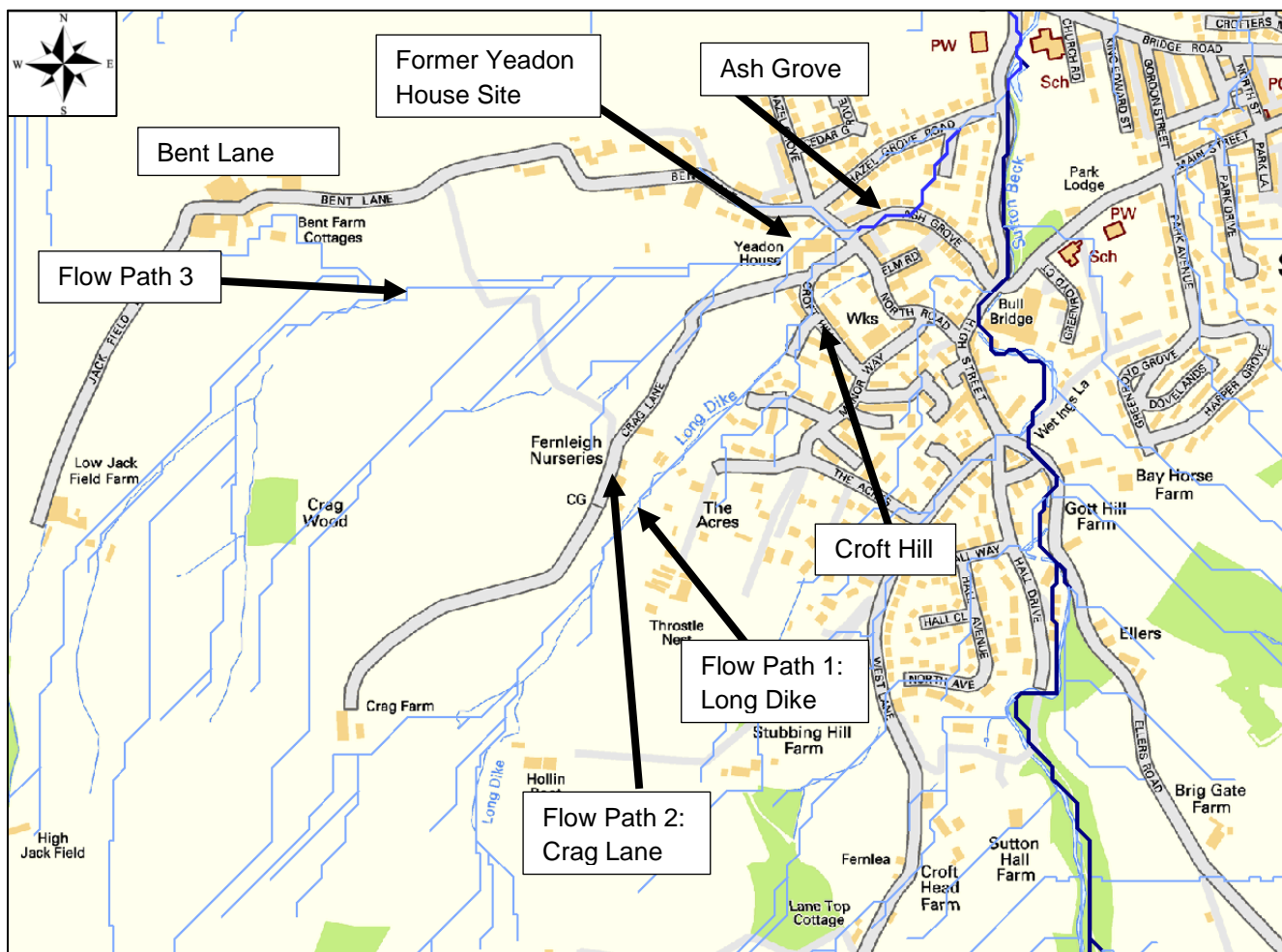


Figure 9.11 Rolling ball analysis for Ash Grove

Local resident’s accounts from the flood event state that there was a large volume of surface water flowing down Crag Lane. It appears from the rolling ball analysis that some of the flows emerging on Crag Lane may be associated with flows from the Fernleigh Nurseries area and a historic culvert whose flow path coincides with Crag Lane.

Analysis undertaken by the EA as part of a view of the weather event across Yorkshire has been used to derive data for this investigation. An analysis of this and information from other sources has shown:

1. The rainfall events of the 25th and 26th created a large amount of surface water on the steep agricultural land around Sutton-in-Craven.
1. The surface water from the surrounding land used the three flow paths discussed and flowed downhill towards Sutton-in-Craven. These observations are supported by NYCC rolling ball analysis (Fig 9.10)
2. Flow path 1 increased the water levels in Long Dike eventually leading to the culvert under Croft Hill surcharging resulting in flows backing up in Long Dike causing it to overflow onto adjacent agricultural land and towards residential properties on Croft Hill, which suffered internal flooding.

3. Flow Path 2, is not shown by rolling ball analysis, but reflects the reports made by local residents and the waterborne debris observed during the site inspection. It appears that surface water from surrounding agricultural land resulted in a considerable flow down Crag Lane, described as 'looking like a river' by some residents. The volume of water coming from Crag Lane also brought a considerable amount of gravel and finer material onto Croft Hill from the un-made surface of this private road. This caused the highway gullies to become blocked and debris to be carried a considerable distance downstream by surface water.
4. Flow Path 3 brings together flows from a wide area and appears to feed into a historic culvert and on into the surface water system at the head of Ash Grove
5. The combination of above ground flow paths entering the highway system, gravel and fines entering the gully pots chocking the drainage system during the event, and the historic culvert discharging directly into the surface water system, caused the surface water system to become overwhelmed.
6. With the surface water system overwhelmed the water flowed to the lowest point, it began to pool on Ash Grove, as shown in Figure 9.11 as it falls in elevation from both ends.

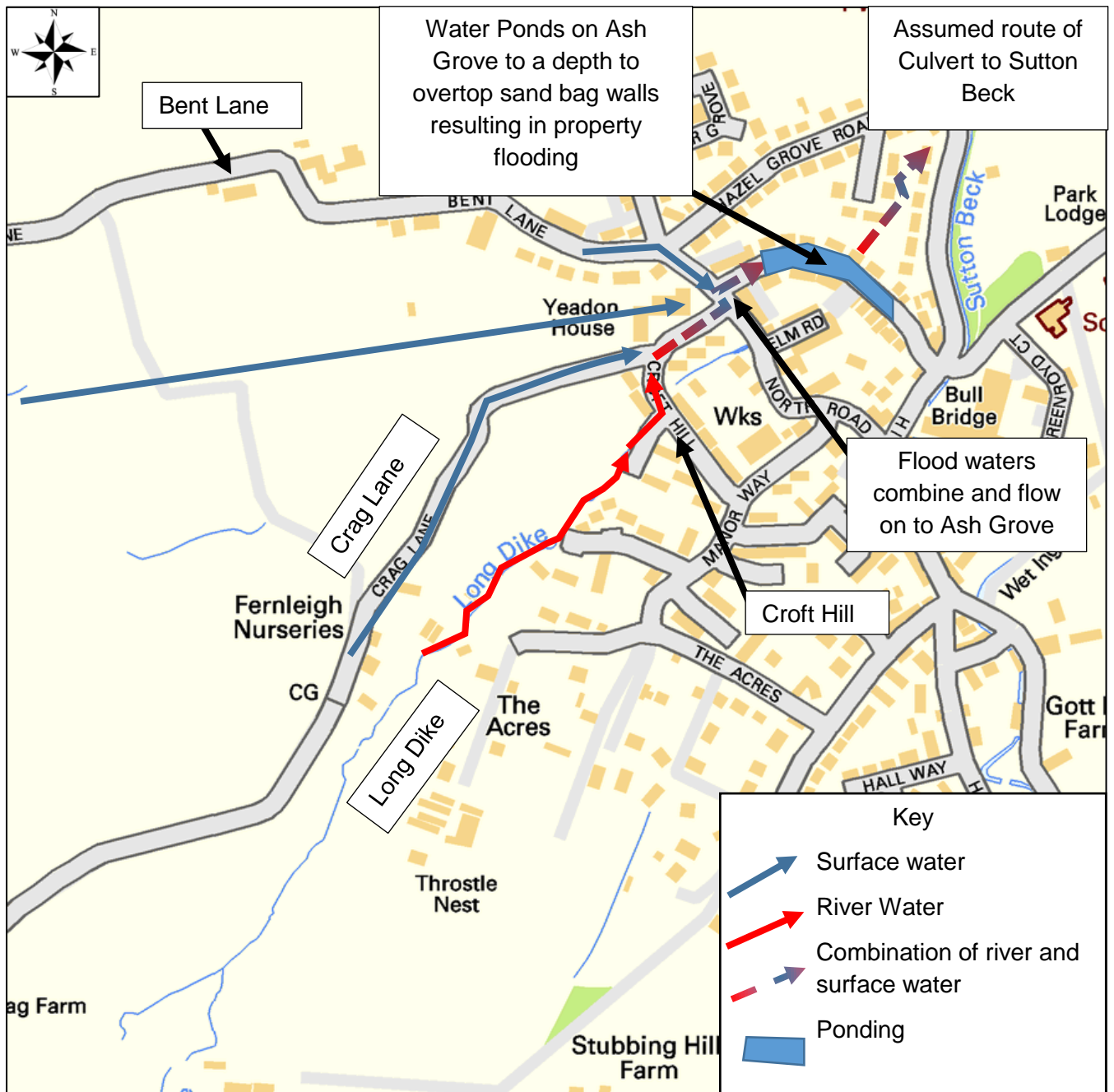


Figure 9.11 Flooding mechanisms at Ash Grove

7. Based on previous experience and the conditions on the ground local residents took action to prevent water flooding their properties. It is understood that they were assisted in the provision of sandbags by Craven District Council and that the emergency services helped to install these across their driveways as shown in Figure 9.12.



Figure 9.12 photograph showing flooding and sandbagging on Ash Grove

8. At the lowest point on Ash Grove the sand bags were overtopped and the surface water flowed down driveways causing property flooding.

9.3.3 Holme Lane and the Sutton-in-Craven Community Primary School

Holme Lane and The School are at high risk of flooding from surface water and medium risk from river flooding from Sutton Beck (Figure 9.3 and 9.4 above). The area near the School is shown to have the highest risk of flooding from both the Sutton Beck and overland surface water flows.

There are three main flow paths converging on Holme Lane, as shown in Figure 9.13; the first being Sutton Beck, which collects large amounts of runoff from the steep sided valley, The Clough, to the south; the second the combination of Long Dike, Crag Lane and a historic culvert, west of Holme Lane, as discussed in the Ash Grove Section; the third is from West Lane flowing on to High Street then Holme Lane.

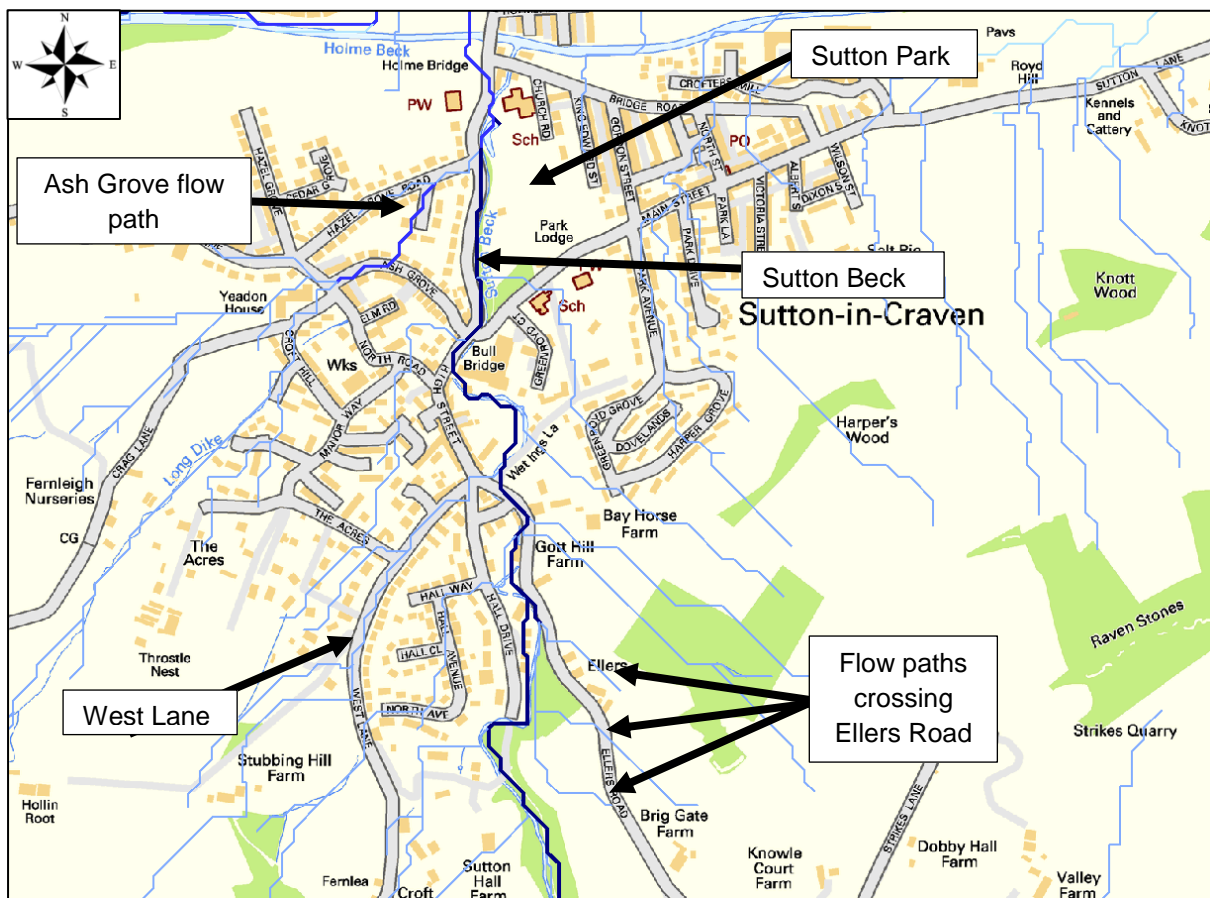


Figure 9.13 Rolling ball analysis for Holme Lane

Local residents’ accounts from the flood event state that there was a large volume of surface water flowing down Ellers Road. It is thought that some of the surface water shown in Figure 9.13 as flowing over Ellers road and into the watercourse is in practice flowing down Ellers Road and not getting to Sutton Beck at all.

Analysis undertaken by the EA as part of a view of the weather event across Yorkshire has been used to derive data for this investigation. An analysis of this and information from other hill sources has shown:

1. The rainfall events of the 25th and 26th created a large amount of surface water on the steep agricultural land around Sutton-in-Craven⁷².
2. The surface water from the surrounding land reportedly used the three flow paths, and Ellers road to flow towards the centre of Sutton-in-Craven. These observations are supported by NYCC rolling ball analysis (Fig 9.13)
3. It was reported by residents that as the rainfall event continued the combination of the surface water flowing down West Lane and Ellers Road turned High Street into a ‘River’. The volume of water on the highways overwhelmed the highway drainage system.
4. The water flowed from High Street on to Holme Lane.

⁷² Hydrology of the December 2015 Flood in Yorkshire, Environment Agency

5. Many houses were protected by sandbags along High Street and Holme Lane, which directed the runoff into the Sutton Park.
6. The river levels of the Sutton Beck rose as the storm continued resulting in surcharging of the culverted section of the Sutton Beck under Bridge Road.
7. The water then backed up in Sutton Beck from this point. The levels rose resulting in river water flowing through a holes in the Beck wall along High Street and onto the highway. This water travelled down the road and pooled at the junction of Holme Lane and Bridge Road, as shown in Figure 9.14. This resulted in the closure of Holme Lane. It is considered that the extent of flooding may have been exacerbated by the runoff of adjacent agricultural land, however the impact of this is thought to be less significance in comparison to that of Sutton Beck.





Figure 9.14 Photographs showing water on the Holme lane close to its junction with Bridge Street

8. The extent of flooding on the junction of Holme Lane and Bridge Street increased resulting in the internal flooding of two adjacent buildings.
9. Additional flooding occurred from a culverted section of Long Dike believed to run down the back gardens of properties on the western side of High Street opposite the park. The water levels in Long Dike increased as the storm continued carrying the flow from the Croft Hill / Ash Grove area, exceeding the culverts capacity.
10. A property's cellar flooded due to water coming through the brickwork⁷³, the resident believes this to be from the Long Dike culvert.
11. Water levels caused Sutton Beck to overtop its banks.
12. The School's surface water system was completely overwhelmed, the water levels in the system rose, and water began to be discharged on to the playground via a surface water drain⁷⁴. Ponding increased in depth as shown in Figure 9.15.
13. It was reported that the School's playground was under 450mm-600mm of water, resulting in the flooding of an isolated classroom where flood water entered via the fire escape.

⁷³ Report by property owner

⁷⁴ School Headteacher



Figure 9.15 Photograph showing the ponding on the playground at the School

14. By the 27th December the water on The School's playground had subsided.
15. The School was checked on the 31st of December and there was no additional flood damage and no flooding of the cellar.
16. However, at the beginning of the school year, it was noticed that the cellar of the building had been flooded, the maximum depth of the water was judged to have be between 900mm and 1200mm. The flood waters damaged The School's boiler forcing the school to close for a week until the heating system could be repaired.

It was not possible to identify the system discharging on to The School Playground, and potentially in the cellar. There are no records available of the surface water system at the school. There is a combined system which may have surcharged and discharged via the overflowing drain.

The flood water in the cellar is considered to be the result of ground water seeping through the walls and floor due to a high water table, or a drain discharging or a combination of both.

10 Risk Management Roles, Responsibilities and Actions

10.1 Risk Management Authority Responsibilities

10.1.1 Environment Agency

Under the FWMA the Environment Agency (EA) has a strategic overview role for all sources of flooding as well as an operational role in managing flood risk from Main Rivers, reservoirs and the sea. As part of this role the EA have developed a National Flood and Coastal Erosion Risk Management Strategy for England – ‘Understanding the Risks, Empowering Communities, Building Resilience.’

This national strategy outlines the EA’s strategic functions as:

- Ensuring that flood risk management plans (FRMPs) are in place and are monitored to assess progress. The plans will set out high-level current and future risk management measures across the catchment.
- Publishing and regularly updating its programme for implementing new risk management schemes and maintaining existing assets.
- Supporting risk management authorities’ understanding of local flood risk by commissioning studies and sharing information and data.
- Supporting the development of local plans and ensuring their consistency with strategic plans.
- Managing and supporting Regional Flood and Coastal Committees and allocating funding.

The EA’s operational functions include:

- Risk-based management of flooding from Main Rivers including permissive powers to do works including building flood defences.
- Regulation of works in Main Rivers through the consenting process.
- Regulation of reservoirs with a capacity exceeding 10,000m³.
- Provision of a flood forecasting and warnings service, working with the Met Office Hazard Warning Service.
- The maintenance and operational management of Main River assets including flood defences.
- Statutory consultee to the development planning process.
- The power to serve notice on any person or body requiring them to carry out necessary works to maintain the flow in Main Rivers.

'Main Rivers' are defined through an agreed map which is updated 2-3 times per year to reflect changes in the designation of a watercourse or in the environment. These Main Rivers tend to be the larger rivers in the country, though some smaller watercourses in sensitive locations are also defined as 'Main Rivers'.

The EA are also category 1 responders regarding flood risk (Civil Contingencies Act 2004). They are required to warn and inform of flood risk.

10.1.2 Water Company

Water companies in England and Wales are named as a Risk Management Authority under the Flood and Water Management Act 2010 and must have regard to the Local Strategy of the LLFA. They are required to manage risks associated with assets or processes that may cause or be affected by flooding, and must share relevant data with other flood risk authorities.

They also have flood risk management functions under the Water Resources Act (1991). Relevant actions of water companies include: the inspection, maintenance, repair and any works to their drainage assets which may include watercourses, pipes, ditches or other infrastructure such as pumping stations.

The Civil Contingencies Act 2004 (CCA) also designates water and wastewater undertakers as statutory category 2 responders to national disasters and emergencies, placing on them duties to share assured information with other responders in an appropriate manner.

10.1.3 North Yorkshire County Council (NYCC)

NYCC, as LLFA, has flood risk management functions which include (but are not limited to):

- Provision of a Local Flood Risk Management Strategy (LFRMS).
- Designation and maintenance of a register of structures or features that have a significant effect on flood risk.
- Consenting and enforcement works on Ordinary Watercourses.
- Responding to statutory consultations on drainage proposals in planning applications.
- Undertaking Section 19 investigations.

NYCC also has responsibilities as a Highways Authority and as an Emergency Responder (under the Land Drainage Act 1991 and the Civil Contingencies Act 2004 respectively) which may relate to flooding.

Highway Authorities are responsible for providing and managing highway drainage which may include provision of roadside drains and ditches, and must ensure that road projects do not increase flood risk.

The Highways Authority has a duty under the Highways Act 1980 to maintain highways that are maintainable at public expense. This includes a duty to maintain existing highway drainage. Highway drainage systems are designed to take highway surface water. Highway drainage systems are not designed as “storm drains”, and do not have the capacity for the level of rainfall from an extreme flash flood. The Highway Authority has powers to improve drainage systems but no duty to do so.

Roadside gullies are subject to routine maintenance in accordance with the NYCC Highway Asset Management Plan. The frequency of cleaning is dependent on an evidence based categorisation of risk, determined by factors relating to the consequence of failure and a range of other operational factors.

10.1.4 District or Borough Council

District and Borough Councils are named as Risk Management Authorities within the Flood and Water Management Act 2010, and are required to comply with the LLFA Local Strategy. Through the planning processes, they control development in their area, ensuring that flood risks are effectively managed.

In addition, in relation to the Civil Contingency Act (2004), the District and Borough Council:

- Is a Category 1 Responder. On a priority basis, they will provide sandbags to residents and businesses where property is at risk of flooding.
- Support the Emergency Services on request by providing Incident Liaison Officers.
- Provide emergency accommodation – i.e. set up rest centre as required and other welfare provision.
- Assist with arranging transport or evacuating areas.
- Participate in vulnerable people searches.
- Assist with co-ordination of recovery.

The NYCC Emergency Planning Unit provides support to the District Council.

10.1.5 Internal Drainage Board

Internal Drainage Boards (IDBs) are local operating authorities established in areas of special drainage need (typically low lying areas) in England and Wales. Their primary role is to manage water levels and reduce the risk from flooding within their designated drainage districts. Their work includes:

- Maintenance and improvement works on watercourses and related infrastructure.
- Consenting works on Ordinary Watercourses.
- Responding to consultations on drainage proposals in planning applications.
- Exercising permissive powers to undertake works where appropriate.

In managing water levels IDBs also have an important role in reducing flood risk in areas beyond their administrative boundary.

10.1.6 All Risk Management Authorities

All RMAs under the Flood and Water Management Act (2010) have a responsibility to cooperate and coordinate with regards to their flood risk management functions, including raising awareness of flood risk and the sharing of information.

10.1.7 Riparian Owners

Landowners whose land is adjacent to a watercourse are known as ‘riparian owners’.

A landowner can be an individual e.g. home owner or farmer, private business or an organisation e.g. the district council as park owner, on school grounds the county council as property owner.

A watercourse is defined as every river, stream, ditch, drain, cut, dyke, sluice, sewer (other than a public sewer) and feature through which water flows, but which does not form part of a Main River.

Riparian owners have legal duties, rights and responsibilities under common law and the Land Drainage Act 1991 for watercourses passing through or adjoining their land. These responsibilities are to:

- Pass on the flow of water without obstruction, pollution or diversion affecting the rights of others
- Accept flood flows through their land, even if these are caused by inadequate capacity downstream.
- Maintain the banks and bed of the watercourse and keep structures maintained
- Keep the bed and banks free from any artificial obstructions that may affect the flow of water including clearing litter, heavy siltation or excessive vegetation.

Guidance on the rights and responsibilities of riparian ownership are outlined in the Environment Agency publication ‘Living on the edge’, available at:

<http://www.environment-agency.gov.uk/homeandleisure/floods/31626.aspx>

10.2 Actions and Responses to December 2015 Floods

10.2.1 North Yorkshire County Council as Lead Local Flood Authority

The Flood Risk Management (FRM) Team provides an overarching view on flood risk management activities within the county. The FRM team have undertaken the following specific activities:

- Supported residents of South Craven communities in obtaining Flood Resilience Grants. 25 properties have applied for the grant in the area of Craven District covered by this report Craven. Examples of measures include

- flood doors and barriers, sump pumps, walls and bunds, Non-Return Valves on private drainage systems.
- Coordinated work with other Risk Management Authorities and local communities to investigate the flood event and the specific mechanisms identified from the December 2015 event.
- NYCC Flood Risk Management team has attended meetings of the South Craven Flood group which has become increasingly active since the December floods. This partnership includes Parish and District councillors, as well as officers from the Craven District Council, NYCC Highways and the Environment Agency, and will provide a valuable platform for the development of future schemes and bids for funding.
- NYCC Emergency planning team have been working with communities to develop community emergency plans. Many existing plans have been updated with new plans being developed with Cononley, Glusburn/Crosshills, Sutton in Craven , Embsey/Eastby, Farnhill

10.2.2 North Yorkshire County Council as Highway Authority

The Highway Authority carries out regular maintenance of the highway drainage system. NYCC, in its capacity as highway authority has undertaken the following specific activities;

- Provided a sweeper to remove debris washed onto the carriageway surface by flood water at various locations.
- Carried out widespread clean-up of the highway drainage system, removing tons of stone, gravel and silt washed into the system by the flood waters.
- Instigated a schedule of drainage investigation works in locations highlighted by the flood event. This includes jetting and camera surveys of drainage in Lidget Road, Low Bradley; A629 and Main Street, Farnhill; West Lane, Bridge Road and Mill Street, Sutton; Colne Road, Main Street, Lothersdale Road, Beanlands Close and Walker Close, Glusburn; Skipton Road, Cononley.
- Drainage repairs at West Lane and Mill Street Sutton; Beanlands Close, Glusburn; Main Street / Nethergill lane, Cononley.
- Footway reprofiling at Holme Lane, Sutton.
- Road edge repairs at New Lane, Crag Lane, Silsden Road and Matthew Lane, Bradley; Ellers road, West Lane and Buck Stone Lane, Sutton.
- Widening of run off slipway on A6068 west of Glusburn bridge to allow excess surface water flow to re-enter the beck.
- Installation of pipe work in the masonry walls of the A629 to allow surface water flow and overspill from Mill Ing Beck to drain onto the flood plain in extreme conditions. Fig 10.1.



Figure 10.1 A629 at Ing Beck Bridge

10.2.3 The Environment Agency

The EA has undertaken the following post flood event activities:

- Promotion of the Environment Agency Flood Warning Service in the area. Following the December 2015 floods 2000 households were visited and 160 new properties registered for the service. This promotional work is on-going through the South Craven Flood Group partnership.
- Application for Flood and Coastal Erosion Risk Management (FCERM) funding for the development of a strategy for managing flood risk within the Glusburn Beck and Long Dyke catchments. This will aim to address flood risk from all sources in combination and as such will require the coordinated efforts of the relevant Risk Management Authorities. Initial funding has been secure from the Regional Flood and Coastal committee to quantify the risks and benefits involved with a view to securing further funding in the FCERM 6 year investment plan outline allocations for next 3 years.
- On-going programme of inspections and maintenance of flood defences.

10.2.4 Yorkshire Water Services Ltd

YWSL has undertaken the following activities:

- Eight customer contacts in all during this period.
- Carried out repairs at Low Bradley to make safe during the event. However, subsequent investigation showing YWSL asset not involved.
- Investigated flooding at Cononley – previously unmapped and unknown sewer identified and cleared of silt.

- Investigations have been carried out in a number of locations in Glusburn and Sutton-in-Craven. Some have been found to involve private rather than public sewers. In all cases sewers found to have been overwhelmed by sheer volume of water and Storm Sewer Overflows unable to spill due to high river levels.
- Yorkshire Water is currently conducting a catchment investigation into the public sewer network in the Skipton area. The area covered (Fig 10.2) extends as far South as Cononley and Low Bradley. Using the model of the sewer network, they will look at how systems will perform under climate change conditions and with predicted new developments.

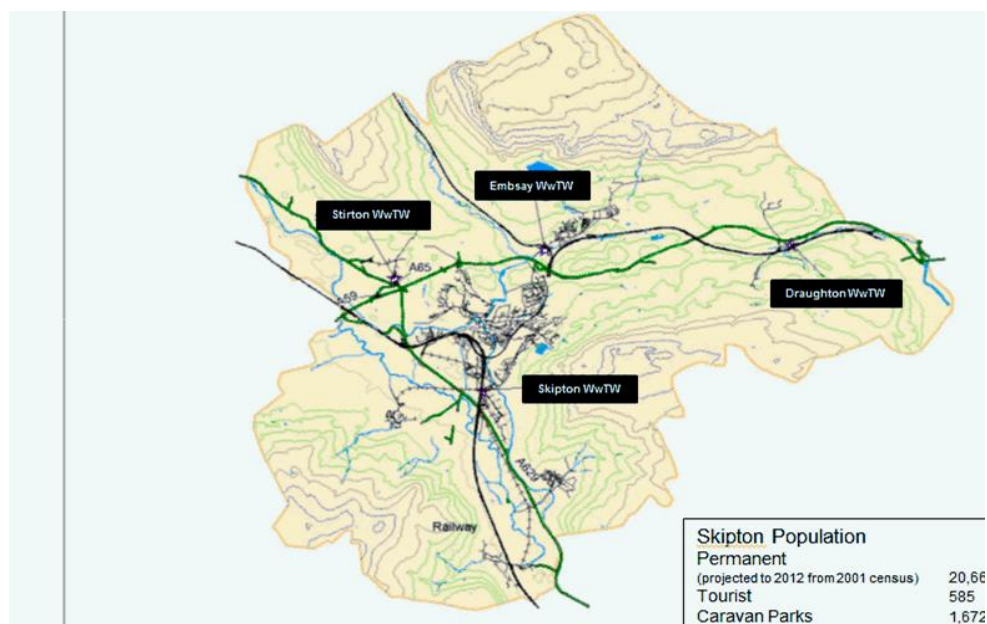


Figure 10.2 Yorkshire Water Network Review Skipton Area

10.2.5 Craven District Council

Craven District Council has undertaken the following activities:

- CDC officers were in attendance during the flood event - delivering and helping to deploy sandbags.
- Since the December 2015 flood event CDC have installed new sandbag stores in Manor Way, Sutton-in-Craven and Valley View Glusburn, liaising with the parish councils to a plan for their deployment.
- CDC officers have supplied grant payments of £500 per household affected by flooding in this event as part of the government Communities and Business Recovery Scheme. This has helped with initial recovery costs such as provision of temporary accommodation.

- In addition CDC has provided council tax discounts for flooded households for a minimum for 3 months following the event.
- Providing information on the flooded properties in South Craven to support the Environment Agency bid for funding.

10.3 Conclusions

December 2015 saw the South Craven area experience flooding from a variety of sources, acting independently and in combination. The flooding was ultimately as a result of the significant rainfall event on the 25th and 26th December and saturated ground conditions resulting from almost record breaking rainfall in November and December.

These factors acting on the steep sided valleys surrounding the six communities covered in this report, led to swift surface water run off which quickly swelled small watercourses and created overland flow routes over farm land and on roads.

In some areas (Low Bradley & Kildwick), historic stone built culverts were overwhelmed by the volume of water coming off the surrounding land, coupled with infiltration of ground water from the saturated ground. In others, the outfalls of surface water drainage systems became submerged by rising waters in the Aire and other tributaries, severely impacting on their ability to discharge.

The highway drainage systems across the South Craven area became overwhelmed, in some cases this was exacerbated by gravel and sediment conveyed by the surface water blocking highway gullies and choking the underlying drainage system.

As the impact of the rainfall moved down the catchment there was a sharp rise in the River Aire, Holme Beck, Eastburn Beck and other smaller tributaries. In some locations these rivers and streams came out of bank causing further property flooding and infrastructure impacts in Cononley, Kildwick, Sutton and Crosshills.

In the period following the flood event the Risk Management Authorities have been involved, both individually and in partnership, in a range of activities to promote flood resilience in South Craven, both in the short and long term. The findings of this investigation show the multi-source nature of flood risk in many of the impacted locations and underline the importance of cooperation between all RMAs and key stakeholders in addressing those risks.

11.0 Recommendations

In order to reduce the future risk of flooding in the locations, this report makes the following recommendations:

- NYCC in its capacity as LLFA to work with local stakeholders to review condition of local riparian watercourses, drainage ditches and culverts.
- NYCC in both its capacities as Highway Authority and LLFA to work with local stakeholders to reduce surface water flow onto the highway and the impact of the debris it carries on local drainage systems.
- The EA to lead on the development of a strategy for managing flood risk in the Glusburn Beck & Long Dyke Catchments, in partnership with existing flood groups.
- Coordination of cross boundary working with neighbouring local authorities to assess and promote catchment wide measures, including natural flood management, to reduce flood peaks for the mutual benefit of both the communities of South Craven and the Upper Aire, and larger urban populations downstream.

NYCC as LLFA will continue to work with RMA's, and local stakeholders to develop action plans to address the issues raised in this report.