Thornborough Section 19 Flood Investigation

Final Technical Report

July 2022

www.jbaconsulting.com

Buckinghamshire Council

JBA Project Manager

Anna Beasley
Pipe House
Lupton Road
Wallingford
OX10 9BS

Revision History

Revision Ref/Date	Amendments	Issued to
S3-P01 14/04/2022	Draft Report	Andrew Waugh
S3-P02 27/05/2022	Draft report with amendments	Andrew Waugh and stakeholders
A1-C01 26/07/2022	Final report	Andrew Waugh and stakeholders

Contract

This report describes work commissioned by Andrew Waugh, on behalf of Buckinghamshire Council, by an email dated 15 March 2021. Buckinghamshire Council's representative for the contract was Andrew Waugh. Anna Beasley, Heather Forbes, Lisa Chatterjee and Seraya Sigsworth of JBA Consulting carried out this work.

Prepared by ..... Heather Forbes BSC (Hons) MSc

Assistant Analyst

..... Seraya Sigsworth

Analyst

..... Lisa Chatterjee BSc (Hons) MSc

Senior Hydrologist

Reviewed by ..... Fiona Hartland MSci

Senior Analyst

..... Anna Beasley BSc MSc CEnv MCIWEM C.WEM

Technical Director

Contributor and editor ..... Andrew Waugh BSc PgCert PgDip

Strategic Flood Risk Management Lead Officer, Buckinghamshire Council

Purpose

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

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

Acknowledgements

We would like to thank Buckinghamshire Council, Thornborough Parish Council and the Environment Agency for their input and support.

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 58g if 100% post-consumer recycled paper is used and 73g if primary-source paper is used. These figures assume the report is printed in black and white on A4 paper and in duplex.

JBA is aiming to reduce its per capita carbon emissions.

Executive summary

Background

Following flooding in Thornborough on 23 December 2020, Buckinghamshire Council (BC) as the Lead Local Flood Authority (LLFA) is undertaking a formal flood investigation under Section 19 of the Flood and Water Management Act 2010[1].

It is a statutory requirement for LLFAs to investigate flooding to the extent that it considers it necessary or appropriate.

Thornborough is a village in North Buckinghamshire, located at the confluence of two small watercourses in the Great Ouse valley, approximately 5km east of Buckingham. The village is mostly surrounded by agricultural land as well as other small villages, such as nearby Thornton and Nash.

Stakeholder engagement

As part of the Section 19 investigation we engaged with multiple local stakeholders in Thornborough, including residents, community representatives and other Council departments.

The objectives of engagement are to:

- Gather facts, opinions and data to aid the understanding of the investigation
- Enable the involvement and buy-in of the community in the investigation
- Disseminate the findings of the investigation to the community

Long-term flood risk

According to the Environment Agency's fluvial flood mapping, most of Thornborough is within Flood Zone 1 where the annual risk of flooding from rivers is less than 0.1% (1 in 1,000). However, Lower End and the area around Thornborough Mill are in Flood Zone 3, where the annual risk of flooding from rivers is at least 1% (1 in 100).

According to the Environment Agency's surface water mapping, there is a heightened surface water flood risk along all of the watercourses through the village, where many of the immediate areas are at risk of flooding from a 3.33% (1 in 30) annual chance rainfall event, and more widespread flooding predicted to have 0.1% AEP (1 in 1,000) chance of occurring.

Groundwater mapping show the potential for high groundwater levels in large areas of the village along the watercourses. This includes most of the area around the central village green, including the High Street, Back Street, Palmers Moor, Chapel Lane crossroads, and along The Green.

Five flood events have been reported in the village since 1935.

Existing FRM activities

The Environment Agency's flood warning area covers flood risk from the River Great Ouse and Padbury Brook, though does not cover the ordinary watercourses through the village.

———————————————————————————————————————

1 Flood and Water Management Act 2010 Section 19 (accessed 17 May 2021): https://www.legislation.gov.uk/ukpga/2010/29/section/19

Lead Local Flood Authorities do not have the infrastructure to manage or issue flood warnings.

Flood risk is currently managed locally by the Parish Council, residents and riparian owners such as the Highways Authority , by way of maintaining ditches, watercourses and drains. The Buckingham and Ouzel IDB maintains Cowerde Brook downstream of the village, below the bridge on Lower End. The installation of resilience measures such as PFR barriers and landscaping changes have also been carried out by residents, both prior to and following the flooding in December 2020.

Hydrology of the event

The total rainfall during the 23 December storm event had a 50% chance of occurring in any one year (return period of 2 years) for the Thornborough village catchment at Cowerde Brook, and a 20% chance (return period of 5 years) for the Thornborough Mill catchment on the Great Ouse. This is not especially extreme but given that the soils were already completely saturated from the notably high rainfall over preceding months, the catchments were very sensitive to heavy rainfall. An approximate flow return period of 5-20 years is estimated for Thornborough village and 10-30 years for Thornborough Mill.

Incident Response

Flooding first began in the village at around 15:00 on 23 December, with the bridge at Lower End Road becoming impassable at around 16:00. The Fire and Rescue service attended shortly afterwards. A widespread flood warning was not issued until 18:35, covering the Great Ouse Flood Warning Area which does not include the watercourses in Thornborough Village. The Thornborough Mill area reported flooding from the river at around 0300 on 24 December, receding the following evening.

Source-pathway-receptor analysis

The sources, pathways and receptors of flooding were as follows:

- Sources – extreme rainfall, overtopping of the three watercourses in the village and the Great Ouse at Thornborough Mill, groundwater emergence
- Pathways –converged overland flow, surface water flow, diverted watercourse overflow
- Receptors – confirmed internal flooding of five residential properties, resident displacement, loss of possessions, negative mental and physical health impacts.

For more information see Section 8.

Condition assessment

The village was visited in September 2021, when an assessment was made of the condition of the watercourses. No significant issues for watercourse condition were identified during the visit, though it is possible that some aspects of watercourse condition, such as a lack of relief flow routes, blockages and vegetation had an impact on flooding during the 2020 event.

Conclusions and recommendations

A series of recommended actions for the Risk Management Authorities and stakeholder organisations are presented below.

For more information on options, recommendations and conclusions see Section 11.

Recommendation	Organisation(s) responsible
Create a community flood action plan and formalise any existing arrangements	Community, Flood Action Group, Parish Council
Engage with landowners/farmers to explore potential NFM/Land management e.g water storage, ditches, buffer strips etc	Parish Council, Flood Action Group
Install PFR at five properties	Community, Parish Council, Flood Action Group
Increase frequency of highway gully maintenance	Transport for Buckinghamshire
Enhanced watercourse maintenance	Riparian owners
Increase riparian awareness (responsibility and maintenance)	Parish Council with support from Flood Action Group and BCC?
Culvert and bridge maintenance	Riparian owners, IDB, Transport for Buckinghamshire

Contents

List of Figures

List of Tables

Abbreviations

AEP	Annual Exceedance Probability
AOD	Above Ordnance Datum
BGS	British Geological Society
BC	Buckinghamshire Council
CCTV	Closed Circuit Television
DTM	Digital Terrain Model
EA	Environment Agency
FEH	Flood Estimation Handbook
FRM	Flood Risk Management
GIS	Geographic Information Systems
JBA	Jeremy Benn Associates
LiDAR	Light Detection and Ranging
LLFA	Lead Local Flood Authority
PFR	Property Flood Resilience
RMA	Risk Management Authority
RoFSW	Risk of Flooding from Surface Water (Environment Agency mapping)
TfB	Transport for Buckinghamshire

Definitions

Culvert	Where a watercourse flows through a pipe, often underground.
Non-return valve	Hinged valve placed on a pipe outlet into a river. Stays open during normal flow but closes when it is submerged, to prevent flow from backing up the pipe.
Foul sewer	Sewer which carries wastewater (e.g., from toilets, sinks, showers and kitchen appliances) to a sewage works for treatment.
Gully	Drainage pit covered by an open metal grated, located at the edge of a road. Drains rainwater from the road into the sewerage system or nearest watercourse.
HYRAD	Real-time radar display system for weather.
Lead Local Flood Authority	County councils and unitary authorities which lead in managing local sources of flood risk (i.e. flooding from surface water, groundwater and ordinary watercourses)

Culvert	Where a watercourse flows through a pipe, often underground.
Main river	A large river or stream designated on the Main River Map. The Environment Agency has permissive powers to maintain and carry out improvements on main rivers, to manage flood risk.
Ordinary Watercourse	All rivers which are not designated as 'Main rivers'. Lead local flood authorities and internal drainage boards can carry out flood risk management work on ordinary watercourses.
Public sewer	Sewers owned and maintained by a Sewerage Company (e.g. Thames Water). Are usually located in roads or public open spaces but may run through private gardens.
Riparian owner	The owner of land that is next to a watercourse or has a watercourse running through or beneath it.
Soil moisture deficit	The difference between the amount of water actually present in the soil and the amount of water which the soil can hold.
Surface water sewer	Sewer which carries rainwater directly to a watercourse.

1 Introduction

1.1 Background to investigation

Following flooding in Thornborough on 23 December 2020, Buckinghamshire Council (BC) as the Lead Local Flood Authority (LLFA) is undertaking a formal flood investigation under Section 19 of the Flood and Water Management Act 2010[2].

It is a statutory requirement for LLFAs to investigate flooding to the extent that it considers it necessary or appropriate. Buckinghamshire Council has outlined its criteria for undertaking a Section 19 investigation in its Local Flood Risk Management Strategy[3].

- Internal flooding (including to basements) to five or more residential properties within an area of 1km^2;
- Internal flooding of two or more business premises within an area of 1km^2;
- Internal flooding (including to basements) of at least one property for one week or longer;
- Flooding of one or more critical infrastructure assets, which could include hospitals, health centres, clinics, surgeries, colleges, schools, day nurseries, nursing homes, emergency services (police, fire, ambulance) stations, utilities and substations; and Any flooding event that a risk management authority deems significant but does not meet the agreed thresholds may be assessed for consideration by the strategic flood management group.

The flooding that occurred in Thornborough caused internal flooding to at least five properties and fulfils the above criteria for a Section 19 investigation. Buckinghamshire Council has appointed JBA Consulting to undertake this investigation on its behalf.

1.2 Aims of the investigation

Section 19 of the Flood and Water Management Act 2010 sets out that a Lead Local Flood Authority (LLFA) must, to the extent that it considers it necessary or appropriate, investigate which risk management authorities have relevant flood risk management functions, and whether each of those authorities has exercised, or is proposing to exercise, those functions in response to the flood.

Within Buckinghamshire, the aims of such an investigation are extended to providing an overview of the flooding incident and its impact, any history of flooding, a rainfall analysis, and determining the main factors and mechanisms involved in the flooding. This investigation also seeks to outline the actions of the relevant authorities, with some discussion of what went well and where improvements could be made in future. However, it is not within the remit of a Section 19 Flood Investigation to apportion blame to any organisation nor hold any risk management authority to account for their response to the floods.

We have also proposed a list of recommendations to help the various stakeholders learn from the event and improve the management of flood risk locally. We have undertaken a high-level appraisal of these recommendations, focussing on benefit, practical and viability considerations. However, it is not within the remit of a Section 19 Flood Investigation to provide designed solutions. The investigation process does not provide Buckinghamshire Council, nor any other authority, with the funding or mandate to undertake flood management works on the ground.

---

2 Flood and Water Management Act 2010 Section 19 (accessed 17 May 2021): https://www.legislation.gov.uk/ukpga/2010/29/section/19

3 Buckinghamshire Local Flood Risk Management Strategy (2017): https://www.buckscc.gov.uk/media/4511603/bcc-lfrms-final-version-may-2017.pdf

The intention is instead to provide a clear understanding of the issues, since this is the first step towards being able to help address a flooding problem.

Given that the scope of the investigations is limited to developing a preliminary high-level screening of options, the reports should not be viewed as an action plan nor strategy that will set out definitive flood management actions that will be taken. However, it does make several recommendations that may be actioned in the short to medium term. It will be for the relevant responsible party to assess these recommendations in terms of their legal obligation, resource implications, priority and the costs and benefits of undertaking such options.

1.3 Site location

Thornborough is a village in the north of Buckinghamshire. It is situated in the Great Ouse valley, approximately 5km east of Buckingham. Thornborough Mill is 1.7km to the north of the main village, on the River Ouse itself. The village is mostly surrounded by agricultural land as well as other small villages, such as nearby Thornton and Leckhampstead, which were also impacted by flooding in the December 2020 event. Separate Section 19 Flood Investigations are being carried out in these locations. The River Great Ouse is approximately 500m to the north west..

1.4 Data collection

A wide range of different data has been collected and assessed to inform the Section 19 investigation. This has been used to understand the causes and impacts of flooding in Thornborough and to establish the context of the area. This includes the following:

- Open source data from GOV.UK – for example the Risk of Flooding from Surface Water mapping (RoFSW), the Flood Map for Planning, LiDAR etc;
- Photographs from a site visit, showing flood sources, pathways and receptors;
- Rainfall data;
- Residents' questionnaires;
- Information from authorities on drainage infrastructure, such as highways and water companies;
- Other data such as photos, newspaper articles and notes from the event.

2 Stakeholder engagement

We engaged with multiple local stakeholders in each location, including residents, community representatives, landowners, other Council departments, Council Members and RMA partners.

The objectives of engagement are to:

- Gather facts, opinions and data to aid the understanding of the investigation
- Enable the involvement and buy-in of the community in the investigation
- Provide more technical debrief with RMA and operational partners
- Disseminate the findings of the investigation to the community

A list of key stakeholders and how we engaged with them is given in Table 2-1. The engagement terminology is taken from Environment Agency's 'Working with Others' (2013) methodology:

- Inform - provide information
- Consult - receive, listen, understand and feedback
- Involve - decide together
- Collaborate - act together
- Empower - support independent action

Table 2-1: Key stakeholders

Role	Organisation	How to engage	Type of engagement
Parish/Town Council	Thornborough Parish Council	Consult	Invitation to contribute, site visit, online survey distribution, correspondence, public engagement meeting
Highways Authority	Transport for Buckinghamshire	Consult	Invitation to contribute, correspondence, data provision
Environment Agency	Environment Agency (Anglian)	Consult	Correspondence, data provision
Internal Drainage Board	Buckingham & River Ouzel IDB	Consult	Correspondence, data provision
Residents	N/A	Consult	Site visit, online questionnaire, correspondence

3 Catchment characteristics

3.1 Drainage system and river network

3.1.1 Watercourses

Larger watercourses are often designated as 'main rivers'. The Environment Agency has permissive powers to carry out maintenance and improvements to main rivers, to manage flood risk. All other rivers are known as 'ordinary watercourses'. The roles and responsibilities of different organisations in managing flood risk are explained in Section 5.1.

The farmland in the upper catchment is drained by two ordinary watercourses which flow from east to west. The northernmost stream is called Thorn Brook, whilst the southernmost stream is called Tonne Brook. In Thornborough village, the watercourses converge to form a watercourse called Cowerde Brook, which continues westwards to discharge into Padbury Brook. Padbury Brook, which is classed as a main river, then joins the Great Ouse another 300m downstream. The section of the ordinary watercourse downstream of Lower End Bridge to the Padbury Brook confluence is managed by the Buckingham and River Ouzel Internal Drainage Board (IDB).

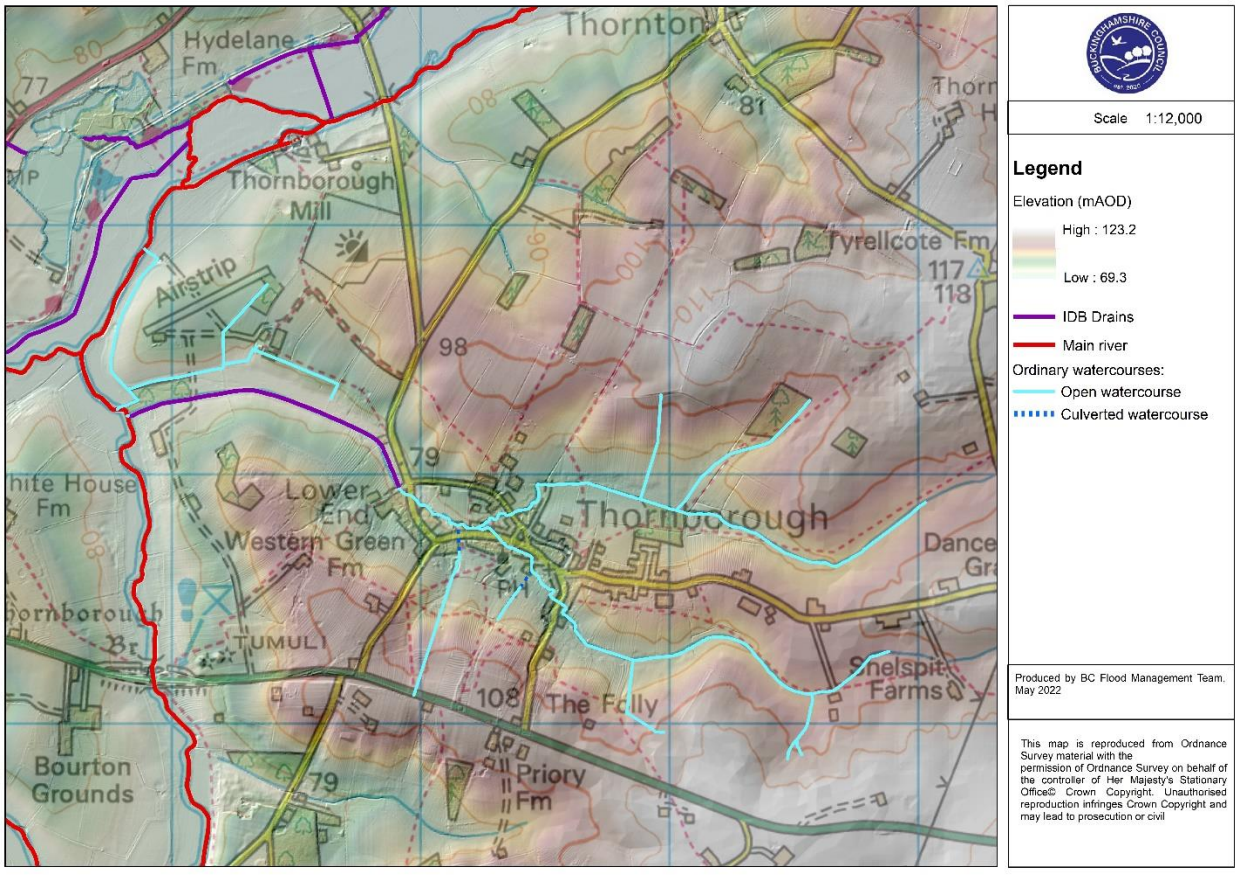


Figure 3-1: Drainage system and river network in the area surrounding Thornborough

3.1.2 Land drainage

In addition to the larger ordinary watercourses, there are a number of small land drains. Some of these are visible in OS map data (Figure 3-1).

3.1.3 Sewers

There is no public surface water sewer system serving Thornborough.

3.1.4 Highways

Roads are drained by a network of highway gullies in the village. These are owned and maintained by Transport for Buckinghamshire, and shown in Figure 3-2 below.

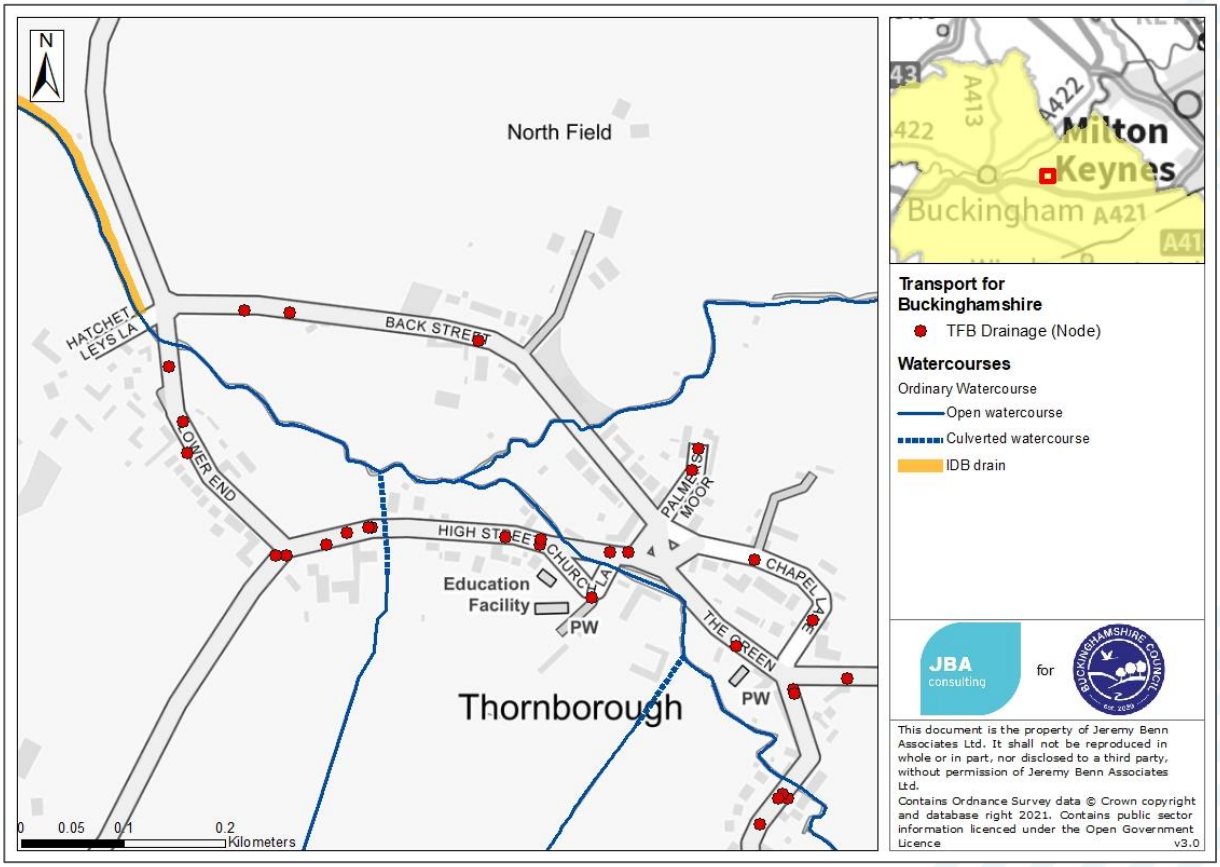


Figure 3-2: Transport for Buckinghamshire highways assets in Thornborough.

3.2 Catchment characteristics

3.2.1 Topography

Thornborough is situated in a shallow valley at the confluence of two small watercourses, at approximately 80mAOD (metres above Ordnance Datum) in elevation. The top of the catchment, which is approximately 5km to the east, reaches 145mAOD. To the west the valley slopes gently down towards Padbury Brook, approximately 1.5km away, where ground levels reach 70mAOD. A map of the topography of Thornborough, from the Environment Agency's 2020 LiDAR dataset, is shown below.

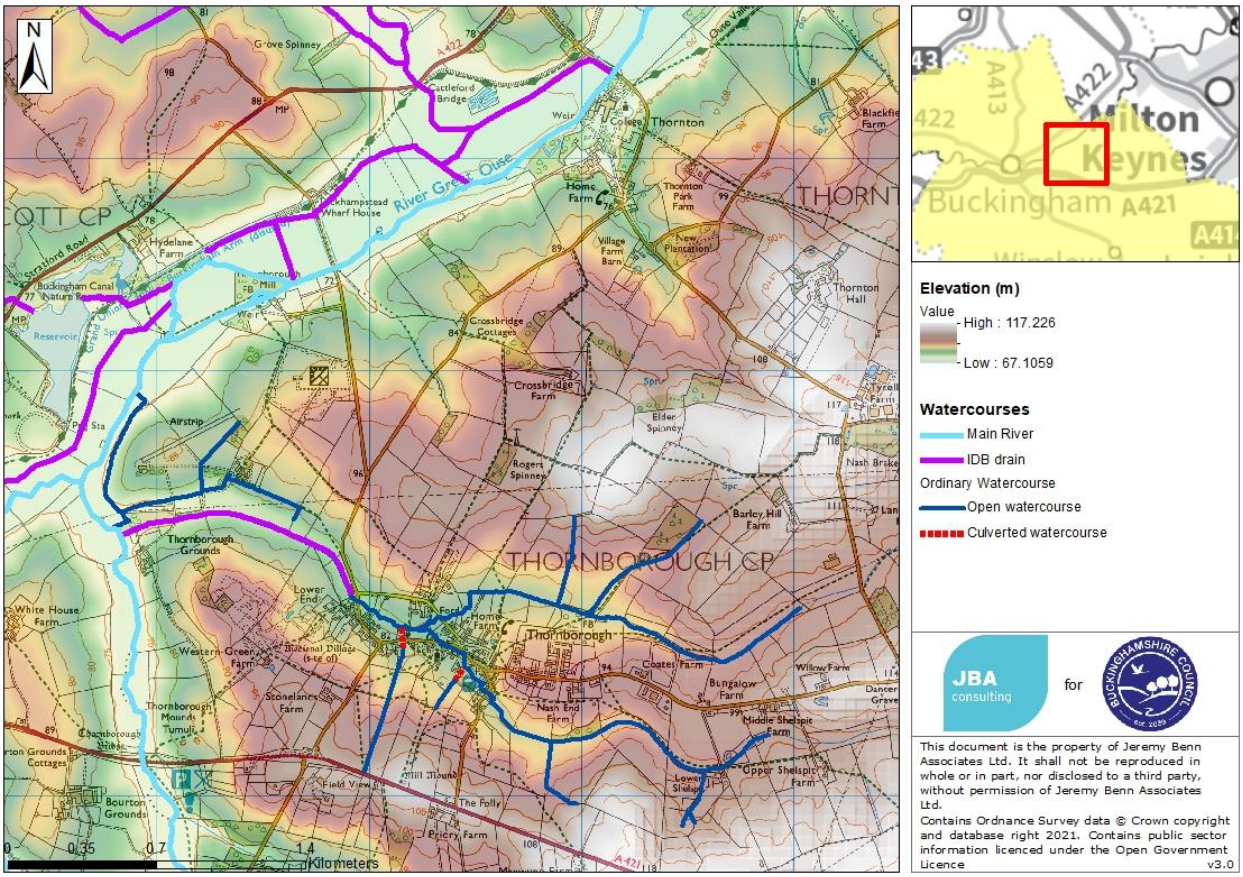


Figure 3-3: Topography in Thornborough

3.2.2 Geology

British Geological Survey (BGS) data indicates that the bedrock underlying the catchment is Mudstone, Siltstone and Sandstone, changing to Sandstone, Limestone and Argillaceous Bedrock to the west (Figure 3-4)[4]. Much of the area is also underlain by superficial deposits of Till, with Alluvium deposits located further west. These superficial deposits consist of silts, clays, sands and gravels and may have variable permeability.

Soils across the catchment and known to be impermeable, with Soilscapes mapping[5] characterising the soil type in Thornborough as 'lime-rich loamy and clayey soils with impeded drainage'.

4 BGS Geology of Britain viewer: https://mapapps.bgs.ac.uk/geologyofbritain/home.html

5 Cranfield University soilscapes mapping: http://www.landis.org.uk/soilscapes/

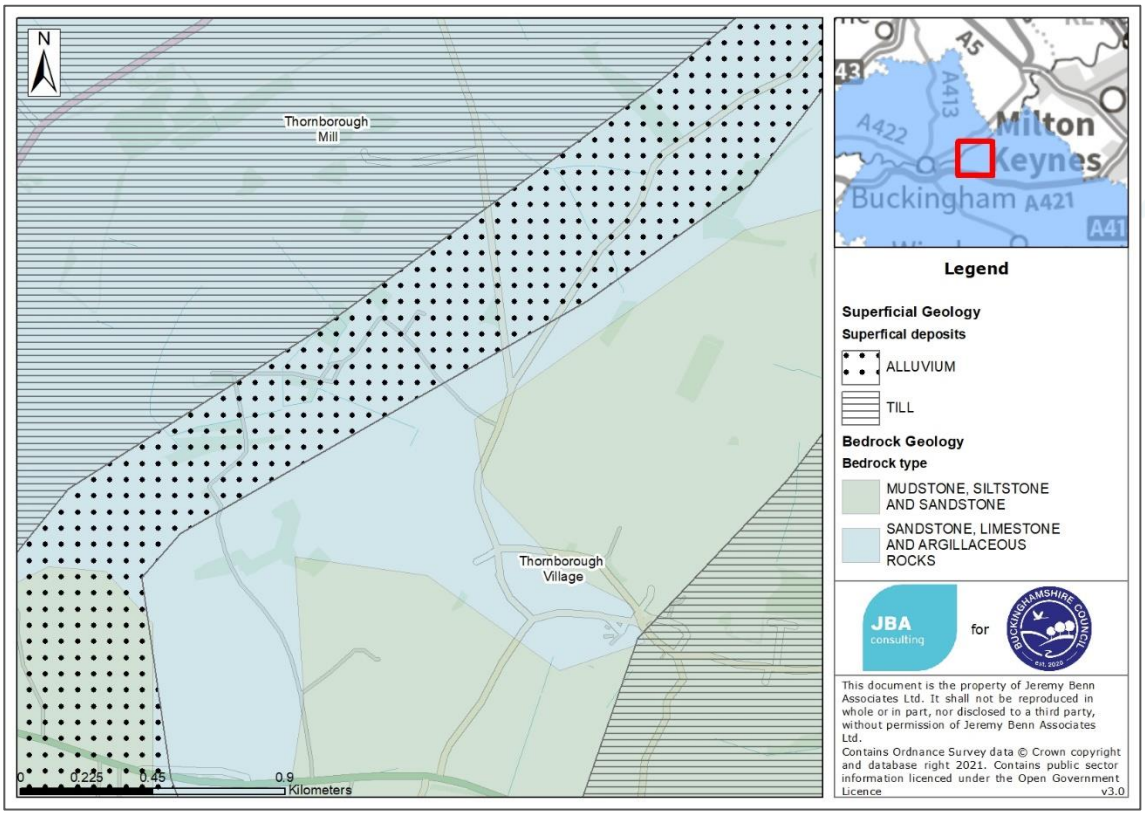


Figure 3-4: Geology of Thornborough, from British Geological Survey (BGS) 1:625000 mapping.

4 Flood risk

4.1 Long-term flood risk information

4.1.1 Risk of flooding from rivers and the sea

Data from the Environment Agency's Flood Zone mapping are shown in Figure 4-1. Most of Thornborough is within Flood Zone 1 where the annual risk of flooding from rivers is less than 0.1%. Areas located within Flood Zone 2, which represents areas with a low risk of flooding (between a 1 in 100 and 1 in 1,000 annual chance of occurring) and Flood Zone 3, which represents areas with a medium risk of flooding (up to a 1 in 100 annual chance of occurring) are confined to the floodplain of Padbury Brook and narrow areas along the Thorn, Tonne and Cowerde ordinary watercourses.

It should be noted that the Flood Zones for the River Great Ouse are based on detailed survey and modelling, however for the Thorn, Tonne and Cowerde ordinary watercourses the Flood Zones are based on less detailed national broadscale modelling at a lower resolution. On smaller watercourses the more recent Risk of Flooding from Surface Water (RoFSW) mapping can be used as a proxy (section 4.1.2).

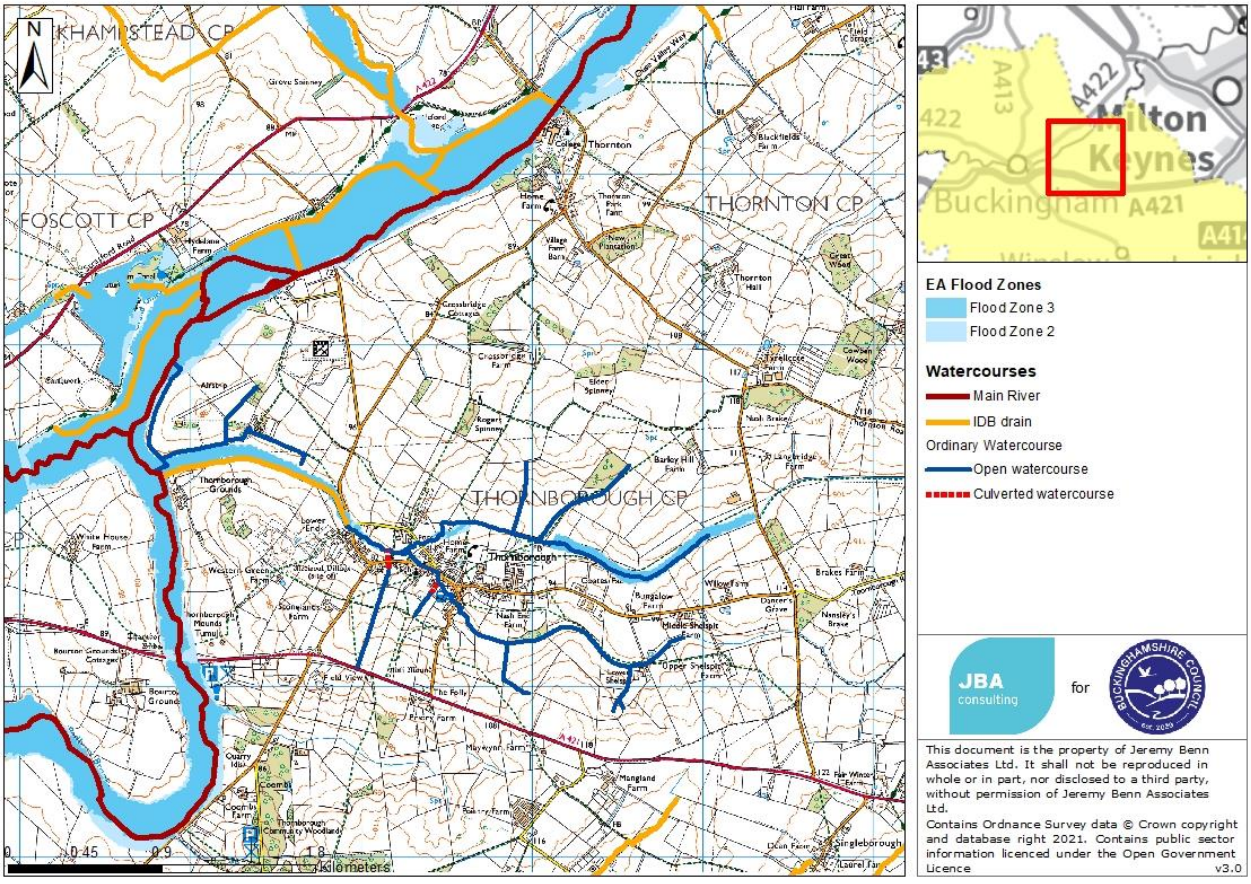


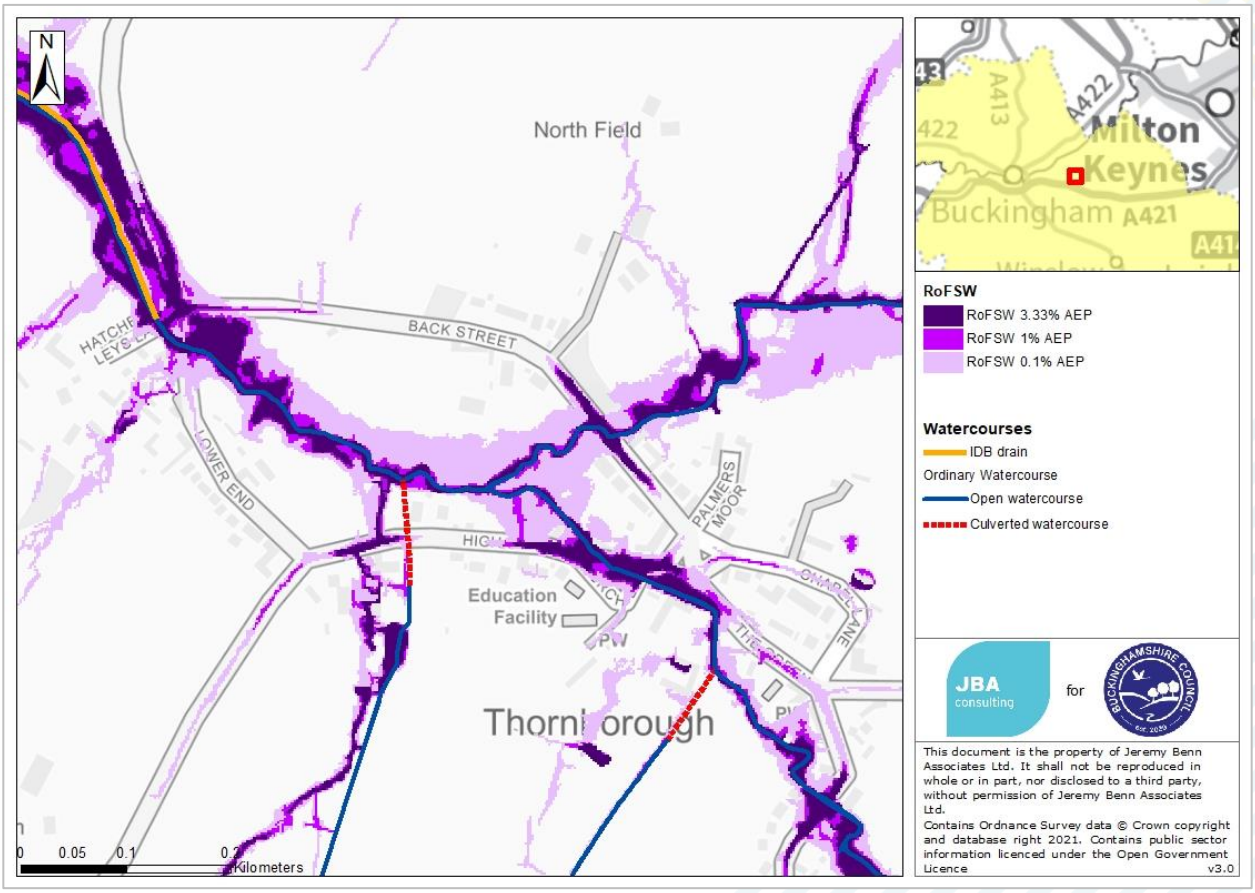
Figure 4-1: Risk of flooding from rivers and the sea, shown alongside local watercourses

4.1.2 Risk of flooding from surface water

The Environment Agency's Risk of Flooding from Surface Water (RoFSW) mapping is shown within Thornborough village in Figure 4-2a and across the wider area in Figure 4-2b. Figure 4-2a clearly shows the flow routes along the small ordinary watercourses through the village, where many of the immediate areas are at risk of flooding from a 3.33% (1 in 30) annual chance rainfall event.

Where the watercourses cross roads, the mapping shows that flows are partially diverted along the roads during rainfall events with a 1 in 30 and greater chance of occurring in any given year. In several locations, the mapping indicates that surface water will follow natural pathways once it gets out of bank, for example the small watercourse which is culverted under the High Street. Within these pathways, the RoFSW mapping shows a risk of flooding during rainfall events with a 3.33% (1 in 30) chance of occurring in any given year, and more widespread flooding predicted to have 0.1% AEP (1 in 1,000) chance of occurring.

a.



b.

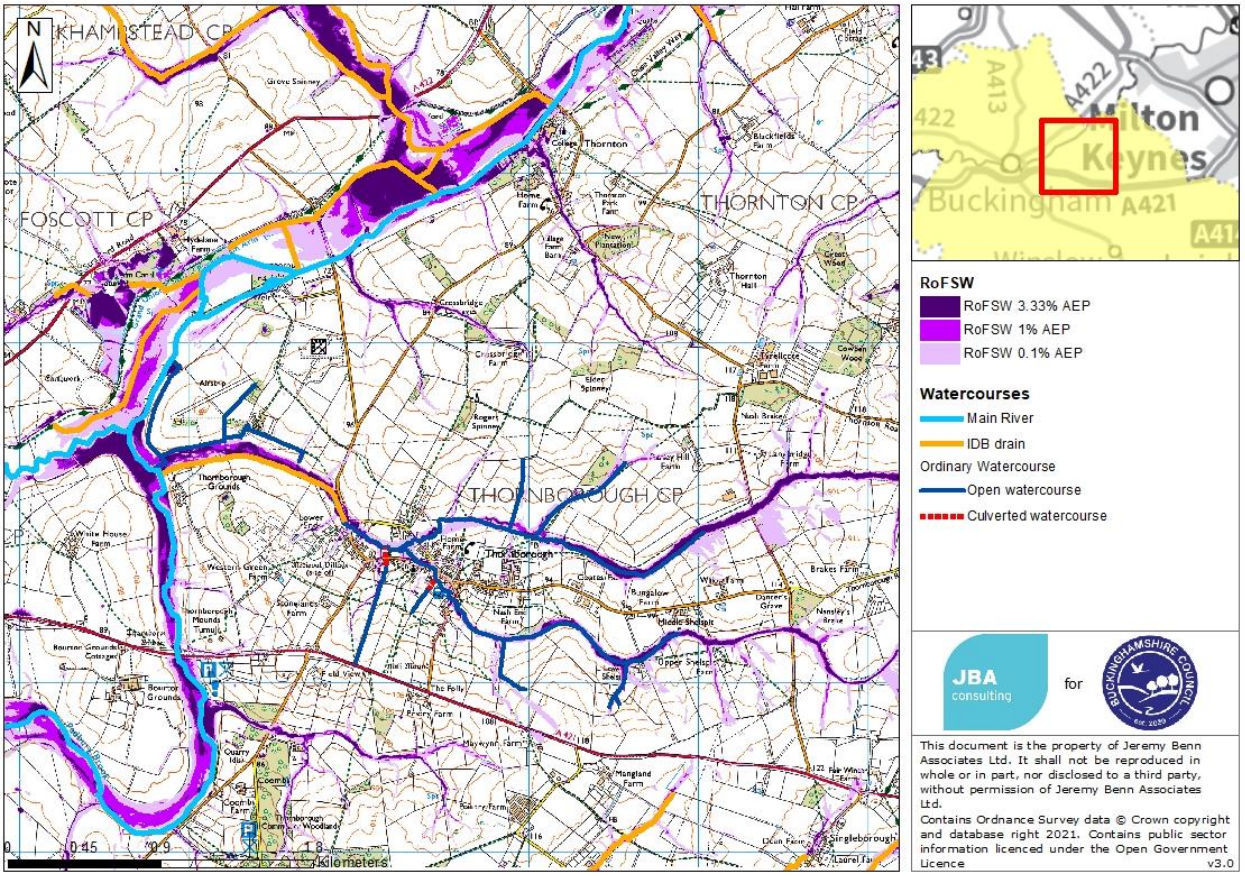


Figure 4-2: Risk of flooding from surface water in Thornborough village, with ordinary watercourses shown in red for clarity (a) and in the local area at a broader scale, with ordinary watercourses not shown for clarity (b).

4.1.3 Risk of flooding from groundwater

The JBA groundwater flood map for Thornborough is shown in Figure 4-3 below. The maps show indicative groundwater levels during a 1 in 100 annual chance three-month rainfall event, which is intended to represent a very wet winter.

Mapping shows that indicative groundwater levels are within 0.025m of the surface in large areas of the village, adjacent to the watercourses. This includes most of the area around the central village green, including the High Street, Back Street, Palmers Moor, Chapel Lane crossroads, and along The Green. Here, there is a high risk of groundwater reaching the surface following prolonged wet conditions.

Beyond the floodplain, groundwater levels are indicated to reach moderately high depths of between 0.5 to 5m below the ground surface. In the upper catchment, where the bedrock is sandstone and mudstone and the superficial geology Till, there is no risk of groundwater reaching the surface.

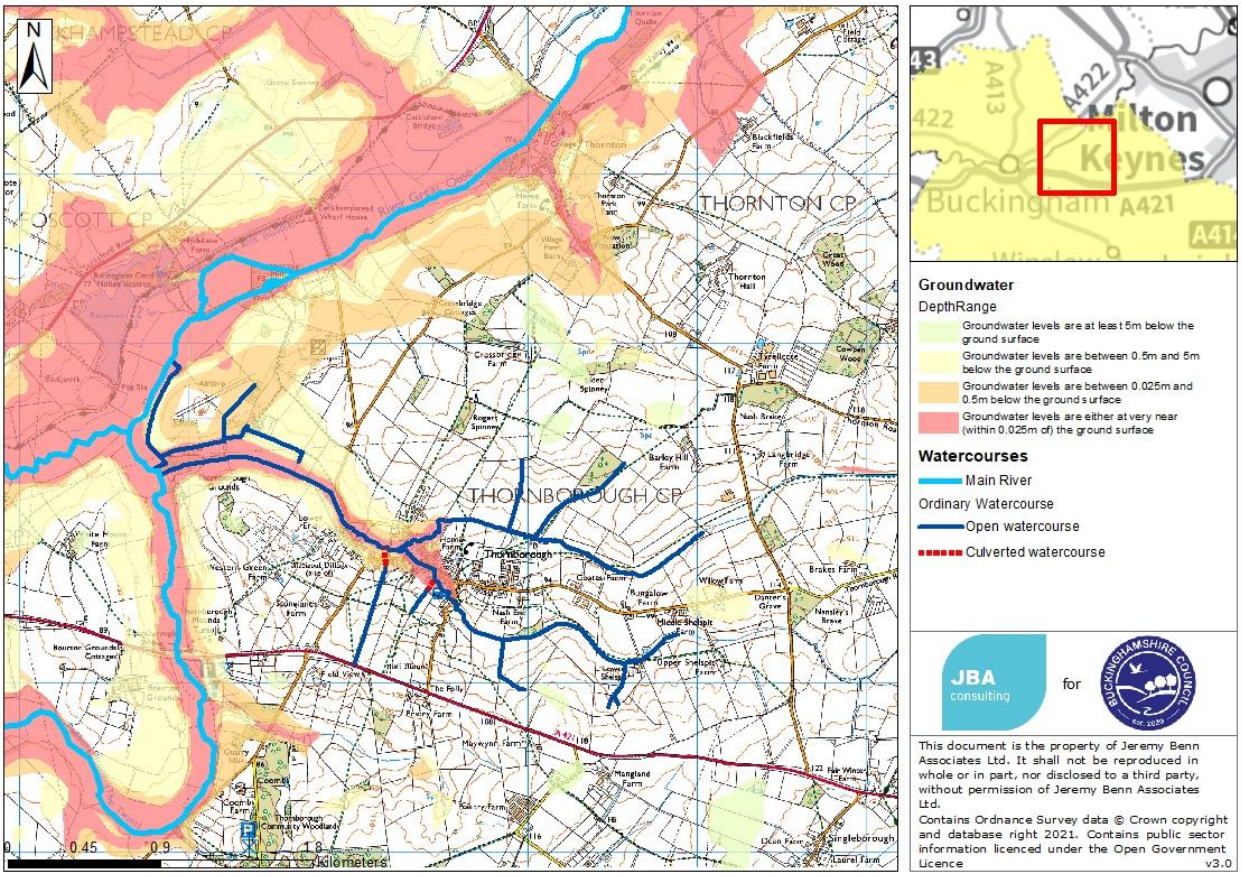


Figure 4-3: JBA groundwater map in Thornborough, showing the modelled levels of groundwater during a 'wet winter'

4.2 Flood history

Table 4-1 details the known flood history in Thornborough.

Table 4-1: Flood history

Date	Source of flooding	Description of impacts
September 1902	Ordinary watercourse/surface water (From JBA Chronology of flash floods)[6]	"[T]he whole village was flooded when the water came into the village so rapidly. Several houses were flooded to a depth of several inches"
September 1935	Ordinary watercourse/surface water, from a storm referred to as "The Great Northamptonshire hailstorm" (From JBA Chronology of flash floods)[6]	"… [H]ouses at Lower End near the brook have commonly been flooded but never have the whole of the houses in Bridge Street and those in the centre of the village been flooded causing much damage to carpets and furniture. The storm broke at 2 pm and the brook at Bridge Street burst its banks at 2.30 forcing down a brick wall and rising quickly to a height of 6 feet. Houses commonly flooded had taken precaution but those across the road were unprepared as the water swept over a 6 foot wall and entered houses to a depth of 1 foot. In one house a cat was carried away when the

6 https://www.jbatrust.org/how-we-help/publications-resources/rivers-and-coasts/uk-chronology-of-flash-floods-1/

		water rose to the sixth stair. A seventy year old resident said he had never seen such a flood. Other cottages on Buckingham road were flooded to 1 foot and a resident said he had not experienced such a flood in 48 years. In the centre of the village [several properties were flooded] (Editor's Note: individual property addresses redacted). Many homes were invaded at Lower End. The water entered 17 or 18 houses in all."
March 1947	Main river/Ordinary watercourse/surface water	Anecdotally, after the overtopping of the River Great Ouse, ordinary watercourses overtopped and floodwater on High Street and Back Street flooded the green to approximately 6ft in depth
April 1998	Ordinary watercourse/ surface water, main river	Road flooding was seen in Thornborough at the ford on Back Street, with water levels anecdotally reaching greater than 6ft in depth. Heavy rainfall during April 1998 led to the highest river levels seen in the River Great Ouse since 1947.
July 2000	Ordinary watercourse/surface water	This affected approximately 10 properties in the village[7]. Water level was noted as above 6ft marker at the ford.
2006	Ordinary watercourse/surface water	Two properties in the village reported having experienced flooding. Water levels were noted to be high at the ford.
July 2007	Ordinary watercourse/surface water, blocked drains, main river	Approximately 10 properties in the village flooded internally or externally.. River Great Ouse believed (but not proven) to have flooded Thornborough Mill area.

5 Flood risk management roles and responsibilities

Responsibility for flood risk can be divided into "flood risk management" and "emergency response". The following section describes the roles of the various bodies involved in flood management, with roles and responsibilities for emergency response described in Section 5.2.

5.1 Flood risk management roles and responsibilities

Flood risk in England is managed by a range of different Risk Management Authorities (RMAs) and other stakeholders. However, it should be noted that the responsibility for reducing the impacts of flooding to any property remains with the owner of that property, not with any risk management authority. Risk Management Authorities may have statutory powers to carry out works for flood risk management purposes, but are under no statutory duty to do so.

The Flood and Water Management Act places a duty on all flood risk management authorities to co-operate with each other. The act also provides Lead Local Flood Authorities and the Environment Agency with a power to request information required in connection with their flood risk management functions.

These roles and responsibilities are summarised in Table 5-1.

7 PFRA Preliminary Assessment Report Final (buckscc.gov.uk)

5.1.1 Lead Local Flood Authority (LLFA)

LLFAs are responsible for coordinating the management of risk of flooding from surface water, groundwater (water which is below the water table under the ground) and ordinary watercourses (non-main rivers). The LLFA is also responsible for developing, maintaining and applying a strategy for local flood risk management in their area and for maintaining a register of flood risk assets.

Buckinghamshire Council is the LLFA for the whole of Buckinghamshire, including Thornborough.

5.1.2 Environment Agency

The Environment Agency (EA) is sponsored by the Government's Department for Environment, Food & Rural Affairs (Defra), and is tasked with the protection and conservation of the water environment in England, the natural beauty of rivers and wetlands and the wildlife that lives there.

The EA is responsible for taking a strategic overview of the management of all sources of flooding and coastal erosion. The EA also has operational responsibility for managing the risk of flooding from main rivers (usually large streams and rivers), reservoirs, estuaries and the sea.

Flood risk management work can include: constructing and maintaining 'assets' (such as flood banks or pumping stations) and works to main rivers to manage water levels and make sure flood water can flow freely; operating flood risk management assets during a flood; channel maintenance; and issuing flood warnings.

The Environment Agency's other responsibilities include: water quality and resources; fisheries; conservation and ecology. The Environment Agency can also do work to prevent environmental damage to watercourses, or to restore conditions where damage has already been done.

Their strategies for flood and coastal erosion risk management show how communities, the public sector and other organisations can work together to manage this risk.

5.1.3 Internal Drainage Board (IDB)

Internal drainage boards (IDB) are independent public bodies, established in areas of special drainage need known as drainage districts. The IDB is responsible for the supervision of land drainage, water level management and flood risk management works and regulation of ordinary watercourses within their Drainage District. The IDB also plays an important role in the areas they cover (approximately 10% of England at present) in working in partnership with other authorities to actively manage and reduce the risk of flooding.

The Buckingham and Ouzel IDB boundary falls north of Lower End, at Lower End Bridge.

5.1.4 Water and Sewerage Company

Water and sewerage companies are responsible for the provision of wastewater collection and treatment systems, including for managing the risks of flooding from surface water and foul or combined public sewer systems providing drainage from buildings and yards.

Anglian Water is the water and sewerage company for Thornborough.

5.1.5 Highway Authority

The Highway Authority for Thornborough is Buckinghamshire Council, and the highways function is managed by Transport for Buckinghamshire. It is responsible for maintaining the highway drainage system to an acceptable standard and ensuring that road projects do not increase flood risk.

5.1.6 Riparian landowners

Riparian landowners who own land or property next to a river, stream or ditch, (including where this runs through a pipe or culvert), have rights and responsibilities over the

management of the land including: a responsibility to let water flow through the land without any obstruction, pollution or diversion which affects the rights of others; keeping banks clear of anything that could cause an obstruction and increase flood risk; maintaining the bed and banks of the watercourse; and keeping structures clear of debris. There is more information on these rights and responsibilities in the Environment Agency guide 'Owning a watercourse[8] and on Buckinghamshire Council's Guidance for Riparian Owners[9].

5.1.7 Local residents

Local residents should find out about any flood risk in the area, sign up for the Environment Agency's free flood warnings and make a written plan of how they will respond to a flood situation. Business owners should also make a flood plan for their business. There are measures that can be taken to reduce the amount of damage caused by flooding and properties at risk should be insured. Local residents can find out if their property is at risk, prepare for flooding, get help during a flood and get help after a flood.

5.2 Emergency roles and responsibilities

The emergency responsibilities of different organisations are outlined in Table 5-1 below. Please note that Parish and Town Councils do not have a legal obligation to respond to emergencies. Whatever service they provide is voluntary and unique to each Parish or Town Council.

Table 5-1: Roles and responsibilities in an emergency, during and after a flood event

Local Authorities (Buckinghamshire Council)
Coordinate emergency support within their own functions
Coordinate emergency support from the voluntary sector
Liaise with central and regional government departments
Liaise with essential service providers
Open rest centres
Manage the local transport and traffic networks
Mobilise trained emergency social workers
Provide emergency assistance
Deal with environmental health issues, such as contamination and pollution
Coordinate the recovery process
Manage public health issues
Provide advice and management of public health
Provide support and advice to individuals
Assist with business continuity

Police Force	Utility Providers
Save life Coordination and communication between emergency services and organisations providing support Coordinate the preparation and dissemination	Attend emergencies relating to their services putting life at risk Assess and manage risk of service failure Assist with recovery process, that is, water utilities manage public health considerations

8 Owning a watercourse (https://www.gov.uk/guidance/owning-a-watercourse)

9 Guidance for Riparian Owners, Buckinghamshire Council (https://www.buckscc.gov.uk/services/environment/flooding/apply-for-land-drainage-consent/maintenance-for-rivers-and-ditches/)

Fire and Rescue Service	Internal Drainage Board
Save life rescuing people and animals Carry out other specialist work, including flood rescue services Where appropriate, assist people where the use of fire service personnel and equipment is relevant	Operate strategic assets to reduce flood risk in partnership with RMAs and public

Ambulance Service	Town and Parish Councils
Save life Provide treatment, stabilisation and care at the scene	Support emergency responders Increase community resilience through support of community emergency plan development

Voluntary Services
Support rest centres
Provide practical and emotional support to those affected
Support transport and communication
Provide administration
Provide telephone helpline support

Environment Agency
Issue Flood Warnings and ensure systems display current flooding information
Provide information to the public on what they can do before, during and after a flood event
Monitor river levels and flows
Work with professional partners and stakeholders and respond to requests for flooding information and updates
Receive and record details of flooding and related information
Operate water level control structures within its jurisdiction and in line with permissive powers
Flood event data collection
Arrange and take part in flood event exercises
Respond to pollution incidents and advise on disposal
Assist with the recovery process, for example, by advising on the disposal of silt, attending flood surgeries

5.2.1 Local Resilience Forum (LRF)

Local resilience forums (LRFs) are multi-agency partnerships made up of representatives from local public services, including the emergency services, local authorities, the NHS, the Environment Agency and others. These agencies are known as Category 1 Responders, as defined by the Civil Contingencies Act.

LRFs are supported by organisations, known as Category 2 responders, such as the Highways Agency and public utility companies. They have a responsibility to co-operate with Category 1 organisations and to share relevant information with the LRF. The geographical area the forums cover is based on police areas.

The Local Resilience Forum is not a legal entity, nor does a Forum have powers to direct its members. Nevertheless, the Civil Contingencies and the Regulations provide that emergency responders, through the Forum, have a collective responsibility to plan, prepare and communicate for emergencies in a multi-agency environment.

The Local Resilience Forum for Thornborough is the Thames Valley Local Resilience Forum (TVLRF), but the Great Ouse catchment is covered by a further six Local Resilience Forums.

TVLRF has Emergency Response Arrangements which provide the response framework for a multi-agency response. The current arrangements for TVLRF require a Partner Activated Teleconference (PAT) to be convened by any TVLRF agency or organisation who feels that this is necessary, or an event meets the trigger criteria. A PAT is not Command and Control but could identify the need for the implementation of Command and Control structures. The purpose of a PAT is information sharing and situational awareness.

The TVLRF Multi-Agency Flood Plan (MAFP) provides the framework for the multi-agency response to a flooding incident in the TVLRF area.

5.3 Existing flood risk management activities

5.3.1 Flood warning information service

The Environment Agency's Flood Warning Information Service has a flood warning area covering areas at risk from the River Great Ouse and Padbury Brook to the north and west of Thornborough. Its coverage is shown in Figure 5-1. The flood warning area only relates to flood risk from the River Great Ouse and Padbury Brook, and does not cover the ordinary watercourses through the village. Lead Local Flood Authorities do not have the responsibility, funding or infrastructure to issue flood warnings for ordinary watercourses.

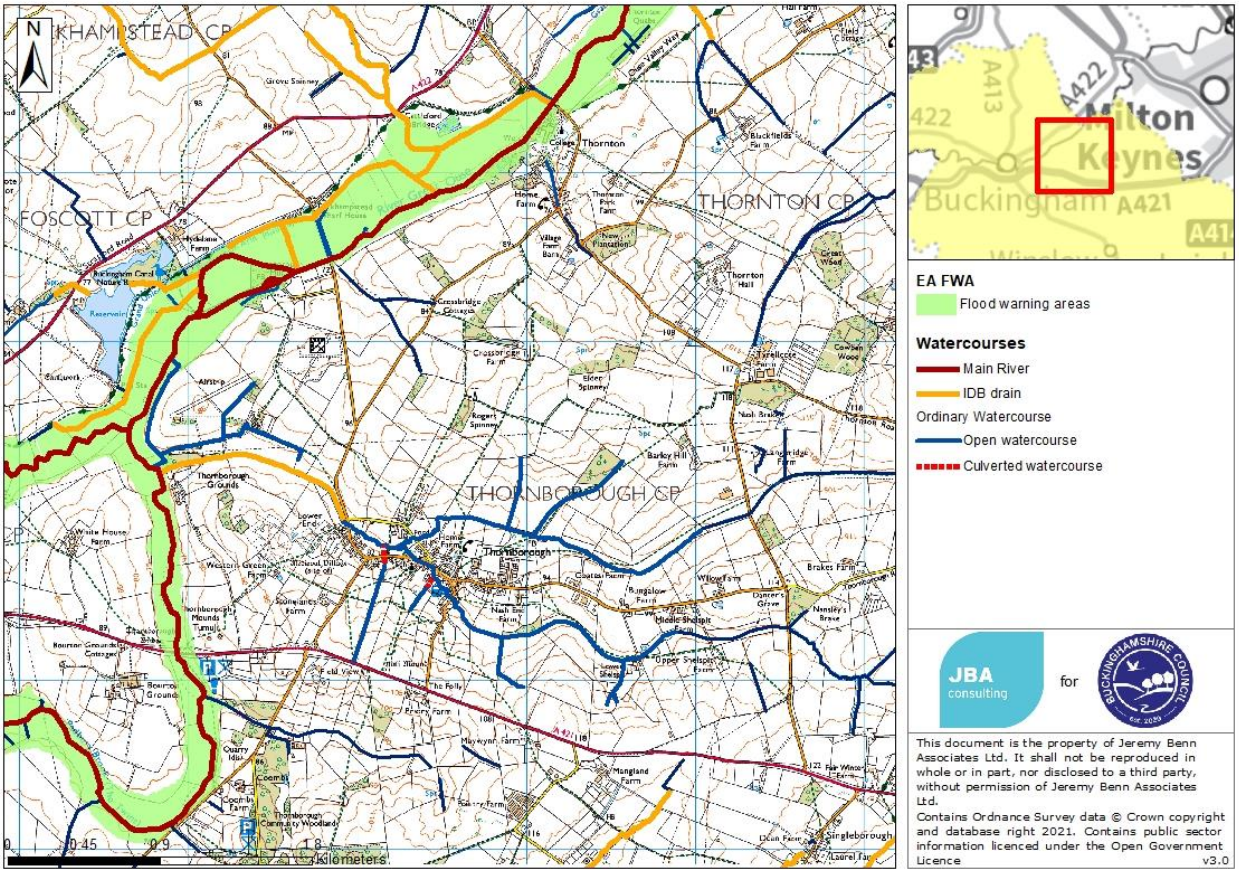


Figure 5-1: Environment Agency warning areas in relation to the village

5.3.2 Maintenance

Flood risk is currently managed locally by residents and riparian owners, by way of maintaining ditches, watercourses and drains. The Buckingham and Ouzel IDB maintains Cowerde Brook downstream of the village, below the bridge on Lower End. Here, a section of the watercourse flows to a pumping station alongside Lower Road.

Figure 5-2: The section of IDB maintained watercourse. The watercourse flows within the ditch to the left, whilst Lower Road is behind the hedge to the right

Figure 5-3: The watercourse between Lower End and Hatchet Leys Bridges, just upstream of the location of Figure 5-2 above

The Highways Authority also regularly maintains watercourses in the village. Fly tipping in the highway ditch on Lower Road, beside the IDB maintained watercourse, is reportedly an issue, as debris has the potential to enter the watercourse. Clearance of ditches draining the highway is the responsibility of the Highways Authority, though residents note that maintenance cannot keep pace with the regularity of the fly tipping. It is understood that the location at which the watercourse passes below Lower End bridge is also the responsibility of the Highways Authority. Transport for Buckinghamshire visited Thornborough following the event, and is reported to have cleared all gullies and culverts in the adopted highway.

Following the flood event in December 2020, the IDB cleared a section of watercourse upstream of the bridge on Lower End to create more capacity, removed a concrete in-

channel weir on the upstream face of Hatchet Leys Bridge and cleared the stream between bridges.

The watercourses around The Green and the pond in the centre of the village are also cleared up to every four years by the Parish Council. However, it is understood that there may be insufficient funding to continue this frequency of maintenance in future years.

Residents and riparian owners also complete watercourse maintenance. On Back Lane landowners have cleared part of the roadside ditch alongside their property, and there are a number of landowner-maintained drainage channels from surrounding fields. At the time of the site visit in September 2021, a resident had also cleared a section of the watercourse alongside the High Street.

Also following the flood event of December 2020, landowners at the Thornborough Mill area worked together to reinstate the ditch alongside the solar farm to channel land drainage.

Figure 5-4: The watercourse at the 'second' bridge in the village on the High Street, which is maintained by riparian owners, February 2021. Credit: Buckinghamshire Council

5.3.3 Property Flood Resilience

During the December 2020 flood event, some residents reportedly deployed property flood resilience measures, such as flood barriers, to limit the ingress of water into their properties.

Several properties located within surface water flow paths flow into the south of the village have made alterations to make their properties more resilient, including landscape changes to their gardens to divert floodwater around the property into Cowerde Brook, sluice gates in garden walls and openings in garage doors to allow flood water to pass through, as well as land raising around properties.

5.3.4 Flood alleviation schemes

There are currently no formal flood risk management schemes in the area.

6 Hydrological analysis of the 23-24 December 2020 event

6.1 Conditions at the time

At the beginning of the autumn in September, rainfall and catchment soil dryness were about normal for the time of year. However, Storm Alex at the beginning of October brought a significant amount of rain, and total rainfall for the month was about three times greater than the monthly average. This also led to a decrease in soil moisture deficit (an indication of soil dryness) to below normal levels, indicating that the soil was already wetter than normal for the time of year. Though November was slightly drier than average, a month's worth of rain fell in the period of December up until the event on the 23 December. This led to notably low soil moisture deficit (within the 0-10mm band), indicating that the catchment had minimal capacity to hold additional rainfall by the time of the storm event on 23 December.

6.2 The event

The Thornborough Mill river level gauge on the Great Ouse shows that river levels were already raised following a number of events in November and December. River levels had initially risen on 22 December, following rainfall on 21 December, and were starting to drop when the storm event of the 23 December occurred.

The graph below shows the rainfall that occurred during the event of the 23 December and the response in river levels at the Thornborough Mill gauge. Catchment average rainfall based on raingauge (Foxcote and Brackley) and Met Office HYRAD radar data are shown. Rainfall data from this raingauge was used due to its proximity to Thornborough.

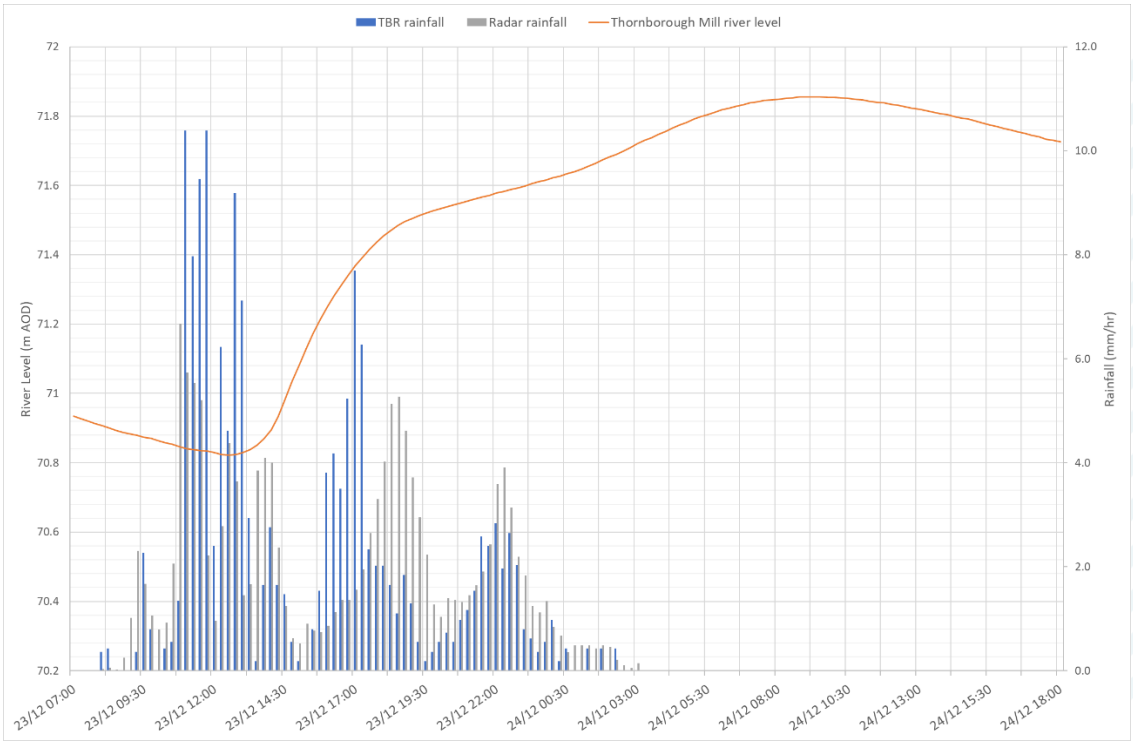


Figure 6-1: Radar and raingauge data for the Thornborough area and river levels at Thornborough Mill during the time of the event

Though there are differences in the patterns of rainfall between raingauge and HYRAD data sources, the overall trend is the same. Rainfall started slowly at about 07:30 on the 23 December becoming more intense at 09:30. The main body of the storm event happened in three waves. The first wave of rainfall occurred between about 09:00 and 15:00, with the main peak at around 12.30. The second wave occurred between 15:30 and 20:00, with the

peak at 17:45. The third wave occurred between 20:00 and 02.00 of 24 December, with the peak at 22:30 on 23 December.

The rainfall event ended at about 02:00 on 24 December with an approximate total of 37mm falling over the Thornborough Mill catchment, as recorded by radar over the preceding 18 hours, and 39mm, as recorded by the raingauges (weighted average), over the same period.

Rainfall for the Thornborough village catchment shows similar totals of 34mm, as recorded by radar, and 28mm by the Foxcote raingauge. As the Thornborough village catchment lies wholly to the east of the Foxcote raingauge this raingauge is the only one used to determine rainfall in the catchment, and is used over other raingauges due to its proximity to Thornborough. This raingauge is known to under-record so the total based solely from this gauge is lower than the other estimates. Analysis is based upon the verified Foxcote rainagauge data however residents in Thornborough measured up to 55mm using their own raingauges over this period. Rainfall up to 45mm was recorded by residents in October 2020 without causing any flooding, however the soil moisture deficit was higher than in December 2020 due to prolonged proceeding rainfall. In December 2020, the Thornborough catchment was saturated therefore the likelihood of flooding was much higher.

The radar data shows that for the majority of the event the storm passed in a northerly direction across the catchment. After about 17:00, as the weather system turned, the storm passed in a southerly direction.

Figure 6-2 shows the observed radar rainfall for the Thornborough Mill catchment (larger black boundary line). The Thornborough village catchment lies within the Thornborough Mill catchment (approximate location shown in Figure 6-2 below). Colours show rainfall rate at the time shown.

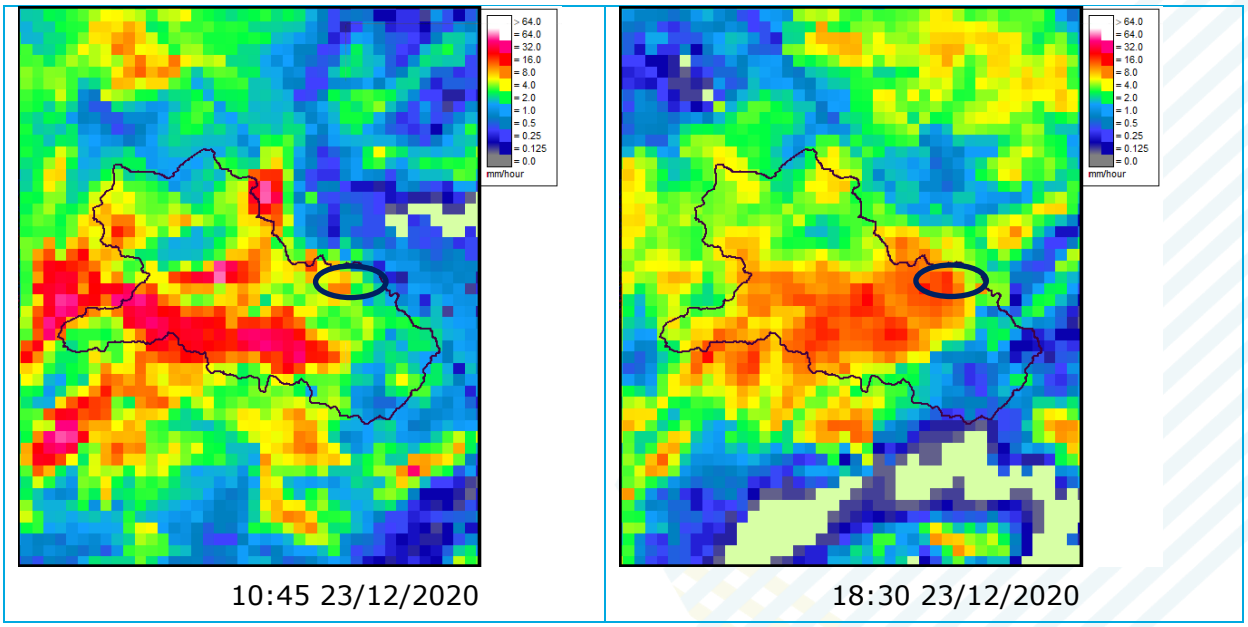


Figure 6-2: Radar rainfall for the Thornborough Mill catchment (larger black boundary). Thornborough village catchment is also shown (small black oval boundary)

Table 6-1: Rainfall totals in the Thornborough area on 23 December 2020

Rain gauge	Distance from Thornborough Village catchment	Distance from Thornborough Mill catchment	18-hour total on 23 December	Grid reference
Foxcote raingauge	5.5km	5.8km	28mm	471278, 235758
Brackley raingauge	16.3km	7.8km	52mm	460115, 236084
Thornborough village (Foxcote raingauge)	-	-	28mm	476256, 233503 (catchment centroid)
Thornborough village catchment average (radar)	-	-	34mm	
Thornborough Mill catchment average (raingauge)	-	-	39mm	467159, 231972 (catchment centroid)
Thornborough Mill catchment average (radar)	-	-	37mm	467159, 231972 (catchment centroid)

6.3 Rainfall return period estimation

The total rainfall during the 23 December storm event had a 50% chance of occurring in any one year (return period of 2 years) for the Thornborough village catchment and a 20% chance (return period of 5 years) for the Thornborough Mill catchment. This is not especially extreme but given that the soils were already completely saturated from the notably high rainfall over preceding months, the catchments were very sensitive to heavy rainfall.

6.4 Flow return period estimation

The estimation of flow return period for Thornborough village and Thornborough Mill is very uncertain. There are no flow gauges on the any of the ordinary watercourses flowing through Thornborough village, and the data from the main river flow gauge at Thornborough Mill since 1979 has been unreliable because the flow calculations do not account for the automatic sluice opening and downstream levels[10].

Based on the information available, which includes historic flood information, subjective observations made at the time of the event, historic flow data and limited river level data at Thornborough Mill, an approximate return period of 5-20 years is estimated for Thornborough village and 10-30 years for Thornborough Mill. This corresponds to a peak flow estimate of 4.3 to 6.0m^3/s at Thornborough village (Cowerde Brook) and 29.0-32.2m^3/s at Thornborough Mill (Great Ouse).

10 NRFA Station Peak Flow Data for 33005 - Bedford Ouse at Thornborough Mill (ceh.ac.uk)

7 Incident response

Several authorities, including Thames Valley Police, Buckinghamshire Council, the Environment Agency and the Ouzel IDB responded to the flooding in Thornborough.

Flooding first began in Thornborough village at approximately 15:00 on 23 December 2020, and in the Thornborough Mill area later in the evening of the same day. There are no records of alerts or warnings until the evening after the floodwaters in the village had started to recede, when the Environment Agency issued a warning for flooding on the Great Ouse. This was not specifically directed at the village but referred to the road around Thornborough. The alert was issued at 18:35 and disseminated via Twitter by Buckinghamshire Council at 20:58[11].

A timeline of the incident response is given in Table 7-1.

7.1 Transport for Buckinghamshire

Transport for Buckinghamshire managed a large number of road closures across Buckinghamshire during the event, including High Street in Thornborough.

7.2 Buckinghamshire Fire and Rescue Service

Buckinghamshire Fire and Rescue Service (BFRS) dealt with a high volume of calls during the afternoon and evening of 23 December, dealing with multiple flood incidents in villages around Buckingham and Milton Keynes. Flooding of the roads made the response difficult, with a number of communities cut off. Main roads, including the A422 and A421 were impassable in places. BFRS stood up their Operational Support Room which remained in place until 23:30.

As the event progressed, attendance was prioritised to focus incidents with a risk to life. There were a number of occasions throughout the period when BFRS were unable to pump water out from properties, simply because the water table was too high and there was nowhere to pump it to.

BFRS itself attended 161 incidents during this period across the area, most of which were flood related, with a number of these flooding incidents involving multiple rescues and multiple properties. In Thornborough, one appliance and crew from Buckingham, one from Aylesbury and an officer attended Hatchell Leys Lane where 13 vehicles were stuck in flood water. One person was led to safety and the road was closed.

Table 7-1: Timeline of incident response

Date	Time	Activity/event	Agency
23/12/2020	15:00	Residents report potential for flooding to the Environment Agency	Residents
23/12/2020	16:00	Internal flooding first observed on Bridge Street, coming up through floor boards of a property.	n/a
23/12/2020	16:00	Lower End Bridge and Hatchet Leys bridge becoming impassable due to flood water	n/a
23/12/2020	17:13	Fire and Rescue called to attend 13 vehicles stuck in flood water at Hatchet Leys Lane	Fire and Rescue service
23/12/220	17:30	Fire and Rescue shut Hatchet Leys Lane for safety reasons	Fire and Rescue service

11 https://twitter.com/BucksCouncil/status/1341850566922817539

Date	Time	Activity/event	Agency
23/12/2020	18:00	Residents on Lower End and High Street deploy resilience measures and sandbags	Residents
23/12/2020	18:35	Environment Agency issue flood warning for Great Ouse at Thornborough Mill	Environment Agency
23/12/2020	20:00	Road outside village hall (Church Lane) flooded	n/a
23/12/2020	20:00	Flood water at Lower End bridge reached approximately 400mm in depth – road impassable	n/a
23/12/2020	Late evening	Thornborough Mill area starts to flood from surface runoff	n/a
23/12/2020	Late evening	Residents at Thornborough Mill deploy resilience measures and sandbags	Residents
23/12/2020	23:00	Flood water receded in village	n/a
24/12/2020	03:30	Thornborough Mill area starts to flood from main river	n/a
24/12/2020	Late evening	Flood water receded at Mill	n/a

8 Source-pathway-receptor analysis

We analysed all of the information available to determine the main sources of the flood water, the pathways it took and the main receptors. These are described below and summarised for the main village in Figure 8-1, and for the Thornborough Mill area in Figure 8-4.

8.1 Source

8.1.1 Extreme rainfall

Extreme rainfall falling on the village and surrounding area caused a large amount of water to fall on to an already saturated catchment. A total of 34mm of rainfall was observed to fall over 18 hours over the catchment, having a return period of 2 years, and a 50% change of occurring in any of year (see Section 6). This contributed to the overland flow paths described in section 8.2.

8.1.2 Ordinary watercourses

The ordinary watercourses were overtopped in at least seven locations in the village during the event, as shown in Figure 8-1. Overtopping occurred on the unnamed watercourse at the Old Manor (10), Cowerde Brook at Hatchet Leys Lane bridge (5, 6), Thorn Brook at Back Street Ford (11), Tonne Brook at the pond next to the Village Hall (2, 13), Bridge Street (15) and the footbridge upstream of the Maltings (14).

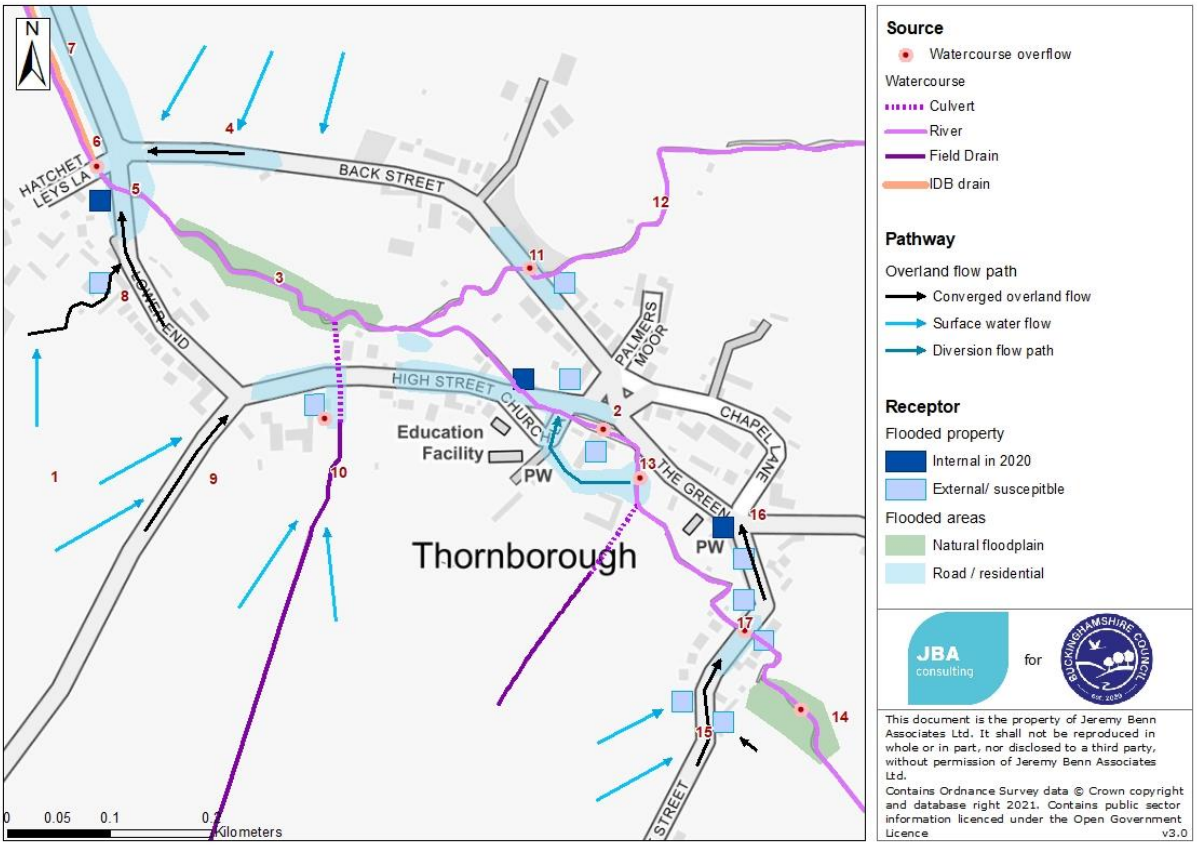


Figure 8-1: Map of sources, pathways and receptors in Thornborough village

Cowerde Brook

At Hatchet Leys Lane (6) Cowerde Brook overtopped the bridge and spilled into the road, submerging areas of Back Street and Lower End. This flooding began at around 16:00 and is shown in the photo in Figure 8-2.

Figure 8-2: Photo of flooding at Lower End Bridge and Hatchet Leys Bridge (Locations 6 and 7), taken at approximately 16:00 on 23 December 2020 from the left bank of the watercourse. Credit: Thornborough residents

Thorn Brook

The ford and footpath on Back Street (11) were flooded from the Thorn Brook and floodwater pooled on the road. The water reportedly reached up to the second railing on the footpath, which corresponds with 5ft 2inches on the flood board.

Tonne Brook

Water exceeded the banks of Tonne Brook near the pond in the village. At Location 13, just upstream of the pond, the brook overtopped on the left bank, before flowing through the grounds of Thornborough Manor. Water also spilled over the banks of the pond to flood the road at Location 2. Overtopping of Tonne Brook also occurred on Bridge Street (17), where water reached the first white railing of the bridge, and in the fields behind the Maltings (14) where a culvert on the access track became blocked with debris.

Near the Old Manor (10) the culvert that runs under High Street surcharged due to the volume of water passing through. Water backed up and flowed out on to High Street, where it combined with surface water exacerbated by blocked drains.

Figure 8-3: Tonne Brook beginning to overtop at High Street, taken from Location 2 and looking downstream. Credit: Thornborough residents.

8.1.3 Main river

There were high river levels on the River Great Ouse during the event, including at Thornborough Mill (Figure 8-4), where the south bank was overtopped.

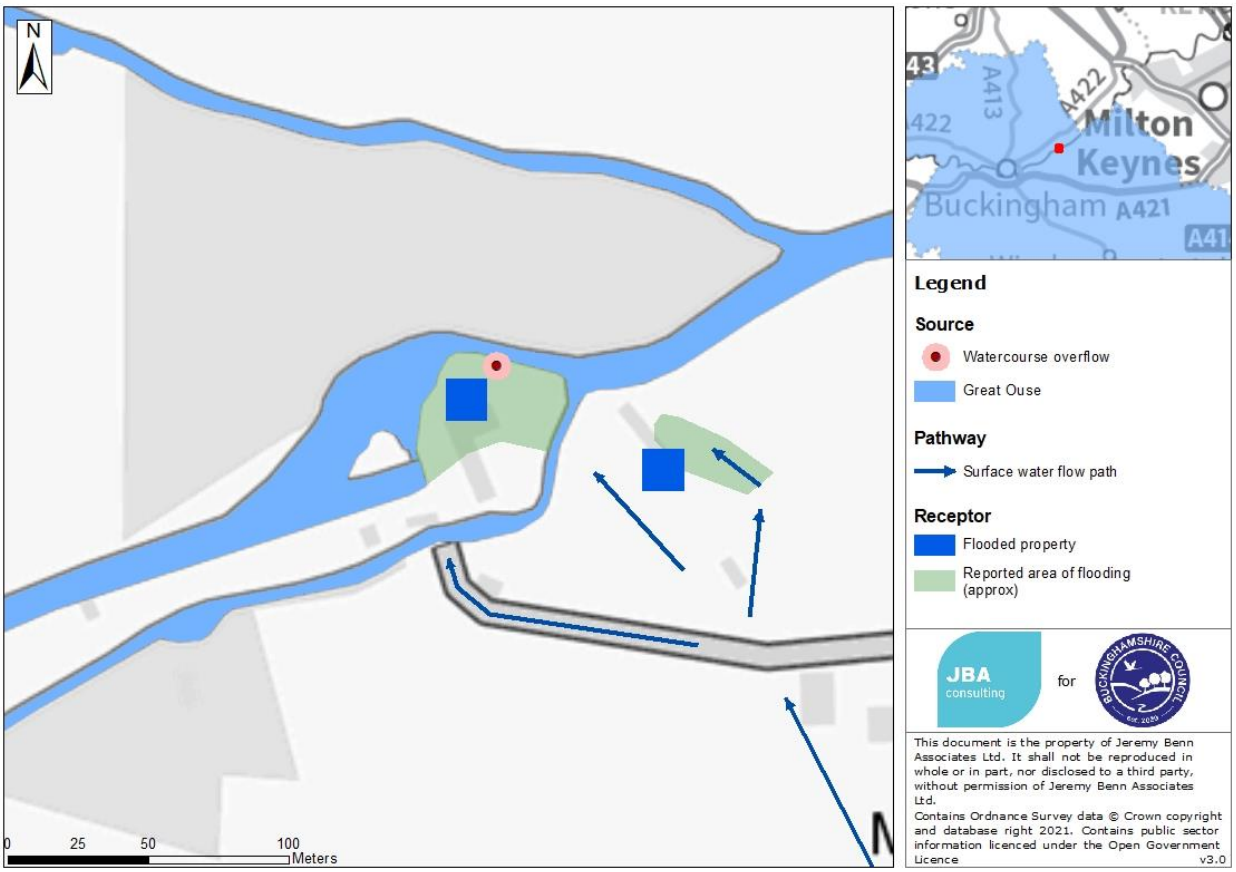


Figure 8-4: Map of sources, pathways and receptors in the Thornborough Mill area

8.1.4 Groundwater

Water was seen emerging from a spring behind the Maltings on Bridge Lane at Location 14, and from the ground on the High Street at Location 9 where residents noted that there used to be a spring.

8.1.5 Sewer and drainage networks

In the village, near Location 2, residents noted that a manhole cover near their property lifted up with flood water, although it was not confirmed whether the source of flooding was groundwater flooding or exceedance of the sewer network. Water backing up from sewers into toilets was noted by residents as an issue on Bridge Street, near Location 17.

8.2 Pathway

8.2.1 Overland surface water flow (from fields)

Extreme rainfall on already saturated fields led to overland surface water flows developing on the fields surrounding the village at Locations 1, 4, 10 and 15 (see Figure 8-1). In particular, flows from the area surrounding Stonelands Farm was noted for contributing significant amounts of water towards the rear of properties on Lower End and High Street (1). Along Back Street (4) water was also observed flowing off the fields and on to the road, exacerbated by an overflowing drainage ditch along a hedge line on the highway verge. Water was also observed 'pouring' off fields and flowing on to the road at Bridge Street (15).

At Thornborough Mill, surface water was also observed flowing off the fields to the south, as indicated in Figure 8-4.

Figure 8-5: Overland flow from fields accumulating on Back Street. Credit: Thornborough residents.

8.2.2 Overland converged flow

Concentrated overland flows were also reported around the village which, unlike the disperse surface water flows from fields, were defined channels of water. Again, these are indicated in Figure 8-1. These converged flows originated from a combination of overflows from the watercourses, heavy rainfall and surface water runoff, as well as groundwater sources (as discussed in Section 8.1).

At Back Street (4) a channel developed from convergence of the surface water flow from the fields to the north. This was seen flowing along the street towards Lower End, as shown on Figure 8-5.

At College Farm (8), a flow path developed from surface water converging from the farmland to the south and being unable to be conveyed by the capacity of the existing ditches. The flow path ran through the property and on to the road at Lower End, where it then flowed northwards towards Hatchet Leys Lane. A channel also developed on High Street, flowing northwards from the spring at Location 9, and directing floodwater towards the village.

A number of overland flows also converged on Bridge Street from the surrounding fields and the reaches of the Tonne Brook behind The Maltings (14, 15). Floodwater running down Bridge Street encroached on the front of one property. On the other side of the bridge a combination of flows, reportedly 30cm deep, flowed down the road into the village (16).

In places these flows also combined with overflows from the watercourses, to exacerbate the flooding. This was particularly the case at Lower End, High Street near location 10 and on Bridge Street, where already significant surface flows and overtopping flow from watercourses met.

8.3 Receptor

8.3.1 People

Residents reported substantial emotional distress resulting from the flooding, including being 'terrified' of flood water entering their property and the associated detrimental mental health impacts. This was worsened by concerns around insurance costs and the potential for future events.

During the event, at least 13 cars became stranded and flooded at the junction of Back Street and Lower End. This was a particularly hazardous situation and required the Fire Brigade to attend to rescue trapped cars.

Following this, another potentially hazardous situation developed in the main village, when residents leaving the village hall following a meeting were met with significant flooding of the High Street and had to wade to their cars. The flooding here started between 19:00 and 20:00 and lasted for approximately five hours, causing significant disruption.

8.3.2 Property

A total of five properties were flooded internally during the event.

Three of these properties were in Thornborough village, as shown on the map in Figure 8-1.

The property at Hatchet Leys Lane (5) flooded from the overflow of Cowerde Brook at Hatchet Leys Bridge, flooding one room inside to approximately 10cm in depth. The fast flowing waters also breached the area of raised land outside the front door, though was held back from causing further flooding by the deployment of a sump pump and other measures. The flooding here was also exacerbated by a convergence of overland flows from Back Street and High Street.

At the property on the High Street near the village hall (2) muddy water entered the house through the floor, the immediate source of which was reported to be a nearby surcharged manhole. Flood waters reached approximately 15-20cm in depth within two rooms in the property.

The Two Brewers pub (16) flooded from a combination of surface runoff flowing off the road and entering the front doors, reportedly due to a blocked or exceeded capacity highway gully, and groundwater ingress through cellar floors. The property has flooded in the past but this event was reportedly the most severe event experienced at the property in the last 40 years. In the cellar, floodwater reached approximately 1m in depth, though the exact depth reached on the ground floor of the property is not known. The existing sump pump in the cellar was overwhelmed during the event and a commercial pump was instead sourced

to manage the rising water levels. This cleared the water temporarily but needed to be emptied regularly, approximately every 30 minutes.

In the Thornborough Mill area (Figure 8-4), two properties reported internal flooding, with flood depths reaching up to 14cm across the ground floor of one property. These properties have subsequently installed flood resilience measures, including raised floor levels.

A number of properties in Thornborough also experienced external flooding. Along Bridge Street six properties flooded externally, with floodwaters of up to 18cm in depth reaching the door thresholds of the properties. At several properties, floodwaters were prevented from entering the property by the installation of Property Flood Resilience measures, such as door barriers. The flooding on Bridge Street resulted from the culmination of field runoff, watercourse overflow and combined flow paths described in Section 8.2, and occurred between 16:00-and 23:00.

In the centre of the village on the High Street (Location 2), two other properties flooded externally, in addition to the internal flooding experienced by another nearby property (noted above). At one property the flood water reached the sill of front door, and at the other, floodwaters from Tonne Brook (13) flowed through the rear garden (denoted by the 'diversion flow path' in Figure 8-1). Residents noted that flooding in this garden is a regular occurrence, and there is a sluice fitted at the bottom of the gate to allow floodwater to pass downstream.

Figure 8-6: The inlet to Thornborough Pond at time of high flow. Credit: Thornborough residents

External flooding was also reported in at least two properties on Lower End and High Street from the field runoff that converges from fields to the south of the village at locations 8 and 10). Resilience measures such as landscaping have also been installed at these properties, to restrict floodwater from reaching the property.

8.3.3 Infrastructure

The flooding affected several roads in and around the village, notably along Lower End, where the Fire and Rescue Service were called to rescue cars stranded in the floodwater. Flooding also occurred along Back Street Ford, Bridge Street, the Green near the Two Brewers pub, and High Street near the village hall. When both Lower End and the Ford on Back Street are flooded, as was the case during this event, residents who live between these two points are cut off until the flood waters recede.

Several playing fields and footpaths located within the floodplain of the village were also flooded, though these did not present a significant hazard to residents.

9 Watercourse condition assessment

9.1 Methodology

On-site observations were used to objectively review the condition of the watercourses in Thornborough village, and the potential impact on the conveyance of flow. The Environment Agency 'T98' asset inspection criteria for watercourses[12], which is used in assessing the condition of fluvial and coastal risk management assets, was used to form the basis of the assessment criteria.

Further details of the approach taken are provided in Section 9.2.

9.2 On-site assessment method

The on-site condition assessment of the watercourses in Thornborough focussed on the following four key areas which impact channel conveyance, as identified in the T98 asset inspection criteria:

- Sediment – presence of siltation and gravel shoals.
- Vegetation – growth across channel, tree growth into watercourse margins, flexibility of vegetation.
- Erosion – collapse of channel edges, undermining/scour of banks.
- Flood flow routes – high ground restricting spread of floodwater, relief flow routes.

As in T98 asset inspections, the severity of conveyance issues on the watercourse was scored a below red-amber-green assessment criteria:

Red	Not acceptable	Remedial work needed
Yellow	Near threshold	Conveyance issue for further consideration
Green	Acceptable	No remedial work needed

A breakdown of the criteria used to assess condition on the watercourse on-site is shown in Table 9-1.

The inspection of the condition of the watercourse was carried out at four locations during a site visit on 23 September 2021. The locations correspond to the areas where the watercourses overtopped, at Lower End/ Hatchet Leys Lane, Bridge Street, Back Street and at the village pond/High Street. An assessment was also made of the IDB drain on Lower End – this was based on residents' photos and other information, as there is no public access to the watercourse.

12 Environment Agency (2014) Asset performance tools – asset inspection guidance. Report SC110008/R2. Available at: https://assets.publishing.service.gov.uk/media/6033bb218fa8f543272b4002/SC110008_R2_report.pdf

Table 9-1: Watercourse condition assessment criteria

Condition criteria	Conveyance scoring		
	Good	Moderate	Poor
Sediment: siltation	10%	10 – 50%	50 – 100%
Sediment: presence of gravel shoals	Minor	Moderate	Severe
Vegetation: growth across river channel	10%	10 – 50%	50 – 100%
Vegetation: Tree growth into margins of watercourse	Minor	Moderate	Severe
Vegetation: Flexibility of vegetation	Flexible	Moderate	Inflexible
Presence of fly-tipped material	Minor	Moderate	Severe
Erosion: collapse of channel edges	Minor	Moderate	Severe
Erosion: undermining / scour of banks	Minor	Moderate	Severe
Presence of relief flow routes	Yes	N/A	No
Presence of high ground/defences at the banks, which would restrict the spread of floodwater	Yes	N/A	No

9.3 Results

At the time of the visit in September, most of the watercourses contained a large amount of flexible, deciduous vegetation. However, all structures, including the bridges on Lower End, Hatchet Leys End, and the pond outlet at the High Street, were clear of vegetation and debris.

Denser and less flexible in-channel vegetation was noted within the Cowerde Brook at the sports fields off the High Street, as well as in the upper reaches of the Tonne Brook. However, these are both locations where the intention is to carry out less frequent maintenance to encourage slower in-channel flows, and storage on the floodplain to mitigate the risk of flooding to downstream properties.

The Cowerde Brook displayed moderate amounts of siltation between the bridges on Lower End and Hatchet Leys End, where low velocity flows were seen, but was otherwise in good condition. Where the Cowerde Brook becomes an IDB drain, downstream of Hatchet Leys End, it was mostly clear of vegetation at the time of the visit. However, residents note that its higher right bank restricts the spread of water onto the floodplain, and the watercourse is reportedly prone to becoming blocked by fly-tipped material.

One particular area for concern is the lack of relief flow routes for watercourses within the village, with properties often located close to the banks. For example, on Bridge Street, the Tonne Brook flows through a steep sided, concrete-lined channel, with the floodplain restricted by houses built on the banks. Its only possible relief flow route is via overtopping of the bridge on Bridge Street, once in-channel water levels back up sufficiently to reach the height of the bridge deck.

Although the Thorn Brook channel is constrained in a culvert and engineered channel with heavily vegetated banks at Back Street, there is a notable relief flow route in the form of the Ford. However, upstream of Back Street, the fields at the right bank of the watercourse are reported to have been raised in recent years, which encourages flow to leave the left bank of the watercourse, and flow towards properties on Back Street.

Figure 9-1: Cowerde Brook at Lower End Bridge

Figure 9-2: Tonne Brook on High Street (pond outlet), September 2021.

Figure 9-3: Tonne Brook on High Street, downstream of the pond, September 2021

Figure 9-4: Tonne Brook on Bridge Street, September 2021

Figure 9-5: Back Street Ford, September 2021

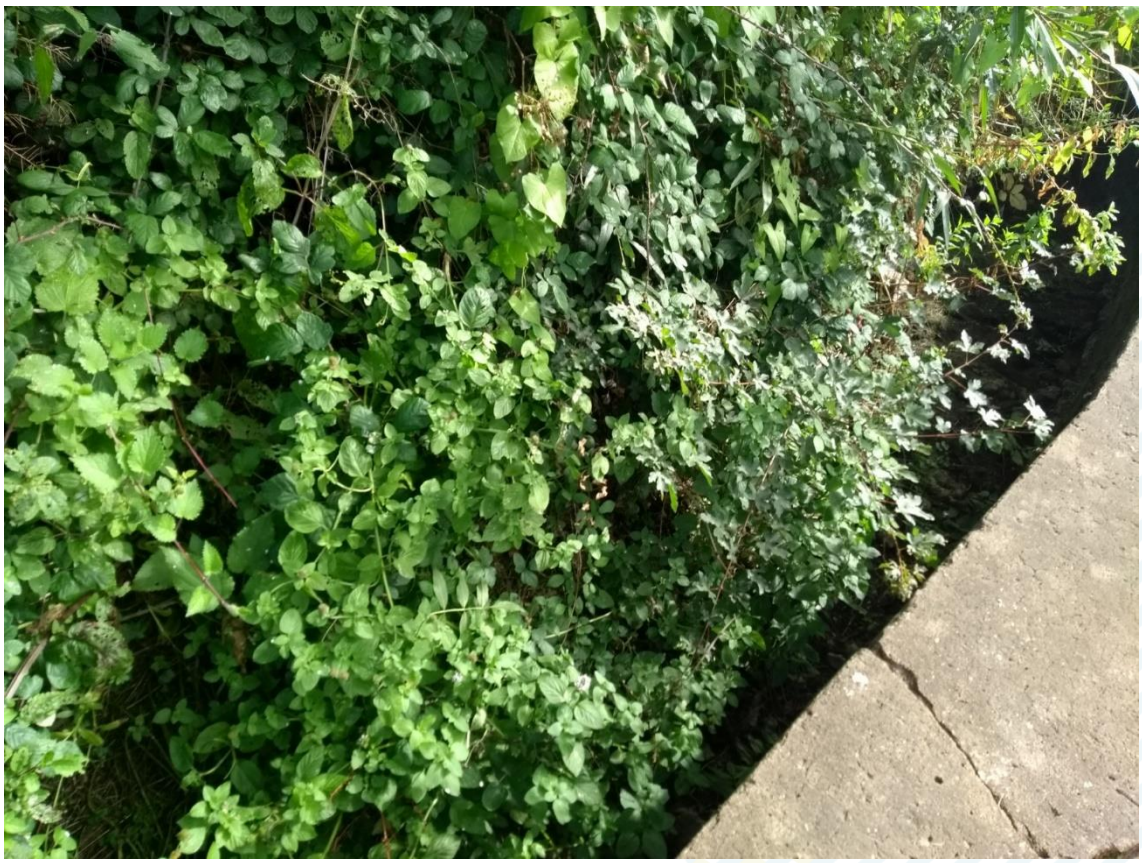


Figure 9-6: Back Street Ford, September 2021

Table 9-2: Results of channel condition assessment

On-site survey	Lower End - between bridges	Lower End - IDB Channel	High Street	Bridge Street	Back Street
1. Siltation	10%-50%	<10%	10%-50%	10%-50%	Minor
2. Presence of gravel shoals in channel	Minor	Minor	Minor	Minor	Minor
3. Vegetation growth across river channel	10%-50%	<10%	>50%	>50%	>50%
4. Presence of tree growth in and into margins of watercourse	Minor	Minor	Minor	Minor	Minor
5. Collapse of channel edges	Minor	Minor	Minor	Minor	Minor
6. Flexibility of vegetation on banks/channel	Moderate	Flexible/ NA	Flexible	Flexible	Flexible
7. Presence of fly-tipped material in the channel	Minor	Moderate (reported)	Minor	Minor	Minor
8. Undermining / scour of banks	Minor	Minor	Minor	Minor	Minor
9. If main channel is obstructed, is there another relief flow route?	No	No	No	No	Yes
4. Is there high ground/defences at the banks, which would restrict the spread of floodwater if river levels were raised by obstructions?	No	Yes	No	Yes	Yes

9.4 Conclusion

One of the most significant overflows occurred on the Cowerde Brook at Lower End, where a combination of vegetation, structures and condition of the watercourse downstream are likely to have reduced the capacity of the channel to convey the flow. For example, there was potential for fly-tipped material to have affected the IDB drain, causing water to back up immediately downstream of Hatchet Leys bridge.

It is possible that the flooding was exacerbated in places, such as on Bridge Street where the narrow, engineered channel leaves no relief flow routes, and on Back Street where there is vegetation in the narrow channel downstream of the Ford. Along High Street within the village the channel is more open, and it is less likely that the condition of the channel had an impact on flooding. Watercourse condition could not be assessed in some key places (for example downstream of Back Street Bridge) as the watercourse was not always publicly accessible.

The potential for enhanced watercourse measures in these locations are discussed in Sections 10.4 and 10.5.

9.5 The channel at Thornborough Mill

9.5.1 Channel and weir

The Great Ouse at Thornborough Mill is a Main River. The Environment Agency is the lead Risk Management Authority responsible for managing the risk of flooding from main rivers. However, the legal responsibility for maintenance of watercourses, including main rivers, lies with the riparian landowners (see Section 5.1.6 for further information).

The river overtopped its banks at Thornborough Mill during the December 2020 event. There is a large floodplain on the left bank of the river, though raised ground at the bank restricts the flow of water from the channel to the floodplain. This raised ground may have been built up by historical channel maintenance. There is also a weir immediately upstream of Thornborough Mill, as shown in Figure 9-7, which controls water levels in the Great Ouse.

At the time of the site visit in September 2021, the watercourse and weir were clear of visible vegetation and sediment. However, there is concern among residents that the weir is contributing towards increased siltation of the channel. Assessment of the impact of the weir on sedimentation of the Great Ouse is beyond the scope of this Section 19 investigation, although it is understood that the Environment Agency is carrying out an appraisal to inform future management of the Great Ouse weir at Thornborough Mill.

Figure 9-7: Weir on the Great Ouse at Thornborough Mill, September 2021

9.5.2 East-West Rail

During the site visit, residents raised concerns that the East-West Rail (EWR) scheme may be having an adverse effect on the flood risk, water quality and accumulation of sediment within the Great Ouse at Thornborough Mill.

Flood risk assessment and mitigation

The EWR scheme was permitted by the Secretary of State through a Transport Works Act Order (TWAO), and the works are being undertaken in accordance with this Act. Condition 13 of the TWAO requires the development to be undertaken in accordance with the EWR Flood Risk Assessment July 2018, with further information to be submitted to and approved in writing by the Local Planning Authority (LPA) in a phased manner to inform each development stage.

The majority of the EWR line is utilising an existing, disused rail line, but the scheme also includes earthworks such as the widening and strengthening of existing embankments. Drainage works are also proposed as part of the works including extensions of culverts and surface water management schemes. For these works the LPA consulted the Buckingham and River Ouzel Internal Drainage Board (IDB) for works which impacted upon watercourses in their district and the LLFA regarding surface water and fluvial flooding from non-IDB

ordinary watercourses. The National Planning Policy Framework (NPPF) (2021), associated guidance, and the consultee roles of the IDB and LLFA on flood risk and surface water drainage are intended to minimise the impact of new development on flood risk.

EWR have also been through the separate processes of Land Drainage Consenting from both the IDB (for works affecting watercourses within the IDB district), and from Buckinghamshire Council as the LLFA (for works affecting non-IDB ordinary watercourses).

In the Council's remit as LLFA, it seeks to ensure that the design of development complies with paragraph 167 of the NPPF (2021), which states that flood risk must not be increased off-site. In terms of surface water drainage, the LLFA were satisfied that the design of EWR's surface water drainage schemes met planning policy – i.e. the drainage design does restrict surface water release to downstream drainage systems or watercourses to the estimated greenfield (or pre-development) condition. With regard to fluvial flood risk associated with ordinary watercourses, where EWR proposed works that may have displaced flood water or otherwise increased flood risk, mitigation in the form of Compensatory Flood Storage Areas was proposed. Hydraulic modelling completed by EWR satisfactorily demonstrated that the engineering works within the jurisdiction of the LLFA would not result in any increase in flows or water levels outside of the EWR land take. The LLFA fully assessed the proposals and the supporting modelling within its remit through both the planning process and Land Drainage Consenting, and was satisfied that the proposals were acceptable.

In terms of verification that the EWR scheme is built as designed, the overall responsibility for ensuring that the flood mitigation and surface water drainage systems are built in accordance with the agreed plans lies with East West Rail themselves. National policy makes no provision for Councils or any other public body to have a specific function for any routine inspection and sign off of flood or drainage systems.

Vegetation removal

We understand that there was also some concern locally about the cumulative impact of the removal of vegetation by EWR on flood risk.

Trees and vegetation have the potential to impact the sources and pathways of runoff in a number of ways. Trees can reduce overall water yield by improving the infiltration rates of soils and by 'sponging up' water through the process of evapotranspiration. Woodlands can also act to slow down surface runoff by increasing the frictional resistance (or 'roughness') to this runoff. It is less clear how the well-understood effects of vegetation change on runoff at the field or plot scale translate to the generation of floods at the catchment scale. There is some evidence that catchment-wide felling, or planting, can have a measurable impact in small catchments (eg. <10 km²) on relatively small flood peaks (typically those more frequent than a 1 in 10 chance of occurring in any given year). Therefore, tree felling across significant extents of a catchment may exacerbate small flood events in small catchments (and vice versa, large-scale tree planting may reduce small flood peaks in small catchments).

The effect of tree cover on flood peaks becomes less important as the flood magnitude increases. The December 2020 event that flooded the Thornborough Mill area is large (estimated to equate to up to a 1 in 30 annual chance event). Also, the impacts of any hypothetical changes to vegetation cover on flood peaks diminish as the scale of the catchment increases, as other influences and contributions become increasingly important downstream and offset any effect from such land use changes.

Although detailed investigation of these concerns is beyond the scope of this study, a high-level check of the potential impact was carried out by comparing the extent of the East-West Rail development against the catchment area of the Great Ouse at Thornborough Mill. The closest rail works are located approximately 8km upstream of the Great Ouse at Thornborough Mill, in the Padbury Brook catchment. The closest highway works related to the East-West rail development are situated approximately 4km upstream of Thornborough Mill, where a tributary of Padbury Brook passes beneath London Road, 200m from the Great Ouse. These highway works relate to temporary access improvements for site traffic.

A map of the catchment and approximate East-West rail development site is shown in Figure **9-8**. Approximate calculations suggest that the extent of the development site comprises only 0.6% of the total catchment area of the Great Ouse at Thornborough Mill, with a development area of approximately 2.5km^2 compared to the catchment area of 388.5km^2. This figure was calculated by applying a precautionary buffer of 25m to the development route shown as detailed in planning applications in Figure **9-8**. As a result, any land use changes within the East-West rail development site would be expected to have a limited effect overall on flood risk on the Great Ouse: the December 2020 flood magnitude was too extreme, and the catchment upstream of Thornborough Mill is too large. Moreover, relevant scientific literature suggests that it is very difficult to detect changes to peak flows when the extent of woodland felling or planting is <15-20% of a catchment[13]. In this case, EWR's land take comprises a very small proportion (significantly less than 1%) of the overall catchment area.

It should be noted that in reality, rather than losing vegetation overall, the EWR Alliance have committed to providing mitigation for any vegetation loss and are delivering 10% Biodiversity Net Gain (BNG) across the project. Whether this mitigation offsets all changes in hydrological processes there may be at a local scale (such as small-scale changes to interception and runoff characteristics) in the short term or over the longer term, there would still be a very limited impact on peak flood levels on the Great Ouse, for the reasons above.

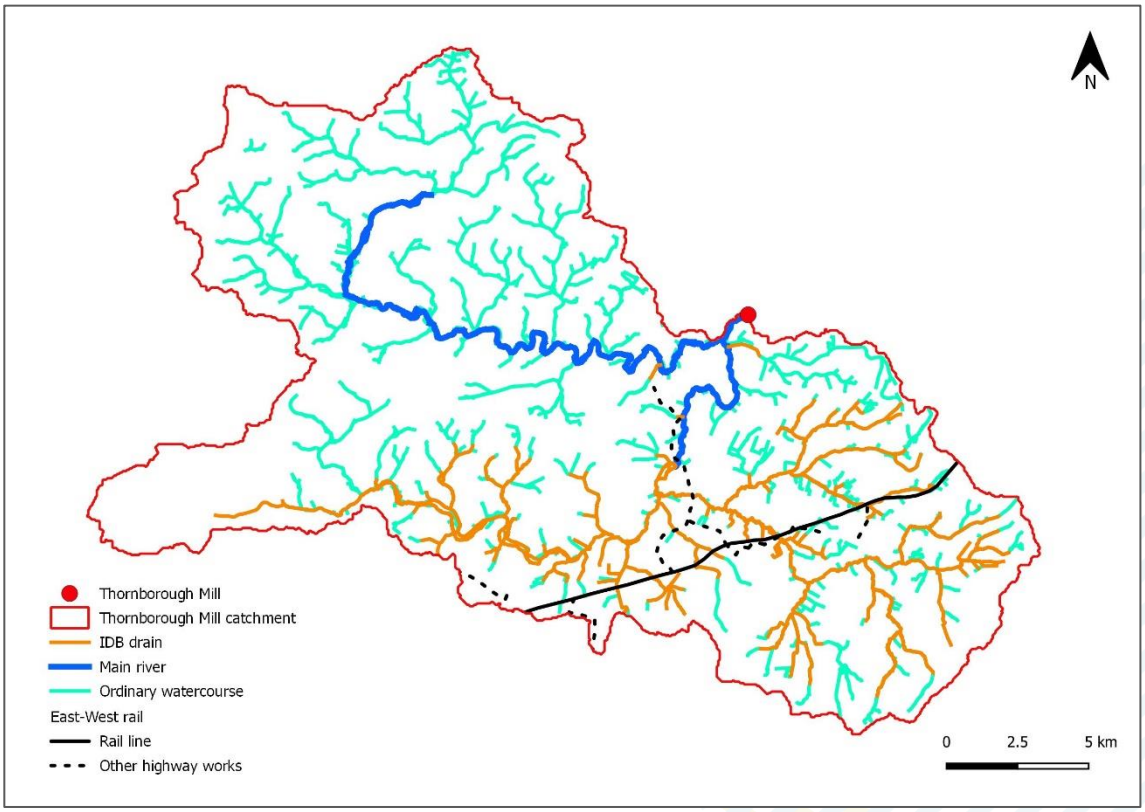


Figure 9-8: Great Ouse catchment boundary at Thornborough Mill and the approximate location of the East-West Rail development (Source: East West Rail planning documents reference TWA/18/APP/04)

13 Working with Natural Processes Directory https://assets.publishing.service.gov.uk/media/6036c5468fa8f5480a5386e9/Working_with_natural_processes_evidence_directory.pdf – p. 64

10 Discussion, appraisal and recommendations

10.1 Introduction

In this section, we consider potential options to mitigate flood risk and reduce damages caused by flooding in Thornborough.

This includes consideration of measures such as improvements to data collection and evidence; flood warning and incident management; community, property and infrastructure flood resilience; maintenance and minor works; asset maintenance and refurbishment and flood risk management capital scheme options.

We undertook a high-level option appraisal focussing on benefit, practical and viability considerations. We carried out a multi-criteria analysis to compare each option which included consideration of:

- Contribution towards reducing flood risk to property
- Contribution towards reducing flood impacts on people/communities
- Contribution to improving the availability of data, evidence and modelling to support option development or flood incident response
- Deliverability (including construction complexity, access, designations, services, space, land ownership, available materials and expert equipment or advice required)
- Community / resident acceptability
- Contribution towards biodiversity and water quality betterment
- Contribution towards amenity benefits
- Contribution to carbon reduction
- Maintenance requirements

Relative costs and timescales are provided for information only and are not included in the scoring.

The scoring criteria and full results are described in more detail in Appendix C.

It is important to note that whilst JBA and Buckinghamshire Council have liaised with partner organisations regarding this assessment, this is a high-level, preliminary assessment undertaken by and on behalf of Buckinghamshire Council. Therefore, it is for the relevant responsible body or persons to assess these recommendations in terms of their legal obligation, resource implications, priorities and the costs and benefits of undertaking such options.

Buckinghamshire Council will monitor progress on these recommendations through the Buckinghamshire Strategic Flood Committee, but does not have powers to enforce their delivery by others.

10.2 Community flood resilience

A community approach to resilience can significantly increase residents' ability to prepare, respond, and recover from floods in the future, and so reducing the impact of flooding on the community.

Local residents and members of the Parish Council have already formed a local community Flood Action Group with the aim of increasing the community's resilience to flooding. Buckinghamshire Council[14] and the National Flood Forum[15] have resources to assist communities with planning and preparing for flooding.

It is recommended that the Flood Action Group or Parish Council develop a Community Flood Plan[16] to inform residents how to prepare for, respond to and recover from flooding. Buckinghamshire Council (both Resilience Team and the LLFA) and the Environment Agency (EA) are able to provide some guidance to the community on this, dependent on resource, and the National Flood Forum can also be approached for support.

At the time of writing, there is funding available through the EA for communities who have completed a suitable Flood Plan to purchase emergency "Flood Toolkits" to help them respond effectively during a flood event with appropriate equipment. These toolkits can include items such as "road flooded" warning signs, Hydrosnakes, high-vis jackets, two way radios, emergency blankets, etc. Communities are able to tailor the contents of the flood kit to their needs up to a certain total value. The local community or Flood Action Group would be responsible for storage, maintenance, and correct usage of the equipment. A community Flood Plan must have been completed and agreed as fit for purpose by the EA before the kit can be provided. Again, the EA and Buckinghamshire Council can provide some support with developing and reviewing the plan.

The Flood Action Group could also create a 'flood preparedness' information pack for existing and future residents in the area. The pack may contain advice on taking out contents' insurance on belongings, property resistance and resilience measures and a checklist of what to do in the event of a flood. This may help to give reassurance to residents on what can be done in the event of another flood and minimise future loss of belongings and damage to properties.

Table 10-1: Recommendations for community flood resilience

Recommendation	Organisation(s) responsible	Multi-criteria analysis score	Recommendation	Timescale
Create a community Flood Action Plan to formalise any existing arrangements.	Community / Flood Action Group, supported by - Thornborough Parish Council - National Flood Forum - Buckinghamshire Council (Resilience Team and the LLFA) - Environment	8	Recommended	1 year

14 Working with your community: https://www.buckscc.gov.uk/services/environment/flooding/how-to-deal-with-a-flood/working-with-your-community/

15 National Flood Forum: https://nationalfloodforum.org.uk/working-together/communities/what-is-a-flood-action-group/

16 Community flood plan template - GOV.UK (www.gov.uk) AND https://thefloodhub.co.uk/wp-content/uploads/2021/05/Community-flood-plan-guidance-notes-and-template.pdf

Recommendation	Organisation(s) responsible	Multi-criteria analysis score	Recommendation	Timescale
	Agency			
Work towards procuring a Community Flood Toolkit for Thornborough	- Flood Action Group - Environment Agency - Buckinghamshire Council (Resilience Team and LLFA)	9	Recommended	1 year
Prepare a 'flood preparedness' information pack for existing and future residents.	Community / Flood Action Group, supported by - Thornborough Parish Council - National Flood Forum - Buckinghamshire Council (Resilience Team and LLFA)	8	Recommended	1 year

10.3 Property Flood Resilience (PFR)

We suggest that Property Flood Resilience (PFR) could be an option for the properties in Thornborough at risk of flooding to make them more resilient. PFR involves assessing how floodwater enters a property and recommending measures at an individual property level to mitigate potential flooding.

PFR could provide effective products and measures, at an individual property level, to reduce the impact of future floods in Thornborough, by either aiming to limit water entry in the first place (resistance) or by adapting the internal fabric of the property to limit damage (resilience) if flooding does occur. Resistance measures can include flood doors, flood barriers, automatic airbricks and non-return valves, depending on the main ingress routes. Resilience measures include raising electrics, using porous plaster, and fitting solid floors or tiled floor coverings instead of carpets.

For example, non-return valves could be used to prevent any back-up of sewers on Bridge Street. A few of the residents in the village already have some measures in place, such as door barriers, and found these to be successful in preventing water ingress during the event. Many of the residents have also made significant landscaping changes in an attempt to redirect flood water away from their properties, but still experienced floodwater reaching close to their properties during the December 2020 event.

Although resistance measures are not able to entirely prevent floodwater ingress, they aim to minimise damage caused by flooding. This would help Thornborough residents recover quickly from any future events, and also help reduce the negative impacts associated with property damage and repair works.

Constraints of both resistance and resilience approaches include funding, resident willingness and the appropriateness of the individual property for installing PFR measures.

PFR can either be taken forward as a community-wide scheme by a lead organisation such as Buckinghamshire Council, or privately by individual property owners. Buckinghamshire Council do have long-term aspirations to lead and deliver PFR more widely across the county in the coming years. However, this would require appropriate staffing and sufficient funding to be secured, and is subject to much uncertainty at present.

Individual property owners at risk of flooding may wish to consider installing PFR products to make their properties more resilient on a private basis[17]. Before any products are fitted, an independent PFR survey should be commissioned to identify the points of ingress and recommend appropriate measures[18]. Kitemarked PFR products should be supplied and installed by an approved supplier, to ensure the efficacy and reliability of the PFR measures.

---

17 The Homeowners' Guide to Flood Resilience' (https://www.knowyourfloodrisk.co.uk/sites/default/files/FloodGuide_ForHomeowners.pdf) aims to inform homeowners about how to reduce flood risk to their homes and the variety of PFR methods available. It also includes contact details for surveyors/providers of Kitemarked flood protection equipment.

The National Flood Forum provide a webpage and guidance leaflet for homeowners on the steps towards installing their own PFR measures, and a tool to provide indicative costs of measures at: https://nationalfloodforum.org.uk/about-flooding/reducing-your-risk/protecting-your-property/

18 The Blue Pages, a directory for flood risk reduction services provided by the National Flood Forum, list a number of companies who may be able to undertake such individual flood risk surveys: https://bluepages.org.uk/listing-category/surveys-building/.

If residents are unable to fund such works individually, the community could look to apply for grant funding from charities that can help with flood recovery (such as Heart of Bucks or the National Lottery Community Fund).

Table 10-2: Recommendations for property flood resilience

Recommendations	Organisation(s) responsible	Multi-criteria analysis score	Recommendation	Timescale
Investigate opportunities for installing PFR at relevant at-risk properties	Homeowners	8	Recommended	1-5 years

10.4 Watercourse condition and maintenance

During the event, floodwaters were observed flowing out of the watercourses in the village at seven locations. At the time of the visit in September 2021, the watercourses in many places were visibly overgrown (see Section 9.3), although the presence of vegetation will have been substantially lower during the December event. With the exception of the reaches of the Tonne Brook and Cowerde Brook where vegetation growth is being encouraged in order to slow the flow of water, it is recommended the watercourses are kept clear of vegetation by the riparian owners, as part of a co-ordinated maintenance plan, in order to help reduce flood risk to properties in the village.

The Parish Council usually clear channels around the centre of the village every four years but have been unable to continue due to funding restrictions. The Parish Council could seek grant funding from local charities such as the National Lottery Community Fund to help deliver such maintenance in future. Clearing vegetation and silt may help to maintain in-channel capacity on sections of watercourse where properties are located in close proximity. However, it should be noted that the channel is bedrock in places, such as by the second bridge on the River Tonne at High Street, meaning there is little additional capacity available. Care must also to time maintenance works on the watercourses, to minimise disruption to habitats in the watercourses.

By making riparian owners aware of their responsibilities, the risk of blockages or problems such as overgrown vegetation in the watercourses is reduced. The Parish Council has already done some work with riparian owners in the village to increase awareness, and this should be continued. Guidance on these rights and responsibilities can be found in the Environment Agency guide 'Owning a watercourse'[19], and on Buckinghamshire Council's Guidance for Riparian Owners[20]. Please see section 4.8 for more information.

The Great Ouse at Thornborough Mill is a Main River maintained by riparian owners, with support from the Environment Agency. The Environment Agency is undertaking an appraisal to understand the flood risk associated with the area and to inform the future management of the weir at Thornborough Mill. As part of the appraisal they are reviewing a range of information, including hydraulic modelling, costs, economic benefits, historical information and feedback from stakeholders to inform a long-list of options. These options will include weir refurbishment/replacement, installation of a fixed weir and creation of a natural bypass channel, and decommissioning of the asset and re-naturalisation of the channel. The long-list of options are currently being assessed in terms of their technical viability, flood risk impacts and environmental constraints.

Table 10-3: Recommendations for watercourse management

Recommendations	Organisation(s) responsible	Multi-criteria analysis score	Recommendation	Timescale
Watercourse maintenance plan and riparian awareness (to include activities required, frequency etc)	Riparian owners, with support from Parish Council and Buckinghamshire Council	6	Recommended	1 year

19 Owning a Watercourse, Environment Agency 2016

20 Guidance for Riparian Owners, Buckinghamshire Council (https://www.buckscc.gov.uk/services/environment/flooding/apply-for-land-drainage-consent/maintenance-for-rivers-and-ditches/)

Complete appraisal for future management of the weir at Thornborough Mill and disseminate findings	Environment Agency	11	Recommended (in progress)	Environment Agency to advise

10.5 Culvert and bridge maintenance

Culverts and bridges within the public highway are the responsibility of Transport for Buckinghamshire (TfB). Those within private land are the responsibility of the asset owner (usually the riparian landowner).

Regular maintenance of all culverts and bridges in the village by the relevant riparian owners (private owners, TfB), such as checking for blockages and vegetation growth, will help to ensure that the watercourses and structures have the greatest possible capacity available to accommodate flow during a flood event.

During the December 2020 event, Cowerde Brook overtopped upstream of Hatchet Leys Lane Bridge. This is a concrete single span structure (see Figure 10-1) to which a gate has been attached on the downstream face for livestock control. The gate does not appear to significantly restrict the flow of water through the bridge under normal conditions, but it has the potential to trap debris which could cause a blockage. Residents have reported that during the event, water pooled upstream of the bridge, causing the watercourse to overtop and spill out on to the surrounding fields, roads and properties. The risk of blockage could be reduced by removing the gate placed on the bridge and providing alternative livestock deterrents.

Consideration could be given to providing a formal bypass route around the bridge by lowering the banks/road on one or both sides of the bridge in order to allow water to flow onto the fields downstream. This could reduce the risk of water backing up. The land in question around the bridge is within the public highway extent, and therefore this would be for Transport for Buckinghamshire to consider further. More detailed investigations into the feasibility and design of such works would be required. However, it is quite likely that this solution would be highly constrained, including being very costly and disproportionate to any flood risk economic benefits, and so may not be deliverable.

Figure 10-1: Hatchet Leys Bridge upstream (above) and downstream (below).

Table 10-4: Recommendations for culvert and bridge maintenance

Recommendation	Organisation(s) responsible	Multi-criteria analysis score	Recommendation	Timescale
Removal of livestock gate at Hatchet Leys Bridge	Riparian owner/Farmer	7	Recommended	1 year
Regular inspection of all bridges and culverts to prevent blockages	Riparian owners, IDB, Transport for Buckinghamshire	6	Recommended	1 year
Investigate feasibility of bypass route at Hatchet Leys Lane	Transport for Buckinghamshire	5	Recommended for further consideration – may not be feasible	1-5 years

10.6 Drainage network

During the event it has been reported that many of the highway gullies were blocked or overwhelmed, resulting in surface water flow paths forming at the sides of the road. In one location this reportedly contributed to the internal flooding of a property.

Transport for Buckinghamshire has since cleared the gullies. It is recommended that the cyclical maintenance plan for gullies in Thornborough is reviewed, and the frequency of maintenance increased, where feasible. It has also been identified that some roadside ditches and verges in Thornborough are susceptible to fly tipping. As this debris may accumulate between cyclical maintenance visits, it is recommended that residents report any issues or known blockages to Transport for Buckinghamshire when they occur.

Table 10-5: Recommendations for drainage network

Recommendation	Organisation(s) responsible	Multi-criteria analysis score	Timescale
Increase frequency of highway gully maintenance	Transport for Buckinghamshire	7	1 year

10.7 Land management/Natural Flood Management (NFM)

Overland flow from farmland to the south of the village caused external flooding around properties off High Street. Although this did not cause any internal flooding, this was mainly due to the resilience works carried out by homeowners to route water round properties following previous flood events. The Parish Council has noted that runoff from fields to the north of Back Street is not managed by field drainage and flows out onto the road and down to the junction with Lower End. A blocked ditch below the solar farm at Thornborough Grounds was also mentioned as a contributor to the overland flows seen in the Thornborough Mill area. Land drainage is managed by the various landowners (see Section 5) in the village.

Natural flood management aims to reduce flood severity and delay flood peaks using a range of techniques to slow down or store flood water. Installation of features such as leaky dams and large woody debris on flow paths could reduce the risk from overland flow pathways.

NFM measures can be utilised in farming and general land management without large disruptions, as they can be delivered without significant land take and can be incorporated as an extension to existing land drainage. They also bring multiple benefits for biodiversity and water quality and have a lower carbon footprint than traditional 'engineered' flood risk management solutions.

There are also changes that can be made to land management that can help to reduce field runoff - for example, measures such as winter crops, ploughing along slopes, maintaining soil health, growing hedgerows and water storage.

Exploring NFM potential with landowners and farmers could be beneficial for areas of Thornborough, especially where runoff from the surrounding fields has a significant contribution to flooding, such as on High Street, Back Street and Lower End. NFM requires careful design and planning in order to reduce the risk of increasing flood risk further upstream or downstream.

The Lead Local Flood Authority team in Buckinghamshire Council have long-term aspirations to identify, resource and progress NFM work across the county, including in this area, in the coming years. However, this is subject to staffing and budget becoming available, and unfortunately at the time of writing there is no guarantee of when or if this could be taken forward.

Thornborough Flood Action Group are keen to implement some form of NFM themselves upstream of the village. To help towards this, Buckinghamshire Council have asked the River Restoration Centre[21] to provide some preliminary advice and recommendations to the Flood Action Group by mapping possible opportunity areas for NFM within the catchment. (This advice note to be provided separately to the Flood Action Group).

It is likely that larger structures, such as storage ponds, would require a drainage engineer or environmental contractor to support the design, construction and supervision, which would be a costly and high risk option. We would not recommend in-channel leaky barriers within the two main brooks close to the village, as they may be easily overwhelmed by significant flood flows – this could lead to a risk of collapse or washout of structures, potentially blocking downstream culverts and bridges or suddenly releasing stored floodwaters close to the village. However, smaller scale, lower risk works (e.g. hedgerow planting or leaky barriers on small headwater ditches further upstream) would require less expert involvement and may be more feasible for a community-led project. The Flood Action Group could seek grant funding from local charities and organisations (e.g. Heart of Bucks, the National Lottery Community Fund, or the Postcode Society Trust) in order to deliver such small-scale NFM interventions.

It should be noted that permission would need to be sought from the relevant landowners, in addition to Land Drainage Consent from Buckinghamshire Council as LLFA. Engagement

21 https://www.therrc.co.uk/

with landowners to develop and obtain approval for such measures, even where landowners are receptive, can be a lengthy process.

Table 10-6: Recommendations for Land management/Natural Flood Management (NFM)

Recommendations	Organisation(s) responsible	Multi-criteria analysis score	Recommendation	Timescale
Engage with landowners/ farmers to explore potential NFM/Land management e.g water storage, buffer strips, blocking ditches, hedgerows etc	Flood Action Group, Riparian owners, Land owners	8	Recommended	1-5 years

11 Conclusion and recommendations

11.1 Conclusion

The flooding that occurred on 23 December 2020 caused internal flooding to at least five residential properties in Thornborough. Buckinghamshire Council, as the Lead Local Flood Authority for Thornborough, has exercised their power to undertake a Section 19 Investigation as this fulfilled its criteria of 'significant flooding'.

The main source of flooding to the main village was due to intense rainfall on already very saturated ground, causing surface water flows and exceeding the capacity of small ordinary watercourses and culverts. As noted in the hydrological report in Appendix A, groundwater levels are likely to have been very high, contributing to the volume of runoff and flows in the watercourse.

At the time of the flooding many of the roads in the village were unpassable. Drains became blocked and overwhelmed which contributed to the flooding. These were reported to Transport for Buckingham and later cleared. In the village, residents noted that a manhole cover near their property lifted up with flood water, although it was not confirmed whether the source of flooding was groundwater flooding or exceedance of the sewer network. Water backing up from sewers into toilets was noted by residents as an issue on Bridge Street.

The ordinary watercourses were overtopped in at least seven locations in the village during the event. These were on the unnamed watercourse at the Old Manor, Cowerde Brook at Hatchet Leys Lane bridge, Thorn Brook at Back Street Ford, Tonne Brook at the pond next to the Village Hall, Bridge Street and the footbridge upstream of the Maltings.

Extreme rainfall on already saturated fields led to overland surface water flows developing on the fields surrounding the village at various locations. In particular, flows from the area surrounding Stonelands Farm contributed significant amounts of water towards the rear of properties on Lower End and High Street. Along Back Street, water was also observed flowing off the fields and on to the road, exacerbated by overtopping of a drainage ditch along a hedge line on the highway verge. Water was also observed 'pouring' off fields and flowing on to the road at Bridge Street.

Concentrated overland flows were also reported which, unlike the disperse surface water flows from fields, were defined channels of water. These developed due to a combination of overflows from the watercourses, heavy rainfall and surface water runoff, as well as groundwater sources (as discussed in Section 8.1).

In the area around Thornborough Mill there were high river levels on the River Great Ouse during the event. Floodwater from the river overtopped the south bank, with surface water observed flowing off the fields to the south (see Figure 8-4). The raised bank of the River Great Ouse may have also locally restricted flows on to the floodplain to the left bank of the river.

Overall, the flooding had a significant impact on the physical and mental wellbeing of residents, due to being "terrified" of flood water entering their properties. Notably residents also reported the stress of dealing with insurance claims, costs and potential for future event.

During the event, at least 13 cars became stranded and flooded at the junction of Back Street and Lower End. This was a particularly hazardous situation and required the Fire Brigade to attend to rescue trapped cars.

Following this, another potentially hazardous situation developed in the main village, when residents leaving the village hall following a meeting were met with significant flooding of the High Street and had to wade to their cars. The flooding here started between 19:00 and 20:00 and lasted for approximately five hours, causing significant disruption.

Analysis of the rainfall on 23 December determined that approximately 34mm of rain fell over an 18-hour period. The rainfall depth had a 50% chance of occurring in any one year (return period of 2 years) for the Thornborough village catchment at Cowerde Brook, and a 20% chance (return period of 5 years) for the Thornborough Mill catchment on the Great

Ouse. These values are not especially extreme but given that the soils were already completely saturated from the notably high rainfall over preceding months, the catchments were very sensitive to heavy rainfall. An approximate flow return period of 5-20 years is estimated for Thornborough village and 10-30 years for Thornborough Mill.

11.2 Recommendations

Based on the identified causes and mechanisms of flooding, we considered potential options to mitigate flood risk and/or damages. This includes consideration of measures such as Property Flood Resilience (PFR) (flood doors, barriers etc), community level resilience, land management and flood attenuation options.

We undertook a high-level option appraisal focussing on benefit, practical and viability considerations. We carried out a multi-criteria analysis to compare each option which included consideration of relative costs and timescales, buildability, health safety and environment, stakeholder perceptions and public acceptability, land ownership etc.

A summary of the recommended actions for the Risk Management Authorities and various parties are presented below in Table 11-1.

The options which scored the highest were around community resilience, such as creating a community flood action plan, procuring a Community Flood Toolkit, and formalising existing flood response arrangements. his was determined to be low cost, relatively quick to implement and effective at reducing flood damage to property.

Other high scoring options were engaging with farmers and landowners in Thornborough to explore Natural Flood Management opportunities and installing Property Flood Resilience measures at the highest risk properties.

It should be noted that several of the options identified would require further investigation on asset networks by a particular authority, such as Transport for Buckinghamshire and the Buckingham and Ouzel IDB. The outcomes of these investigations may result in a more beneficial solution being identified.

Table 11-1: Summary of recommended actions for stakeholders in Thornborough

Recommended actions	Risk Management Authority/Stakeholder
Create a community Flood Action Plan	Flood Action Group, supported by - Thornborough Parish Council - National Flood Forum - Buckinghamshire Council (Resilience Team and the LLFA) - Environment Agency
Work towards procuring a Community Flood Toolkit for Thornborough	- Flood Action Group - Environment Agency - Buckinghamshire Council (Resilience Team and LLFA)
Prepare a 'flood preparedness' information pack for existing and future residents	Community / Flood Action Group, supported by - Thornborough Parish Council - National Flood Forum - Buckinghamshire Council (Resilience Team and LLFA)
Engage with landowners/farmers to explore potential NFM/Land management e.g water storage, reinstating or installing ditches, buffer strips etc	Flood Action Group, Riparian owners, Land owners

Investigate opportunities for installing PFR at relevant at-risk properties	Homeowners,
Increase frequency of highway gully maintenance	Transport for Buckinghamshire
Removal of livestock gate at Hatchet Leys Bridge	Riparian owner/Farmer
Further investigation into gulley network	Transport for Buckinghamshire
Culvert maintenance	Riparian owners, Transport for Buckinghamshire
Bridge maintenance	Riparian owners, Transport for Buckinghamshire
Watercourse maintenance plan (to include activities, frequency etc)	Riparian owners, Flood Action Group, Community
Increase riparian awareness (responsibility and maintenance)	Riparian owners. Parish council with support from Flood Action Group and BC

Appendices

A FEH calculation record – Thornborough Village

B FEH calculation record – Thornborough Mill

C Multi-Criteria Analysis

We have considered potential options to mitigate flood risk and reduce damages caused by flooding.

This includes consideration of measures such as improvements to data collection and evidence; flood warning and incident management; community, property, and infrastructure flood resilience; maintenance and minor works; asset maintenance and refurbishment and flood risk management capital scheme options.

We undertook a high-level option appraisal focussing on benefit, practical and viability considerations. We carried out a multi-criteria analysis to compare each option which included consideration of:

- Contribution towards reducing flood risk to property
- Contribution towards reducing flood impacts on people/communities
- Contribution to improving the availability of data, evidence and modelling to support option development or flood incident response
- Deliverability (including construction complexity, access, designations, services, space, land ownership, available materials and expert equipment or advice required)
- Community / resident acceptability
- Contribution towards biodiversity and water quality betterment
- Contribution towards amenity benefits
- Contribution to carbon reduction
- Maintenance requirements

Relative costs and timescales are provided for information only and are not included in the scoring.

The scoring criteria and full results are shown below. Options with a score of 6 or above were taken forward to become recommendations.

Multi-criteria analysis scoring criteria

Flood risk benefit to property	Likely change in internal flood risk to property	
	-2	Increase in flood risk to any property
	-1	N/A
	0	No perceived change
	1	Reduction in flood risk to 1 - 10 properties
	2	Reduction in flood risk to 10 - 30 properties
	3	Reduction in flood risk to 30 - 70 properties
	4	Reduction in flood risk to 70-100 properties
	5	Reduction in flood risk to >100 properties
Flood risk benefit to people	Likely change in flood impacts on people/communities. Encompassing community preparedness and resilience; stress, health, mental health impacts; nuisance flooding (gardens, roads etc); disruption to access and egress; vehicle damages; risk to life and evacuation costs.	
	-2	Major negative change in flood impacts on people/communities

	-1	Minor negative change in flood impacts on people/communities
	0	No perceived change
	1	Minimal positive change in flood impacts on people/communities (e.g. reduction in nuisance flooding)
	2	Minor positive change in flood impacts on people/communities (e.g. reduction in disruption to toilet use)
	3	Minor positive change in flood impacts on people/communities (e.g. improvements to access and egress)
	4	Medium positive change in flood impacts on people/communities (e.g. increasing community flood preparedness and ability to act)
	5	Major positive change in flood impacts on people/communities (e.g. reduction of risk to life and evacuation costs)
Contribute to improving the availability of data, evidence and modelling to support option development or flood incident response	This criteria focusses on the benefits of further data collection and evidence studies to support option development	
	0	Does not improve the availability of data, evidence and modelling
	1	
	2	Will provide additional data, evidence or modelling, helpful in development of interventions
	3	
	4	
	5	Improvement to data, evidence and modelling which is essential to the development of a capital scheme
Deliverability	Likely deliverability of the intervention considering construction complexity, access, designations, services, space, land ownership, available materials and expert equipment or advice required.	
	-2	Deliverability is at high risk of complexity/constraints
	0	Not known/not applicable
	-1	
	0	Not known/not applicable
	1	
	2	Deliverability is at low risk of complexity/constraints
Community / resident acceptability	Community buy in or perceived residents opinion.	

	-2	Community/residents are likely to have objections
	-1	Community/residents may not be receptive
	0	No known objections / constraints
	1	Community/residents are likely to be receptive but may have some constraints
	2	Community/residents are likely to be receptive and have no constraints
Contribute towards biodiversity and water quality betterment	Potential for the intervention to provide creation of habitats and river restoration, as well as improving existing water quality.	
	-2	Significant detriment
	-1	Some detriment
	0	No perceived change
	1	Some betterment
	2	Significant betterment
Contribute towards amenity benefits	Potential for the intervention to improve the amenity value of the surrounding area.	
	-2	Significant detriment
	-1	Some detriment
	0	No perceived change
	1	Some betterment
	2	Significant betterment
Contribute to carbon reduction	Potential for the intervention to contribute towards carbon reduction via sustainable construction techniques or carbon sequestration from increased planting.	
	-2	Significant net carbon increase
	-1	Some net carbon increase
	0	Not known/no effect
	1	Some net carbon reduction
	2	Significant net carbon reduction
Maintenance	High level assessment of maintenance requirements.	
	-2	N/A
	-1	High cost/frequency maintenance, requires new and specialised maintenance routines
	0	Not known/no effect
	1	Low-cost maintenance, can be completed as part of existing maintenance routines
	2	No active maintenance required (passive maintenance designed)
Timescale	1	Long term strategic aim (>10yrs to progress, funding route unclear)
	2	

	3	Likely to be able to progress in next 1 - 5 yrs e.g. through FCERM partnership funding programme
	4	
	5	Quick win (<1yr), BC able to fund directly
Cost	High level assessment of cost of implementing	
	1	£>2m
	2	£1m to 2m
	3	£500k-£1m
	4	£100-500k
	5	<£100k

Buckinghamshire Section 19 Investigations
Multi-Criteria Appraisal Matrix

Originated	Seraya Sigsworth	12/10/2021
Checked	Anna Beasley	19/05/2022
Approver	Anna Beasley	19/05/2022

Evaluation Scoring: See tab 'Scoring Criteria' for details

-2	Major negative impact.
-1	
0	Neither positive or negative impacts
1	
2	
3	
4	
5	Major positive impact

Objective	Weighting
1	1
2	1
3	1
4	1
5	1
6	1
7	1
8	1
9	1
10	0
11	0

			1	2	3	4	5	6	7	8	9	10	11	
Reference	Opportunities	Lead RMA	Flood risk benefit to property	Flood impact on people	Data and evidence	Deliverability	Community/ resident acceptability	Biodiversity and water quality betterment	Amenity benefits	Carbon reduction	Maintenance costs	Timescale	Cost (for information only)	**TOTAL**
1	Do nothing	N/A	-1	-1	0	0	-1	0	0	0	0	0	5	-3
2	Business as usual	All	0	-1	0	0	0	0	0	0	0	0	5	-1
	Options													
3	Investigate opportunities for installing PFR at relevant at-risk properties	Homeowners, Buckinghamshire Council (LLFA)	1	4	0	1	1	0	0	0	1	3	5	8
4	Set up a Flood Action Group and create a community Flood Action Plan to formalise any existing arrangements	Community, supported by Parish Council and Buckinghamshire Council (LLFA)	1	4	0	2	2	0	0	0	2	5	5	11
5	Prepare a "flood preparedness" information pack for existing and future residents	Community, supported by Parish Council and Buckinghamshire Council (LLFA)	1	4	0	2	2	0	0	0	2	5	5	11
6	Increase frequency of highway gully maintenance	Transport for Buckinghamshire	1	3	0	1	0	0	0	0	2	4	5	7
7	Engagement with landowners/farmers to explore potential for NFM/land management e.g water storage, ditches, buffer strips/headgerows etc	Parish Council, Flood Action Group, Riparian owners, Land owners	1	4	0	0	0	1	0	1	1	3	5	8
8	Watercourse maintenance plan and riparian awareness (to include activities required, frequency etc)	Riparian owners, with support from Parish Council and Buckinghamshire Council	1	3	0	1	0	0	0	0	1	4	5	6
9	Complete appraisal for future management of the weir at Thornborough Mill and disseminate findings	Environment Agency	1	2	4	2	2	0	0	0	0	5	4	11
10	Regular inspection of all bridges and culverts to prevent blockages	Riparian owners, IDB, TfB	1	3	0	1	0	0	0	0	1	4	5	6
11	Removal of livestock gate at Hatchet Leys Lane	Riparian owner/Farmer	1	3	0	1	0	0	0	0	2	5	5	7
12	Investigate feasibility of bypass route at Hatchet Leys Lane	Buckinghamshire Council	1	4	0	-1	1	0	0	0	0	3	5	5

Offices at

Coleshill
Doncaster
Dublin
Edinburgh
Exeter
Haywards Heath
Isle of Man
Limerick
Newcastle upon Tyne
Newport
Peterborough
Saltaire
Skipton
Tadcaster
Thirsk
Wallingford
Warrington

Registered Office
1 Broughton Park
Old Lane North
Broughton
SKIPTON
North Yorkshire
BD23 3FD
United Kingdom

+44(0)1756 799919
info@jbaconsulting.com
www.jbaconsulting.com
Follow us:

Jeremy Benn Associates Limited

Registered in England 3246693

JBA Group Ltd is certified to:
ISO 9001:2015
ISO 14001:2015
ISO 27001:2013
ISO 45001:2018