Lancaster City Surface Water Management Plan

SWMP Report & Action Plan

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Contents

1. Background

1.1 December 2015 Floods

December 2015 was an extraordinary month in both meteorological and hydrological terms, with some of the most widespread and severe flooding witnessed in the UK.

In the period preceding December 2015, November was a stormy month, with a series of vigorous depressions bringing heavy rainfall and strong winds. These included three named storms: Storms Abigail, Barney and Clodagh. Whilst notable daily rainfalls were registered, the primary feature of the heavy rainfall was its persistence with rain falling almost every day throughout this period. The rainfall totals in the North West were more than twice the normal for the region (215%), with eleven catchments across Cumbria, Lancashire and Yorkshire for which the rainfall for November was second highest on record (since 1910) and second only to November 2009[1].

The above average rainfall in November 2015 effectively caused high ground and lower-lying areas to become saturated, decreasing its hydraulic capacity and in effect reducing the ability of the soil to absorb future rainfall.

Over the period of December 2015, slow-moving low-pressure systems (including the named storms Desmond, Eva and Frank), driven by a sustained moist south-westerly airflow, brought record-breaking levels of rainfall, which resulted in exceptional flow levels within major rivers across Lancashire and Cumbria. Several major flood events followed causing widespread and severe impacts with around 16,000 properties flooded in England in December alone[2]. In January, the Association of British Insurers (ABI) estimated the final bill for the flood damage caused by storms Desmond, Eva and Frank to homes, businesses and motor vehicles to be £1.3 billion[3].

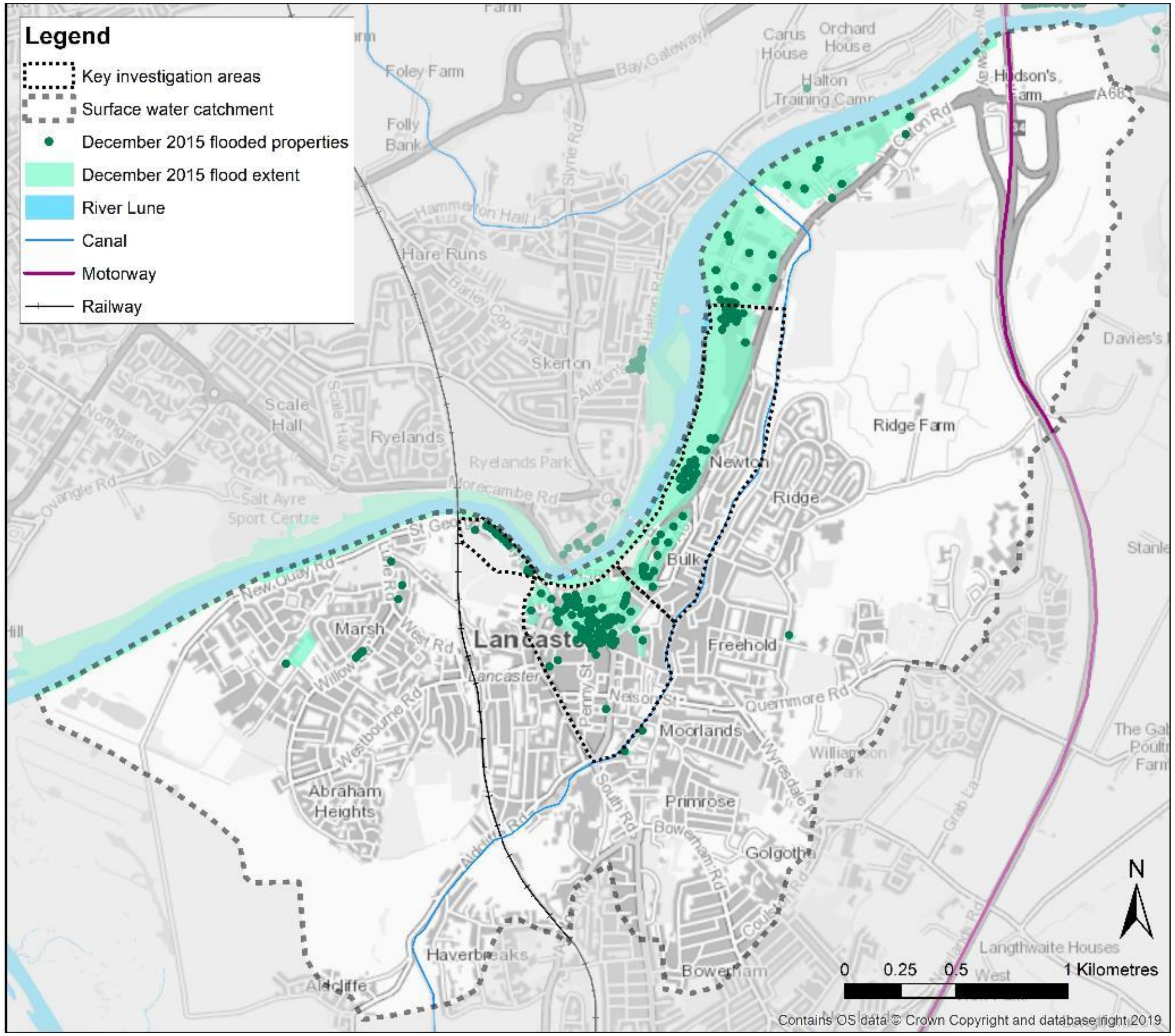
Throughout Lancashire, approximately 2,500 homes across 229 separate communities were flooded[4]. The City of Lancaster was one of the worst affected areas over the period of the 4th – 7th December 2015.

The cause of flooding in Lancaster appears complex. During this event, the River Lune reached a flow of 1,742m^3/s at the Caton gauging station, the highest flow ever recorded on the Lune and a new record for an English river at the time. These high flows and level resulted in the Lune overtopping its banks and flooding the Lansil Industrial Estate. Although the Lune played a part, anecdotal evidence and observations made during the event suggest that other sources and mechanisms including surface water runoff, may have played an important role when focusing on the City Centre. With persistent heavy and intense rainfall, urban drainage networks were overloaded, with local topography and high levels in the River Lune causing tide locked culverts, leaving nowhere for the water to go, and ultimately causing the flooding within the City centre. River levels dropped over the 48 hours after the flooding event; however, surface water drainage networks in parts of the City continued to be exceeded causing continual extensive but shallow surface water flooding, particularly around the Damside Street and North Road area.

Whilst the City centre has been subject to localised flooding events in the past, it has not experienced such a significant incident as the December 2015 floods, with the combination of flood sources resulting in approximately 332 properties / businesses flooded throughout the City. In addition, overtopping of the River Lune also affected an electricity substation, on Caton Road, which resulted in approximately 61,000 homes and businesses being without power for nearly 48 hours. The flooding also damaged private gardens, garages and out-buildings, business premises, agricultural property and many items of critical public infrastructure including roads, bridges and retaining walls, water treatment plants, power and communications installations, and essential community buildings such as schools, village and town halls[5].

During the flooding and recovery period, the police, fire and rescue service, and NHS provided immediate emergency support to those in need. Risk Management Authorities (RMAs) including Lancashire County Council, the Environment Agency, United Utilities and Lancaster City Council also played a major role undertaking flood risk activities and ensuring the free flow of communication and collaborative works between other parties and the local community. These activities occurred for several weeks after the event as the disruption of the flood event and subsequent recovery phase continued within the City.

Figure 1-1: December 2015 flood extents




Lancaster Bus Station


Lansil Industrial Estate

1.2 Post-Event Flood Risk Management Actions

Given the severity of the flooding in December 2015, the Environment Agency are currently delivering a £10.8million scheme to provide 2.8km (1.7 miles) of enhanced flood defences to provide protection from the River Lune to Lansil Industrial Estate, Riverside Industrial Estate, and Caton Road Retail Park from fluvial flooding. The work started in January 2020 with the works substantially completing in early 2021. Additional landscaping and tree planting works will be taking place in Spring 2021.

Lancashire County Council as Lead Local Flood Authority (LLFA) and other RMAs including the Environment Agency, United Utilities, Lancaster City Council also started to work together to undertake several key instigations, surveys and studies to understand and manage the risk of **surface water flooding** within City centre. A timeline of these works is provided below.

Figure 1-2: Timeline of key instigations, surveys and studies

Dec 2015	Major flood event impacts City Centre	*RMA respond to flood event and undertake repairs, investigation and improvement works.*
Oct 2016	Publication of Section 19 Investigation Report and District Flood Reports	*The Council publish its investigation under the requirements of S19 of the FWMA 2010 into how communities were flooded during the December 2015 event. The investigation recommends RMA support to the Environment Agency on progressing Phase 3 of the Lancaster FAS and additional work to reduce the risks of surface water flooding around the City.*
Dec 2016	Multi-agency Steering Group	*A **Steering Group** is formed between Lancaster City Council, United Utilities and the Environment Agency, with Lancashire County Council leading as the lead flood risk authority.*
Mar 2017	Catchment Study	*Defra, the Environment Agency, Lancaster City Council and Lancashire County Council commit funds to undertake a **Catchment Study** to understand the possible sources, probability, mechanics, and consequences of extreme surface water flood events within the City centre.*
Sept 2018	Catchment Study workshop	*The results of the catchment study are presented to the Steering Group including discussions on potential strategic options to reduce surface water flood risk.*
Mar 2019	Investigations and Surveys	*The Steering Group commission a detailed survey of the Mill Race drainage system, a surface water management study along Caton Road (referred to as Phase 3a), and this City centre **Surface Water Management Plan**.*
Dec 2019	Mill Race Survey	*A 3D laser scan of the **Mill Race** underneath the City is undertaken over the summer of 2019 and CCTV survey in summer 2020 with data collected to understand its exact location and condition of the culvert.*
Jan 2020	SWMP Workshop	*A workshop held to provide partners with an opportunity to share local knowledge and discuss how surface water flood risks can be managed collectively through various existing or future investments, plans and policies.*
Mar 2021	Final SWMP	*Publication of this final SWMP report, which is ultimately the amalgamation of the above works in one coherent document, which then sets out the future strategy for reducing the risk of surface water flooding in the City centre.*

2. Preparation

2.1 Why a Surface Water Management Plan?

Since March 2017, Lancashire County Council in partnership with other RMAs have commissioned Jacobs UK Ltd to undertake several investigations, studies and surveys, as outlined in the timeline in Section 1.2. Each of these aims to **develop the understanding of surface water flood risk** across the City centre, the role in which existing surface water drainage assets may play, and the potential for possible flood management or alleviation works to take place.

Following the completion of the Catchment Study in 2018[6] and given the unique geographical and urban constraints within Lancaster, it was clear that no single solution would be able to address the risk of surface water flooding. A longer-term strategic vision would therefore be required that allows all partners and stakeholders to work together to improve flood resilience by making the best land use and development choices, protecting people and places, and responding to and recovering from flooding and coastal change, whilst all the time adapting to climate change.

It was therefore agreed that the completion of a Surface Water Management Plan (SWMP) would provide the most suitable vehicle to progress the development of this vision. This will be achieved by bringing partners and stakeholders together to understand the causes and effects of surface water flooding and agree the most cost-effective way of managing surface water flood risk over the long term. This could utilise existing capital investment, operational and maintenance programmes, and/or non-flood risk plans, policies and strategies.

The framework for undertaking SWMPs is set out in the national SWMP Technical Guidance, which was published by Defra in 2010[7] and was written for Local Authorities to assist them as they co-ordinate and lead local flood risk management activities as required under the Flood and Water Management Act 2010. Figure 2-1 helps to illustrates this framework and the specific study objectives.

By working through the four main stages, the aim of the SWMP is ultimately to establish a long-term action plan to manage surface water. The implementation of this strategy should then be monitored and reviewed, with partners and stakeholders regularly meeting to provide updates on actions and agree further work if necessary.

In this context **surface water flooding** describes flooding from:

- Surface water runoff as a result of high intensity rainfall when water is ponding or flowing over the ground surface (including overland flows from the urban/rural fringe entering the built-up area) before it enters the underground drainage network or watercourse, or cannot enter it because the network is full to capacity, thus causing flooding (known as pluvial flooding).
- Flooding from groundwater (including overland flows resulting from groundwater sources) where groundwater is defined as all water which is below the surface of the ground and in direct contact with the ground or subsoil.
- Sewer flooding[i]; flooding which occurs when the capacity of underground systems is exceeded due to heavy rainfall, resulting in flooding inside and outside of buildings. Note that the normal discharge of sewers and drains through outfalls may be impeded by high water levels in receiving waters as a result of wet weather or tidal conditions.
- Flooding from open-channel and culverted watercourses, which receive most of their flow from inside the urban area and perform an urban drainage function.

By **resilience**, we mean *"The capacity of people and places to plan for, better protect, respond to and recover from flooding and coastal change."*

[i] Consideration of sewer flooding in 'dry weather' resulting from blockage, collapse or pumping station mechanical failure is excluded from SWMPs as this is for the sole concern of the sewerage undertaker.

4. IMPLEMENTATION & REVIEW OBJECTIVES

This stage focuses on preparing an implementation strategy (i.e. the Action Plan), delivering the agreed actions and monitoring the implementation of these actions. The Action Plan shows how partners and stakeholders will work together to finance and implement the preferred strategy.

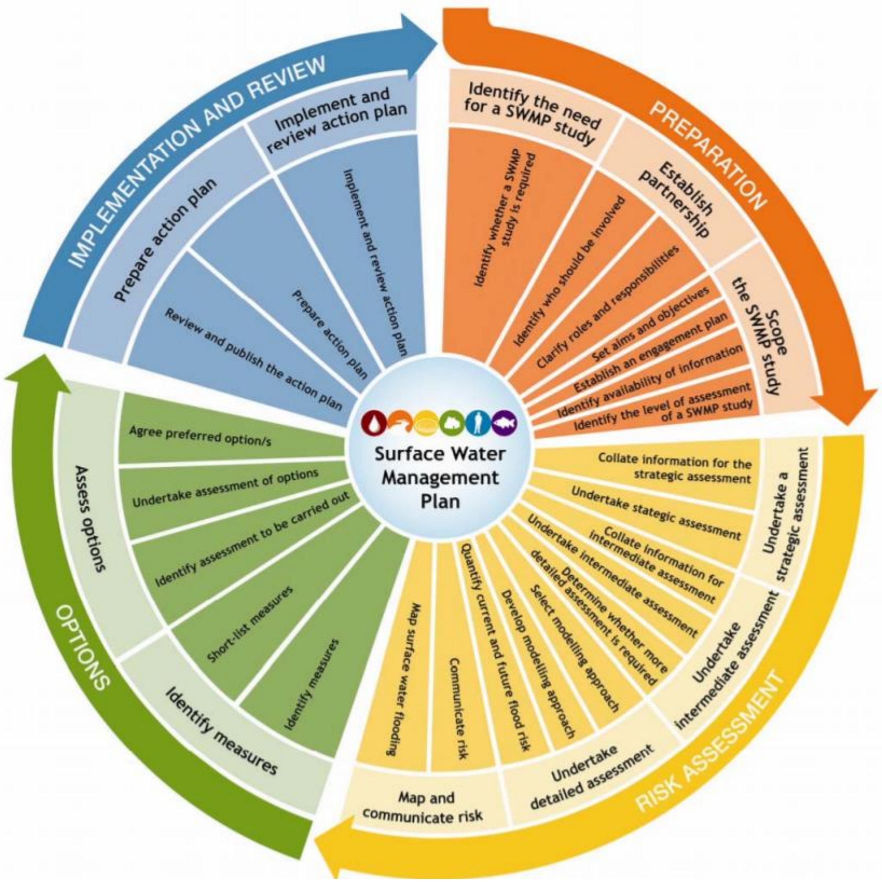
This stage was completed with the Steering Group and the project partners as part of the review and approval process of this SWMP.

3. OPTIONS OBJECTIVES

The first objective of this stage focuses on the development of a long-term surface water management strategy to reduce the risk of surface water flooding in the City that aligns with wider stakeholder responsibilities and priorities. This strategy was informed by the findings of the SWMP workshop.

Following the development of this strategy, the next objective is to identify effective, affordable, achievable and, cost-beneficial measures (or options) that help to achieve the objectives and goal of the strategy. These shortlisted options would then be taken through to the Action Plan.

Figure 2-1: SWMP framework and study objectives



1. PREPARATION

The first stage of a SWMP study focuses on preparing and scoping the requirements of the study.

A multi-agency Steering Group was formed at the beginning of the Catchment Study and strategic aims and objectives defined. These, along with findings of the Catchment Study, have helped define the objectives and scope of the SWMP.

2. RISK ASSESSMENT OBJECTIVES

This stage has largely been informed by the results of the Catchment Study and includes:

- A data review of existing data, studies and surveys undertake post 2015;
- Site visits with stakeholders to gain an understanding of hydrological systems such as drainage / sewer networks;
- a detailed narrative of surface water flood mechanisms. This includes mapping of predictive surface water flood data, so that a detailed understanding of the study area can be visualised, understood and quantified; and
- consideration of the consequences of surface water flooding, now and in the future, so that priorities can be established merits of different mitigation strategies compared.

2.2 Study area

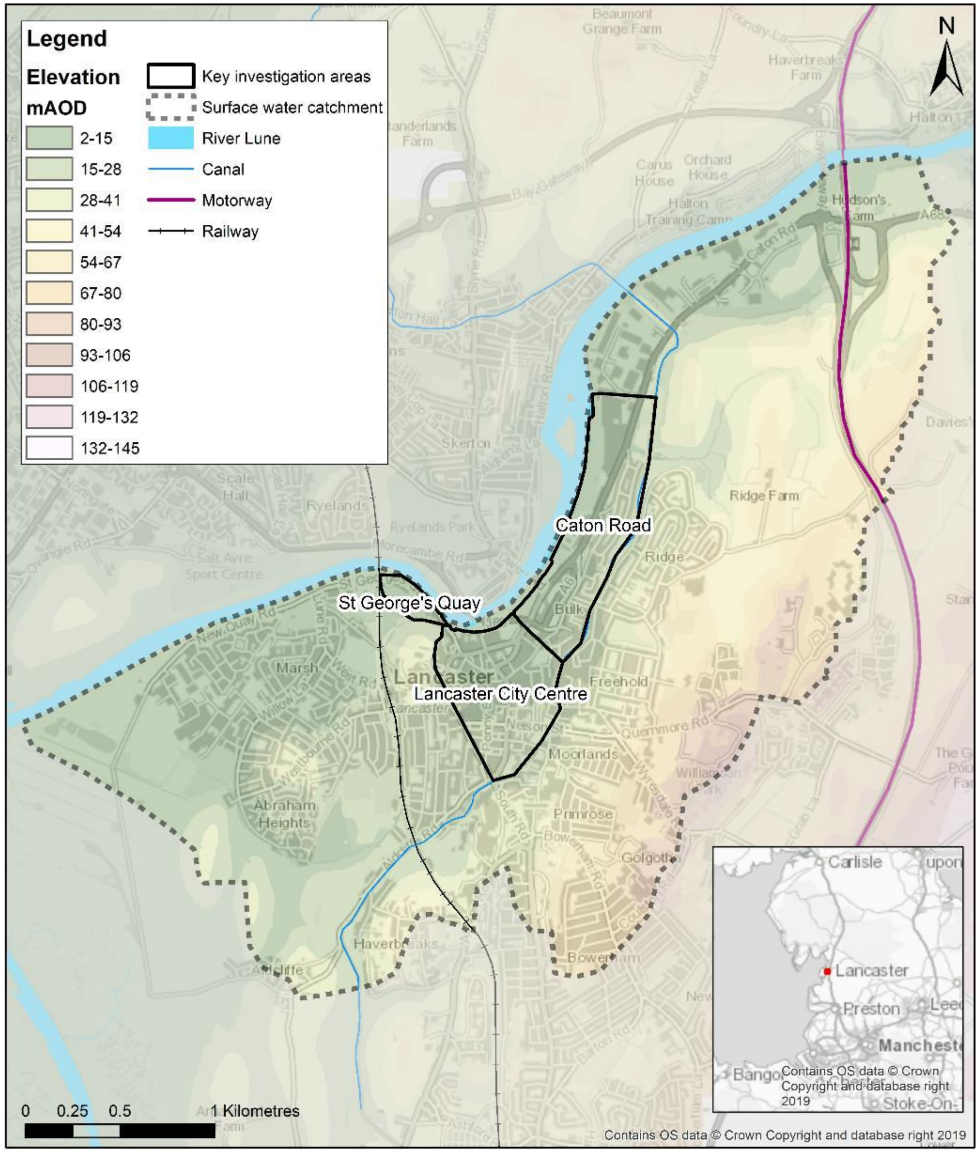
The City of Lancaster is situated on the northern end of the Lancashire plain on the River Lune between the fells of the Forest of Bowland to the east and Morecambe Bay to the west. The historic City is predominately a residential area but is the main administrative centre for both Lancaster District and north Lancashire, providing a range of commercial and business functions for its residents and the wider rural district.

The City is strategically placed on the national road network (M6), the rail network (West Coast Mainline) and is located on the edge of Morecambe Bay, The Lake District National Park, The Yorkshire Dales National Park and two Areas of Outstanding Natural Beauty.

The City is home to two universities; Lancaster University and the University of Cumbria, which makes Lancaster a centre for knowledge and learning which benefits not only the local economy but also the wider region. Lancaster also has a wealth of history dating back to Roman times. It is dominated by Lancaster Castle and the numerous historic buildings within its core.

The focus of this SWMP is the known areas of surface water flooding during the December 2015 floods, including Caton Road, the City centre, and St. Georges Quay. The SWMP study area is however driven by the natural surface water catchment and the urban drainage area catchment, as illustrated in Figure 2-2.

Figure 2-2: SWMP study area



2.3 Partnership Working

Lancashire County Council, as LLFA, led the delivery of this SWMP. They were supported by several other partners and stakeholders who have a duty, responsibility or interest for flood risk management within the City.

Identifying and engaging with the right authorities, organisations, individuals or groups who are, or could become, interested in, involved in or affected by, or have an effect on, flood risk management policies and activities, at the right level, and at the most appropriate stage, will be essential in achieving integrated and efficient flood risk mitigation where multiple organisations are involved.

Some partners and stakeholders will need engaging throughout as statutory consultees, others hold specific data or information that will need integrating into the study, others will have greater input into the design or implementation of any flood risk management actions recommended, whilst potential beneficiaries will also need consulting prior to contributions sought. This becomes critical in locations like Lancaster, when it is inevitable that multiple targeting interventions will be required that will rely heavily upon external stakeholders, including (for example) third party funding contributions and/or planning-led initiatives. Ultimately, this will only become a reality if stakeholders are given the opportunity to fully participate in the development of the scheme, at every stage, and contribute to the decision-making process.

2.3.1 Multi-agency steering group

A multi-agency Steering Group was established in December 2016 following the publication of the Lancaster Section 19 Investigation Report and District Flood Reports into the December 2015 floods. This group was formed to commission the Catchment Study and consisted of the key Risk Management Authorities (RMAs) that cover Lancaster. RMAs and their roles and responsibilities within flood risk management are set out in the Flood and Water Management Act (2010). Appendix B provides further details on the role and responsibilities of each RMA.

The multi-agency Steering Group have been consulted at key stages of the SWMP process as highlighted in Figure 2-3 and referred to through this report.

Figure 2-3: Multi-agency Steering Group

3. Risk Assessment

3.1 Introduction

This section of the SWMP provides a risk assessment of surface water flooding within the City centre. Since there is a history of surface water flooding in the city (Section 3.2.5) and areas of high flood risk are known (referred to as flood hotspots), this detailed risk assessment aims to enhance the understanding of flood source, frequencies (probability), mechanics and consequences, knowing that potential mitigation measures will need to be considered at the next stage of the SWMP process (Section 4, Options).

3.2 Approach

This assessment has been informed by a range of existing data and information including the results of the purpose-built 1D-2D integrated hydraulic model developed as part of the Catchment Study previously undertaken and new survey of the Mill Race.

3.2.1 Existing data and information

To begin any risk assessment, maximum use should be made of existing data and information including previous studies and investigations. Much of this data and information has been collected by RMAs as part of their specific roles and responsibilities. This was then supplemented by information provided by other stakeholders, including data on surface water drainage assets and local evidence of historical flooding incidents.

Table A.1 in Appendix A contains a list of key datasets and outlines how these have been used to inform the risk assessment. Table A.2, also in Appendix A, provides an overview of with key findings and recommendations from previous plans, studies, and investigations.

3.2.2 Site visits

As part of the Catchment Study, on the 5th October 2017, a site visit was undertaken by Jacobs UK Ltd, the multi-agency Steering Group and additional RMA staff members with specific expertise. The objectives of the site visit were to:

- Help bring issues to life around the December 2015 flood event;
- Gain an understanding of hydrological systems such as rivers and drainage / sewer networks;
- Identify local site characteristics that may influence flooding mechanisms; and
- Identity wider opportunities and constraints that may influence flood risk management measures.

The October 2017 site visit was then supplemented by a second site visit by Jacobs UK Ltd on 12th December 2017 with a focus on understanding the surface water catchment and urban features and how these may translate into the 1D-2D integrated hydraulic model to be developed as part of the Catchment Study.

3.2.3 Hydraulic modelling

As part of the Catchment Study in 2018, a purpose-built 1D-2D integrated hydraulic model of the City centre was developed to provide a useful tool that would define the frequency and consequence of surface water flooding across a range of design rainfall events and climate change scenarios. The integrated hydraulic model itself was built in 2D using TUFLOW[8], with the 1D component modelled using ESTRY (a 1D modelling software included in TUFLOW), with both elements used to represent:

- Direct rainfall on the study area;
- Overland flow through the built environment; and
- Interaction between the surface, the sewer network, and watercourses.

To simulate surface water flooding across the area of interest, the hydraulic model uses the Direct Rainfall approach, which consists of applying a rainfall hyetograph representative of a storm event to every active cell within the 2D surface model.

During a simulated event, the hydraulic model computes the rainfall that would be absorbed through natural infiltration into the ground, the rainfall runoff that would be routed overland by gravity and the runoff volume that would drain into and be conveyed through the storm drainage network. The overland flow routed through the built environment (2D surface model) and the flow conveyed through the drainage system are dynamically linked at each manhole. In a similar manner, there is also a dynamic link between the drainage system and the pipes discharging into River Lune and other local watercourses. Figure 3-1 provides an overview of the general model schematic.

A suite of model outputs was produced including detailed flood depth maps. Further details of the modelling approach and key findings can be found in the Catchment Study report.

Annual Exceedance Probability Event

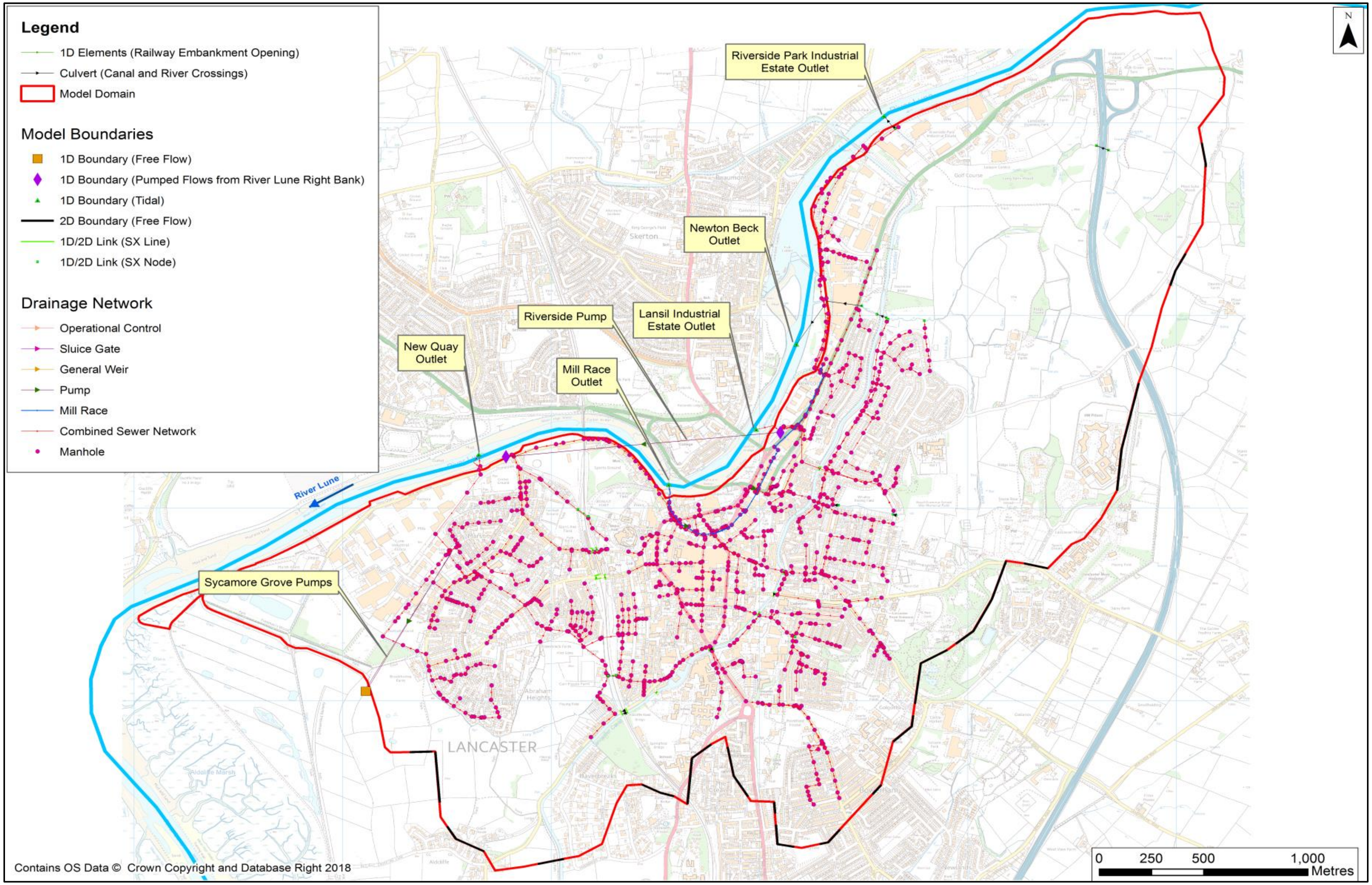
This report uses the term annual exceedance probability (AEP) to express flood frequency. This is a better approach when presenting hydraulic model results in comparison to the annual maximum return period. This is due to the misconception that return periods are associated with a regular occurrence rather than an average recurrence interval e.g. the 100-year flood will not only occur every 100-years but has a 1% chance of being exceeded in any year. However, to aid the understanding of flood frequency, the table below provides a comparison of AEP to return periods.

AEP	20%	10%	5%	3.33%	1.33%	1%	0.5%
Return Period	5-yr	10-yr	20-yr	30-yr	75-yr	100-yr	200-yr

The hydraulic model has been found to offer a good representation of flood mechanisms and identifies known overland flood flow routes and areas of ponding, which have been validated against historical surface water flooding datasets (e.g. December 2015 flood outlines and wrack marks) and anecdotal information from RMAs. The model itself is based upon best available information at the time of its construction including surface water drainage network datasets and best practice hydrological estimation methodologies. However, with any hydraulic model, several assumptions remain. Whilst these do not limited the usefulness of the model for the SWMP, they will be important to remember during Section 3.3, which describes the surface water flooding mechanisms. These include:

- The hydraulic model does not include a detailed representation of the highway drainage network i.e. road gullies and pipes, as this is considered too detailed for this type of model.
- An outline representation of the Mill Race is included based upon best available information from United Utilities' InfoWorks ICM model. The model does not include any survey data discussed in Section 3.2.4 as this was collected after the Catchment Study was complete.
- At the time of model development, the Lancaster Phase 3 FAS, which includes a fluvial flood defence scheme along the bank of the River Lune adjacent to the Riverside Park Industrial Estate and the Lansil Industrial Estate had not been constructed. The hydraulic modelling however assumed it to be present and represented the defence as a "glass wall" boundary condition.
- Whilst the model includes the contributing surface water catchment around Junction 34 of the M6, the model pre-dates the construction of the Bay Gateway road scheme and therefore, does not include any associated changes to topographical or the surface water drainage network.
- A storm duration of 6 hours was found to be critical for various areas including the city centre. However, for the catchment of Newton Beck, the critical storm duration was found to be 1hr. Some areas within the Lansil Industrial State and the Riverside Industrial State showed a critical storm duration between 8hrs to 10hrs. The model has not been calibrated due to lack of gauged data for pluvial events.
- Two baseline scenarios have been considered, these are the Do-Minimum and the Do-Nothing scenarios. Both scenarios assume a mean high-water spring (MHWS) as tidal boundary condition for the outlets into the River Lune and as a result free flow conditions of surface water drainage outfalls.

Figure 3-1: General model schematisation



3.2.4 Mill Race surveys

The historic Mill Race in the City centre, which dates back to 1610, has over time been gradually covered over by structures and buildings, lost with the building of railway sidings and the Kingsway, or subsumed within local drainage system.

The Mill Race was included in the 1D-2D integrated hydraulic model of the city centre as a key drainage network using the 1991 survey and network data provided by United Utilities. The hydraulic model results show that during a rainfall event, the Mill Race carries a significant amount of flow in comparison with the combined sewer pipes that run parallel to it. Blockage sensitivity testing carried out also shows that any reduction in capacity increases surface water flood depths at Bulk Road, Damside Street and Cable Street.

Although represented in the 1D-2D integrated hydraulic model, there remained a significant data gap regarding condition, connectivity, capacity and its role within surface water drainage across the city centre. Following completion of the Catchment Study in 2018, Lancashire County Council commissioned additional work in July 2018, which included 3D laser scanning survey and CCTV of the Mill Race to:

- Confirm its alignment with consideration to ownership and affected parties;
- Understand the combined systems and interactions / functionality;
- Understand specific storage capacity (although further modelling will be required);
- Identify origin and consideration to 'Jelle Beck' and significance as a watercourse and out fall condition;
- Consider future specific flow monitoring; and
- Understand opportunities for possible future use in Lancaster flood alleviation.

A full suite of digital deliverables was created including 3D topographic survey, 360 colour HDR imagery, 3D surface mesh datasets and CCTV. Further details of the survey approach and key findings can be found in the Mill Race Survey report[9].

3.2.5 Flood History

Historical flood incident data are a critical source of information to understand flood locations. This information can also be used to understand the history of flood incidents within a location and changes to flooding patterns over time.

According to the data provided by the Environment Agency, the main historical flood mechanisms recorded are overtopping of channel banks and defences along the River Lune and Lune estuary as a result of heavy rainfall events (for example in 1872, 1903 1919, 1985 and 1995), whilst tidal and coastal events have overtopped embankments and quaysides (for example in 1977, 1983 and 2002)[10].

However, whilst Lancaster City centre has been subjected to localised flooding associated with a range of fluvial, tidal and surface water flood events, the flooding that the City experienced on the 5th December 2015 as a result of Storm Desmond remains the most significant incident.

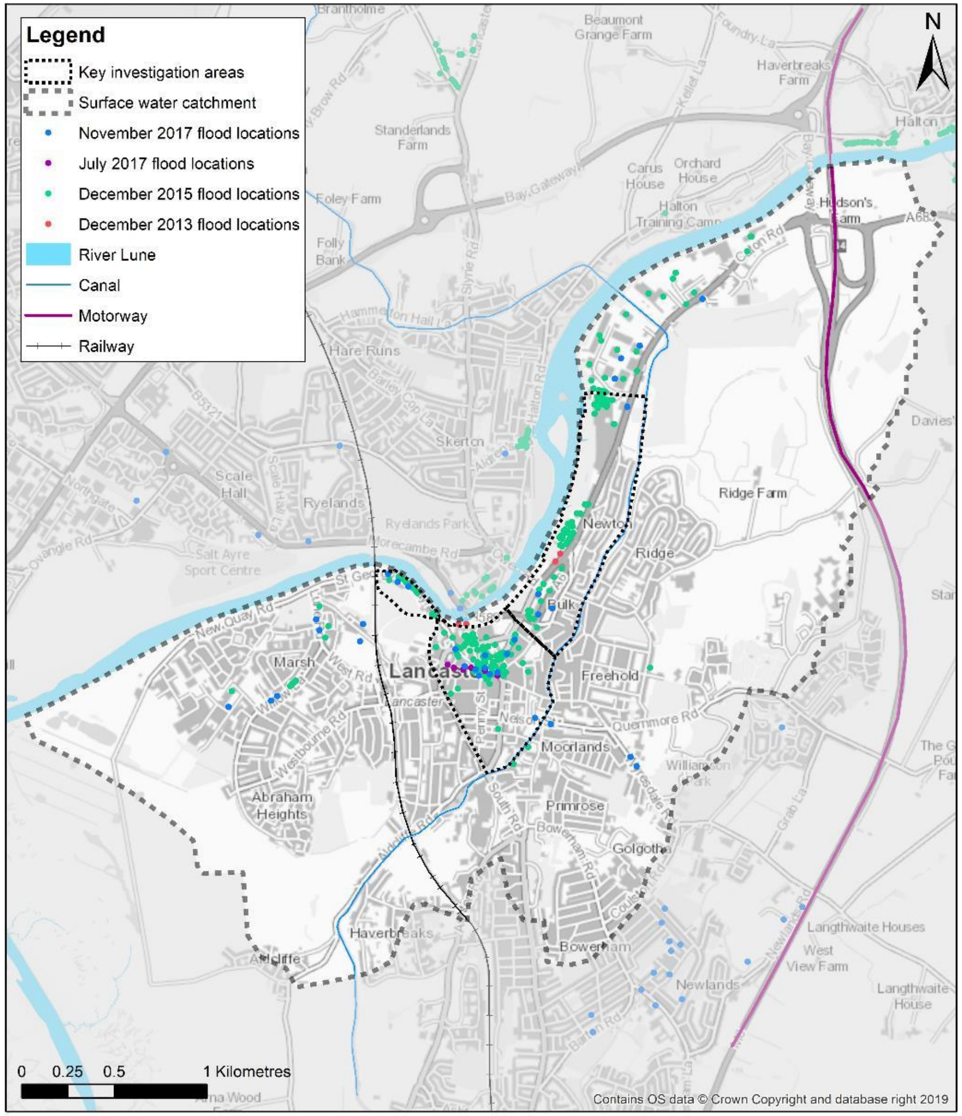
Table 3-1 provides an overview of the larger known surface water flood events affecting the City centre. Using data provided by the Environment Agency, Figure 3-2 helps to illustrate the extent and location of areas within the City centre affected by these flood events. There are no records of surface water flooding prior to 2000.

Table 3-1: Known surface water flood events, mechanisms and consequences

Date	Flood Source / Mechanism	Flood Consequence
12th Jan 2000	High river levels along the River Lune causing local drainage and surface water flooding.	Flooding in Halton and Lancaster.
5th Dec 2013	A storm coinciding with high tides caused the large storm surge on the River Lune in 60 years. This caused some flooding along the Lune at Ladies Walk and the subway between the Millennium Bridge and Lune Street[11].	No reliable figures on numbers of properties flooded. It is reported that the Quay Flood Barrier held and protected property from major flooding at St George's Quay.
5th Dec 2015	Prolonged and heavy rainfall through the month leading to December coupled with an intense rainfall event associated with Storm	332 properties known to have suffered from internal flooding within the City centre.

Date	Flood Source / Mechanism	Flood Consequence
	Desmond resulting both fluvial and surface water flooding across Lancaster. This included overtopping of the River Lune upstream of Skerton Weir and overwhelmed drainages systems leading to surface water flooding within the City centre. The rain gauge at Hazelrigg (Lancaster University) recorded 59.7mm of rainfall in 24-hours[4].	Overtopping of the River Lune also affected an electricity substation, on Caton Road, which resulted in approximately 60,000 homes and businesses being without power for nearly 48 hours[4].
19th July 2017.	Intense rainfall overwhelmed highway drains with water ponding in low lying areas of the city. Highways drains and sewers were reported to be partially blocked with leaf litter and rubbish[12]. Flooding was also experience on 30th July 2017; however, no information is available on sources or consequences.	No reliable figures on number of properties of flooded but photographs show flooding of non-residential properties along Church Street[13]. Firefighters attended nine properties to pump out water or isolate electrics[14].
22nd - 23rd Nov 2017	On the night of 22nd - 23rd November 2017, a heavy intensity rainstorm was recorded travelling from the Irish Sea coast at Blackpool to the north-easterly extent of Lancaster District. The rain gauge at Hazelrigg (Lancaster University) recorded 73.6mm of rainfall in 24 hours - the highest level in more than 50-years since the centre started weather observations. The resulting rainfall overwhelmed public sewers and highway drainage systems, resulting in surface water flooding within the City centre[15].	Surface water flooding of roads, homes, businesses and open space. A total of 41 properties reported flooding across 39 streets, with 16 properties flooded internally.

Figure 3-2: Historical flood events



3.3 Catchment Characteristics and Flood Mechanisms

Together, all data introduced above helps to build a conceptual understanding of surface water flooding mechanisms as described next in Section 3.3, with the results of the integrated hydraulic modelling used to assess flood consequences such as number of properties at risk and likely economic flood damages (Section 3.10).

3.3.1 Catchments

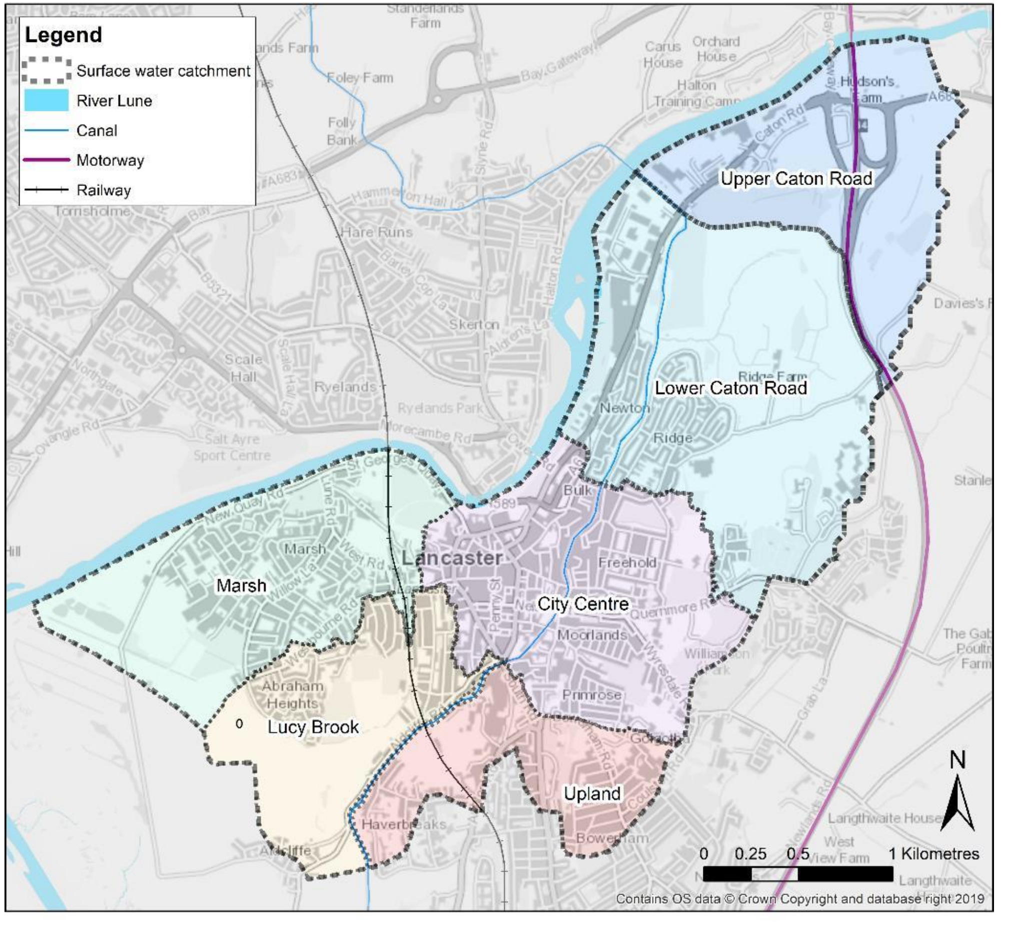
To help build the conceptual understand of surface water flood risk, the three surface water catchments as defined by the Catchment Study has been further divided into six sub-catchments as shown in Figure 3-3, including:

- Sub-catchment A: Upper Caton Road
- Sub-catchment B: Lower Caton Road
- Sub-catchment C: City Centre
- Sub-catchment D: Upland
- Sub-catchment E: Lucy Brook
- Sub-catchment F: Marsh

Whilst these sub-catchments help to compartmentalise the surface water issues, these are not hard boundaries, and as illustrated by the hydraulic model results, roads and subsurface drainage will act as surface water pathways between each sub-catchment.

It will be important to keep this in mind throughout the later sections of this report when discussing possible options and why targeted incremental interventions across all sub-catchments will be required to achieve the overall goal.

Figure 3-3 Surface water sub-catchments

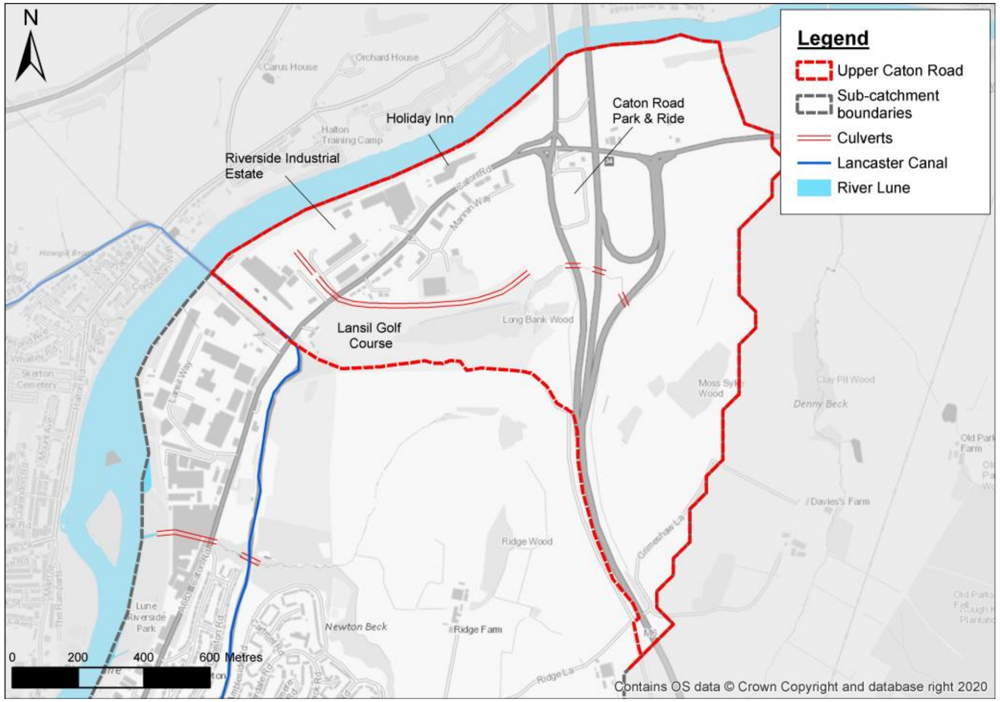


3.4 Catchment A: Upper Caton Road

3.4.1 Catchment Characteristics

The Upper Caton Road catchment lies in the north-eastern extent of the Lancaster surface water catchment (Figure 3-4). It is bounded by the River Lune to the north, the Lune Aqueduct (Lancaster Canal) to the west, and high ground to the south and east. The head of the catchment lies in the south, and peaks at an elevation of 75 metres Above Ordnance Datum (mAOD). High ground extends north from this peak as a ridge along the eastern catchment boundary, where the elevation drops slightly to 55 mAOD. High ground also exists to the south of Long Bank Wood (50 mAOD).

Figure 3-4: Upper Caton Road sub-catchment



The catchment slopes steeply northwest in the south and east, but most of the north and west are relatively flat and lie at an elevation of less than 20 mAOD, which comprises the base of the Lune Valley. The area of land situated between the River Lune and Caton Road forms the lowest part of the catchment, lying at a similar elevation to, or only 1-2m higher, than the banks of the River Lune (7-10 mAOD). Another key feature influencing the topography in the catchment is the M6 motorway and the Bay Gateway junction, which runs north-south through the centre of the catchment and forms a raised embankment that has the potential to effect surface water runoff. Historical and present-day Ordnance Survey maps show the area surrounding the junction as a marsh, i.e. an area with potential for wet and boggy ground conditions.

Land use throughout large parts of the catchment, and on higher ground, is agricultural with small areas of woodland. Urbanisation has been confined to the low-lying reaches including the Riverside Park Industrial Estate, the Lancaster Business Park, and the Park and Ride (adjacent to the M6 / Bay Gateway junction).

The River Lune flows southwest along the catchment's northern boundary. It's reach in this location lies beyond the normal tidal limit (generally considered as Skerton Weir[6]), but during high tide, backwater effects could be felt further upstream (to Halton Weir). During historical flood events, e.g. December 2015, this area did not benefit from formal flood defences. However, at the time of writing (Autumn 2020), the Environment Agency are constructing the Lancaster Phase 3 FAS. This comprises a flood wall along the left-hand bank of the River Lune from the Holiday Inn on Caton Road to a point approximately 150 m north of Skerton Bridge providing a Standard of Protection (SoP) up to the 1% AEP fluvial flood event.

An unnamed Ordinary Watercourses issues from the area of high ground in the south of the catchment and flows north alongside the eastern M6 embankment. The watercourse turns west and flows through three culverts beneath the motorway, before continuing in open channel towards Lansil Golf Course. The watercourse is culverted through the golf course (in twin 450 mm pipes), and beneath Caton Road. At Caton Road there is a restriction in flow, caused by the downsizing of the twin 450mm pipes, to twin 150 mm diameter pipes. Downstream of this restriction (on the north side of Caton Road), the culvert is upsized to a single 750 mm pipe. The watercourse is then culverted under most of the Riverside Park Industrial Estate, before eventually discharging into the River Lune via a Tideflex non-return valve structure. The watercourse is joined by several smaller tributaries that flow northwards, issuing from Long Bank Wood, or from the western M6 embankment in the south. Several small sections of Ordinary Watercourse are also shown on Ordnance Survey maps in the east of the catchment, two of which originate from springs visible on historical maps. It's unknown if these are hydrologically connected to the main Ordinary Watercourse that flows through Lansil Golf Course.

Lancaster Business Park is served by separate foul and surface water sewers, with foul waste pumped out of the catchment to Riverside Pumping Station (located in Catchment C: City Centre). Surface water is drained to a point on Caton Road, opposite the Holiday Inn, where it enters the highway drainage network. The highway drainage network then discharges into the River Lune behind the Holiday Inn. A combined sewer system serves the Riverside Industrial Estate (in part), which drains southwest into the Lower Caton Road catchment.

Soils across most of the catchment are described as loamy and clayey soils[16], although historical borehole records show more of a sandy soil to be present, with sandy and loamy soils in the west[17]. Mapped superficial geology in the west of the catchment (by the Riverside Park Industrial Estate and the Lancaster Business Park) comprises made ground, with alluvium and river terrace deposits, overlying glaciofluvial sands and gravels. Historical borehole records show the lithology of these deposits to be highly permeable, comprising ballast (coarse stone and sand) and/or sand and gravel, to a depth of between 5-17 metres below ground level (mbgl). At the time of drilling, groundwater was recorded between 1-2 mbgl, and could indicate generally shallow groundwater levels within this area. Glacial till is mapped in the southwest of the catchment and was found in historical boreholes, underlying the sand and gravel deposits, described as a clay with gravel. Below the till, a bedrock of interbedded sandstone, gritstone and marl was encountered at depths of around 20-30 mbgl, belonging to the Roeburndale Member of the Silsden Formation.

In the north of the catchment, glacio-fluvial sands and gravels are present to a depth of between 7-11 mbgl, directly overlying bedrock, with groundwater encountered up to 1.8 mbgl. In the south and east, glacial till is mapped and described as a sandy clay; although there are several small areas where the till is absent, including in the far south where the main Ordinary Watercourse issues. Historical borehole records along the route of the M6 motorway show a series of sand, and sand and gravel deposits to a depth of 3-6 mbgl, either overlying glacial till, or bedrock where the till is absent. These borehole records pre-date motorway construction and could therefore indicate that parts of the south and east of the catchment are covered in more permeable sand, or sand and gravel deposits that are not mapped, although this is not certain. Bedrock in the north, south and east of the catchment is the Pendle Grit Member of the Pendleton Formation, comprising permeable interbedded sandstone and siltstone.

3.4.2 Flood Mechanisms

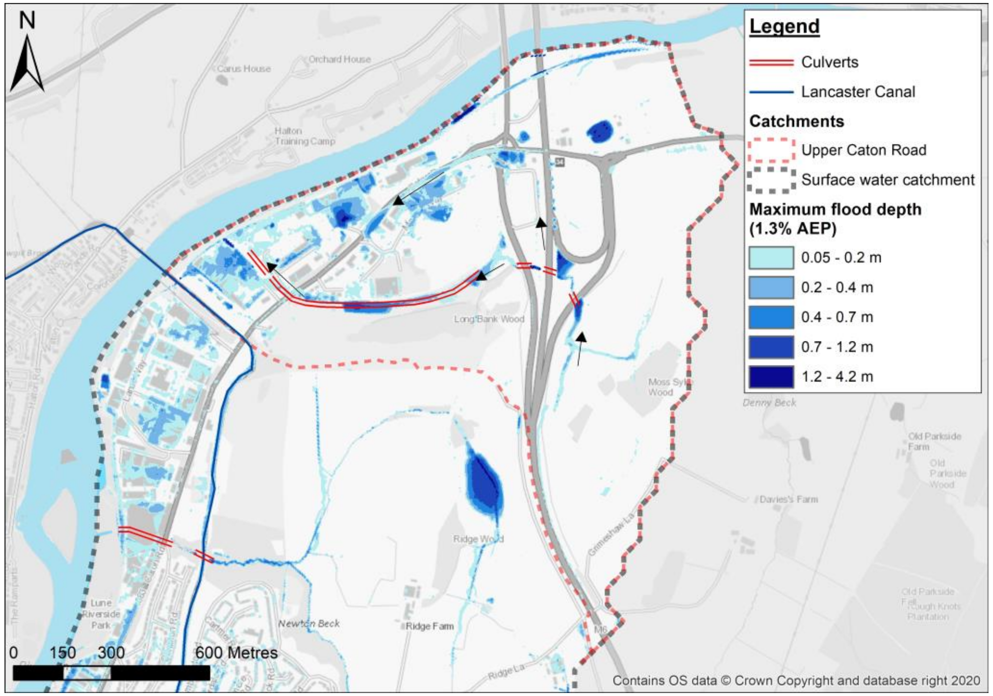
Surface water flooding due to direct rainfall runoff

- Potential for significant surface water runoff generation from steep slopes in the south and east of the catchment. This may be enhanced by lower permeability soils and glacial till deposits, which likely limit infiltration and corresponding recharge rates to the underlying superficial aquifer[ii].
- A degree of natural surface water attenuation would likely occur in topographic lows to the west of Moss Syke Wood, as well as the M6 motorway junction and the Caton Road Park and Ride.
- The 1D-2D integrated hydraulic model outputs show two main surface water flow paths during the 1.33% AEP pluvial event (Figure 3-5). One flow path forms the rainfall-runoff response for the unnamed Ordinary Watercourse. When the Lansil Golf Course and Caton Road culverts surcharge, flood flows continue west towards the Riverside Park Industrial Estate. A second flow path originates when the M6 (western slip road) culvert surcharges, with flood flows routed northwards onto Caton Road Park and Ride, where they combine with

[ii] An aquifer is a saturated permeable geological unit that stores groundwater and allows it to flow under normal conditions. Where groundwater flows from an aquifer into a watercourse, this is defined as baseflow. It is possible, in the right hydrogeological setting, for groundwater flows to increase fluvial flood risk and vice versa for high river levels/tidal locking to increase groundwater levels in an adjacent aquifer.

runoff from Hudson Farm in the northeast of the catchment. Flows are then conveyed along Caton Road and are intercepted (in part) by highway drainage.

Figure 3-5: Upper Caton Road surface water flood risk map



Fluvial flooding from unnamed Ordinary Watercourse

- The Caton Road culvert along the unnamed Ordinary Watercourse surcharges during events more frequent than the 50% AEP pluvial event and contributes to the surface water flow paths described.
- Peak water levels within the River Lune are above the soffit level of the watercourse outfall during events more frequent than the 50% AEP fluvial flood event, which could prevent flows from discharging and contribute to increased flooding upstream (see Table 3.8 in the Catchment Study).

Direct groundwater flooding

- Made ground deposits and superficial geology are expected to be highly permeable in the north and west of the catchment, giving rise to rapid responses in groundwater levels following recharge events. At times, groundwater levels may be shallow, and approach the ground surface in the low-lying parts of the catchment. This may cause flooding to below ground infrastructure, such as basements, cellars etc. where present.
- Where there are no significant sub-surface barriers, there is potential for water levels within the River Lune and the alluvial / sand and gravel aquifers to be in hydraulic continuity. When river levels are high, pressure heads could recharge the aquifer(s), and cause groundwater levels to rise away from the flood defences, even when the river flows remain in bank.
- Where foundations for the Phase 3 FAS comprise continuous below-ground structures, e.g. sheet piles, groundwater flows may be prevented from discharging into the River Lune as baseflow, and cause groundwater levels to be artificially higher on the upgradient side, thus increasing groundwater flood risk. This would also be the case (at a localised / property level) where building foundations, below ground chambers etc. are present and lie perpendicular to the groundwater flow direction.

Groundwater contribution to other flood sources

- A shallow water table in parts of the catchment may limit rainfall infiltration, increasing the rate of runoff and surface water flooding. Potential groundwater ingress into drainage and sewer systems could reduce their efficiency for conveying surface water and cause them to surcharge at an earlier onset.

Highway drainage and sewerage infrastructure

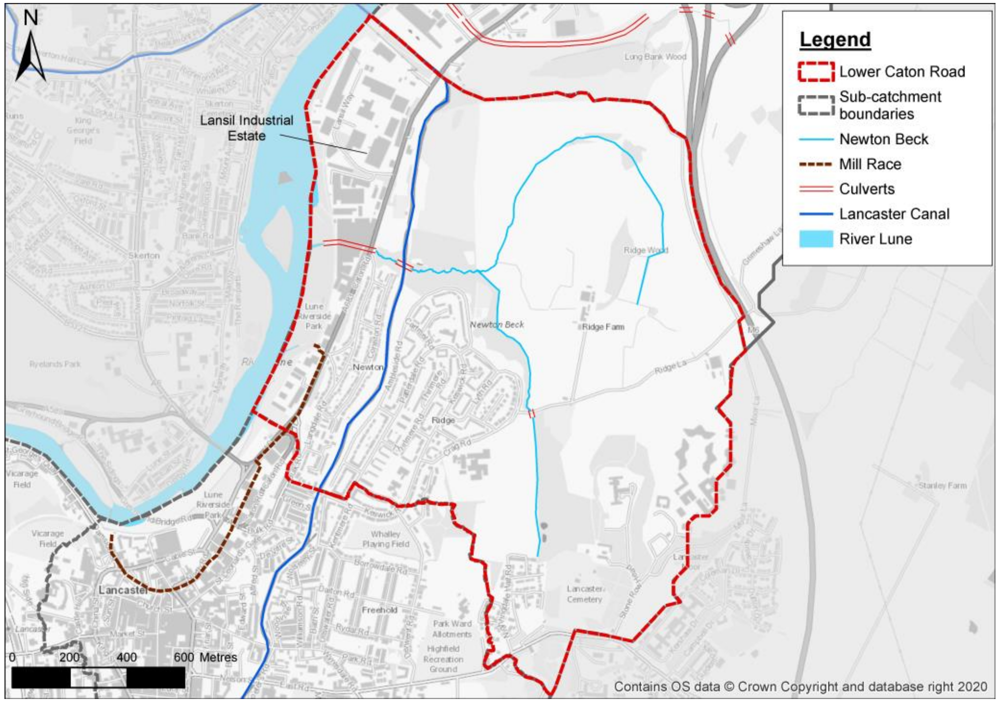
- During prolonged or heavy rainfall events, the drainage and sewer systems may start to surcharge, and contribute to the surface water flow paths. If water levels in the River Lune rise above soffit level of surface water outfalls, flows could become locked, leading to networks surcharging and flooding during more frequent pluvial events.

3.5 Catchment B: Lower Caton Road

3.5.1 Catchment Characteristics

The River Lune marks the western boundary of the Lower Caton Road catchment (Figure 3-6), with high ground bordering the catchment to the north, east and south. The topography generally slopes steeply westwards, towards the River Lune. However, there are several ridges of higher ground which run north-south within the catchment. Between these ridges lie several basin-like areas, which are likely to promote the ponding of surface water and shallow groundwater.

Figure 3-6: Lower Caton Road sub-catchment



The Lancaster Canal runs south to north through the west of the catchment, east of Caton Road, which could influence the topography and surface water flow paths within the pluvial catchment. The highest part of the catchment is in the southeast, which lies at an elevation of approximately 90 mAOD. The lowest-lying area is situated to the west of Caton Road, lying approximately 1-2 m above the banks of the River Lune (at 7-10 mAOD).

Land use in the north and east of the catchment is predominantly agricultural, with patches of woodland and some areas of marsh shown on historical maps. The residential areas of Ridge and Newton occupy the southwest of the catchment, either side of the Lancaster Canal. In the southeast, Lancaster Cemetery lies within the vicinity of a small residential area, and HM Prison Lancaster Farms. Industrial land uses are confined to the lowest-lying area, situated along Caton Road.

Newton Beck is the main Ordinary Watercourse, and likely originates from the residential area to the west of Lancaster Cemetery. Newton Beck flows north through the centre of the catchment, before turning west to the north of the Ridge residential area. As it flows west, Newton Beck passes through culverts beneath the Lancaster Canal, Caton Road, and Standfast Barracks, before discharging into the River Lune. Several tributaries are shown to issue from either side of Ridge Farm and converge with the beck in the centre of the catchment.

The stretch of the River Lune that borders this catchment includes Skerton Weir, which is generally considered to be the normal tidal limit. However, during high tide, tidal influences can extend upstream as far as Halton Weir.

The area to the west of the Lancaster Canal is primarily served by a combined sewer network, except for the northern part of the Lansil Industrial Estate. The latter is served by a separate foul / surface water system, with the surface water system discharging into Newton Beck. The combined network also includes flows which originate from the Riverside Industrial Estate. This combined system ultimately feeds into the Riverside Pumping Station in the City centre. The area to the east of Lancaster Canal is primarily served by a separate foul / surface water sewer network, although some areas are served by a combined system. The surface water network discharges into Newton Beck, upstream of the Lancaster Canal, whereas the foul and combined networks feed into the Riverside Pumping Station.

The Mill Race forms a key component of the drainage and sewerage infrastructure present within the catchment (see Mill Race survey report[9] for more information). The asset is known to receive inputs from the combined sewer and surface water drainage networks, but the original inlet from the River Lune is assumed to no longer receive fluvial inflows. Based on the results of a recent topographical survey[9], the Mill Race was found to be situated at a relatively shallow depth (typically between 2 – 4 mbgl), with the potential to alter shallow groundwater flow regimes.

Soils and geology within the catchment are complex. Most of the catchment comprises low permeability loam and clay soils, with loam and sandy loam soils located in the area to the west of the Lancaster Canal[16]. Made ground is expected to be present in the residential and industrial areas. Where encountered in historic boreholes, the deposit is generally described as comprising brick, concrete, stones, ash / clinker and similar materials, to depths of between 0.5-3.0 mbgl[17]. Alluvium is mapped between Caton Road and the River Lune and extends eastwards along the course of Newton Beck. Beneath the alluvium, in the west of the site, are sand and gravel deposits; either of glaciofluvial origin or comprising river terrace deposits. Across most of the catchment, and at depth beneath the other superficial deposits, is glacial till, described as a silty sandy clay with gravel. Drumlins are mapped throughout the catchment, creating the previously mentioned ridge features.

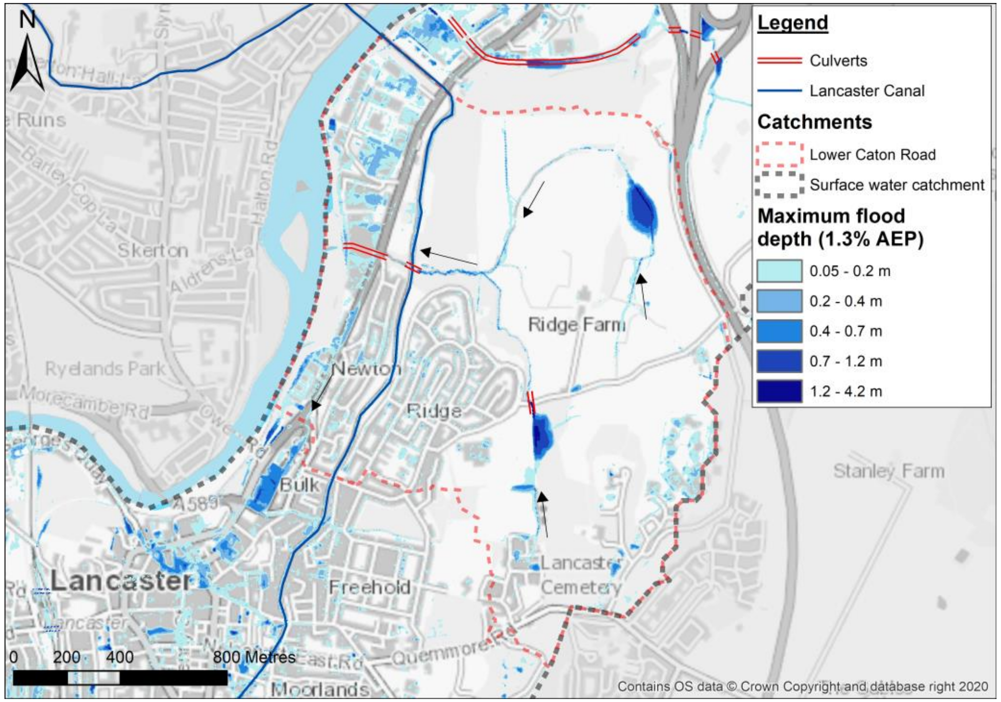
A bedrock of interbedded sandstone and siltstone underlies most of the catchment, belonging to the Pendle Grit Member, with two sandstone units along parts of the eastern and northern catchment boundaries. In the northwest, the Roeburndale Member is shown to be present, comprising interbedded sandstone, gritstone and marl. Historical borehole data suggests that the Roeburndale Member may extend further south and is reached at depths of between 15-30 mbgl.

3.5.2 Flood Mechanisms

Surface water flooding due to direct rainfall runoff

- Potential for significant surface water runoff generation from steep slopes in the east of the catchment. This may be enhanced by lower permeability soils and glacial till deposits, which likely limit infiltration and corresponding recharge rates to the underlying superficial aquifer.
- A proportion of surface water flows are likely to be attenuated naturally within the topographic lows present between the ridges (drumlins) in the centre and east of the catchment. The northern and southern reaches of Newton Beck Ordinary Watercourse will also capture surface water runoff from the east (Figure 3-7).
- The Lancaster Canal likely acts as a hydraulic barrier for surface water flows from the upper catchment. The canal footpath in the north, and Ridge Lane in the south, could convey runoff from the east of the canal, but flows are expected to be minimal due to areas of high ground which limits connectivity to the west. Direct rainfall to the west of the canal is shown by hydraulic model outputs to cause flooding of the Lansil Industrial Estate.

Figure 3-7: Lower Caton Road surface water flood risk map



Fluvial flooding from Newton Beck

- There is a low risk of fluvial flooding from this watercourse up to an including the 1% AEP flood event. Culvert capacities and high levels within the River Lune are not expected to cause fluvial flooding from Newton Beck.

Direct groundwater flooding

- There is a moderate risk of groundwater flooding in the northwest of the catchment[18], as well as the areas surrounding Newton Beck, with a probability greater than the 1% AEP (Figure 3-8). This confirms the current understanding of groundwater flooding mechanisms within the catchment.
- The Mill Race may present a semi-impermeable barrier to groundwater flows, and generally lies perpendicular to the main groundwater flow direction in the catchment. There is potential for groundwater levels to be artificially raised on the upgradient side of the asset, increasing localised groundwater flood risk. This may also be an issue due to local building foundations, below ground chambers etc.

Groundwater contribution to other flood sources

- A shallow water table in parts of the catchment may limit rainfall infiltration, increasing the rate of runoff and surface water flooding.
- In addition to direct ingress into drainage and sewer systems, groundwater ingress into the Mill Race through misconnections, culverts, shafts, cracks etc. could reduce its capacity to convey surface water and sewer flows out of the catchment, causing the Mill Race, and associated surface water and sewer systems to surcharge at an earlier onset.

Highway drainage and sewerage infrastructure

- If water levels in the River Lune rise above soffit level of surface water outfalls, flows could become locked, leading to networks surcharging and flooding during more frequent pluvial events. The drainage and sewer network generally start to surcharge from the 2% AEP pluvial event, with exceedance surface water conveyed along Caton Road, either into the City Centre catchment or towards the Alexandra Barracks.

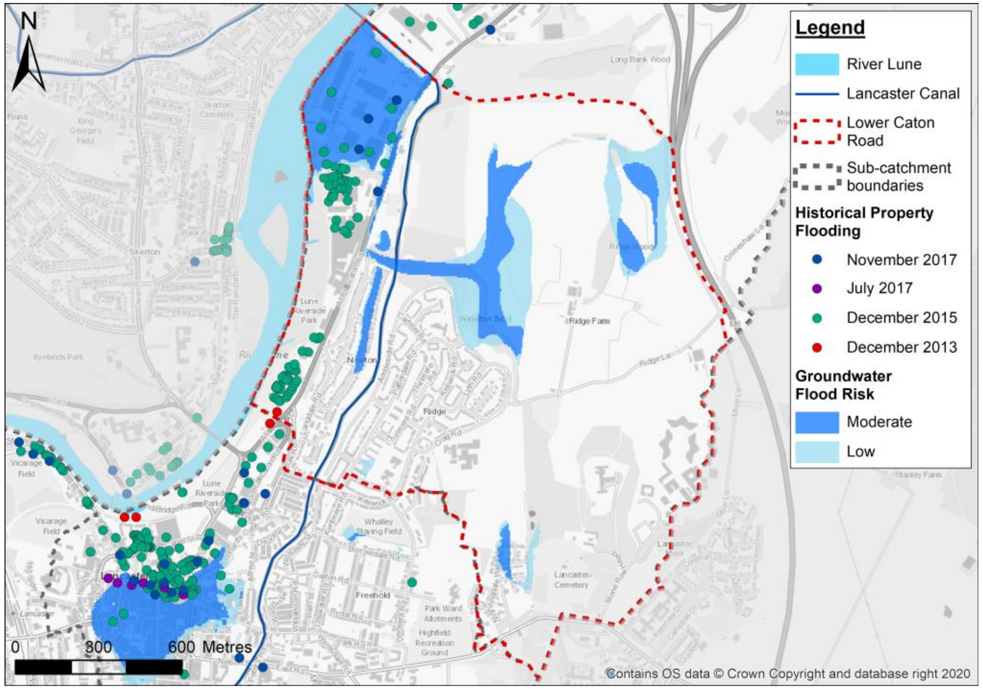
Mill Race

- A combination of inflows to the asset, from surface water drainage, combined sewer overflow (CSO) connections, and foul and surface water sewers, likely cause the Mill Race to surcharge during frequent pluvial flood events. This could lead to increased groundwater flood risk adjacent to the asset.

Lancaster Canal

- The hydraulic modelling identifies a risk of flood water overtopping the Lancaster Canal embankments at certain locations along its reach during heavy rainfall and strong winds. Flood flows would be routed westwards by the topography, and either cause direct flooding or enter drainage and sewerage systems (where possible).

Figure 3-8: Lower Caton Road groundwater flood risk map

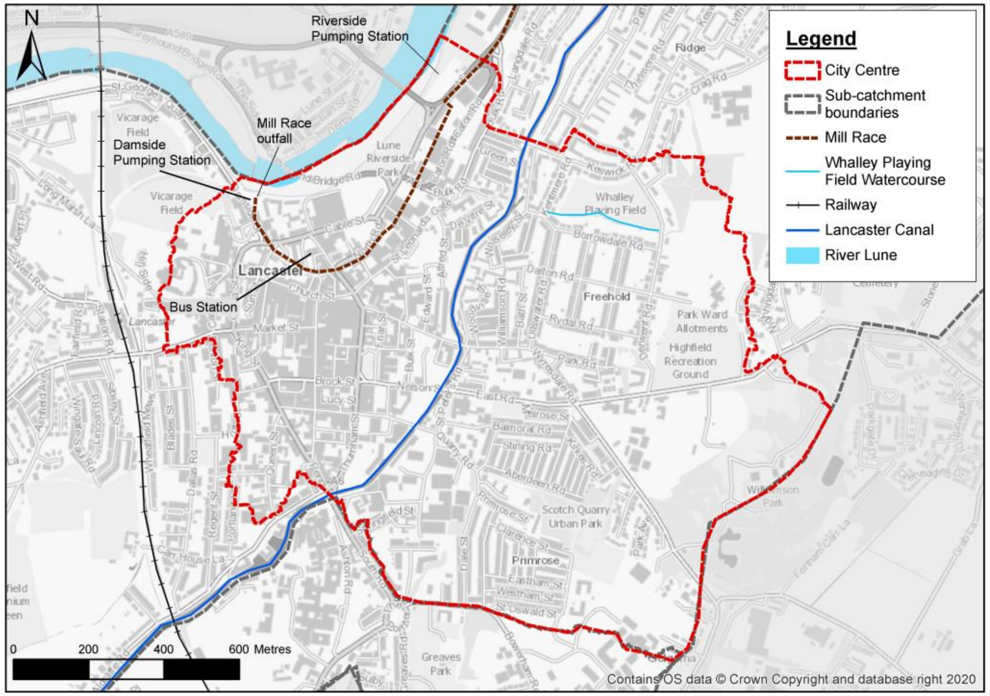


3.6 Catchment C: City Centre

3.6.1 Catchment Characteristics

The City Centre catchment is bounded by the River Lune to the northwest and an unnamed Ordinary Watercourse to the northeast, with high ground to the south, east, and west (Figure 3-9). The head of the catchment lies in the east, and peaks at an elevation of 105 mAOD.

Figure 3-9: City Centre sub-catchment



The catchment slopes steeply northwest in the south and east, but most of the north and west are relatively flat and lie at an elevation of less than 20 mAOD, which broadly correlates with the area to the west of the Lancaster Canal. Like the two Caton Road catchments, the area of land adjacent to the River Lune lies at a similar elevation to, or only 1-2m higher, than the riverbanks. The Lancaster Canal runs southwest to northeast through the centre of the catchment and is built into the hillside, with potential to alter surface water flow paths throughout the city.

The catchment is heavily urbanised, with residential, commercial, and public buildings occupying the largest parts of the city. The industrial areas are predominantly located adjacent to the River Lune, in the lowest lying parts of the catchment. On the outskirts of the city are several recreational parks and green open spaces, including Williamson Park, Scotch Quarry Urban Park, Whalley Playing Field, and Highfield Recreation Ground; all situated in the far east of the catchment. Extensive quarrying has historically taken place in the south and east of the city, which will have altered ground conditions in these areas.

The section of the River Lune that borders the City Centre catchment lies within the normal tidal limit, with river levels subject to not only typical tidal cycles and fluctuations, but also to higher magnitude tidal flooding events. An unnamed Ordinary Watercourse flows west through Whalley Playing Field in the north of catchment and enters culvert (via two twin 225mm diameter pipes) under Kentmere Road. This culvert conveys the Ordinary Watercourse northwards, at depths of approximately 5 mbgl, and discharges into Newton Beck in the Lower Caton Road catchment.

The longest section of the Mill Race is located within the City Centre catchment. As identified through the Mill Race survey[9], in addition to surface water connections, there are five CSOs which discharge into the asset at various locations along its reach. One of these CSOs is connected to a storm detention tank located beneath Lancaster Bus Station. Water collected by the Mill Race may include varying proportions of groundwater (due to ingress), surface water inflows from drainage and sewer systems, and CSO and foul system discharges. Springs are also known to issue at Calkeld Lane and Rosemary Lane, which are understood to drain into the existing surface water drainage network[19].

Most of Lancaster City centre is served by a combined sewer network, including two pumping stations (at Damside and Riverside), located in the northwest and northeast of the catchment, respectively. The Riverside Pumping Station conveys flows to Lancaster Wastewater Treatment Works (WwTW) and has an associated CSO. The CSO spills into the River Lune when the pump capacity is exceeded. The Damside Pumping Station conveys flows from the Mill Race into the combined sewer network under low flow conditions. If flows within the Mill Race exceed the pumping capacity at Damside, water will discharge into the Lune Estuary. If discharge is impeded by high river levels, this could increase the risk of the Mill Race surcharge and the risk of flooding.

Water quality is generally expected to be poor within the catchment, based on Water Framework Directive (WFD) classification of the Lune Transitional WFD Water Body (currently failing Environmental Quality Standards (EQS) for several priority hazardous substances). This is supported by ground investigation records from the construction of the Bus Station storm detention tank[19], which identified several Controlled Water Screening Criteria exceedances around Damside Street, for both organic and inorganic substances. These pollutants likely transmit via the Mill Race to the Lancaster WwTW. Contaminant pathways to groundwater and surface water bodies are also expected.

Mapped soils in the east of the catchment comprise low permeability loams and clays, whereas loam and sandy loam soils cover the centre and western parts of the catchment[16]. Given the degree of urbanisation in the city centre, made ground deposits are expected to be extensive, comprising varying lithologies, and extending to depths of between 0.5-5 mbgl[17].

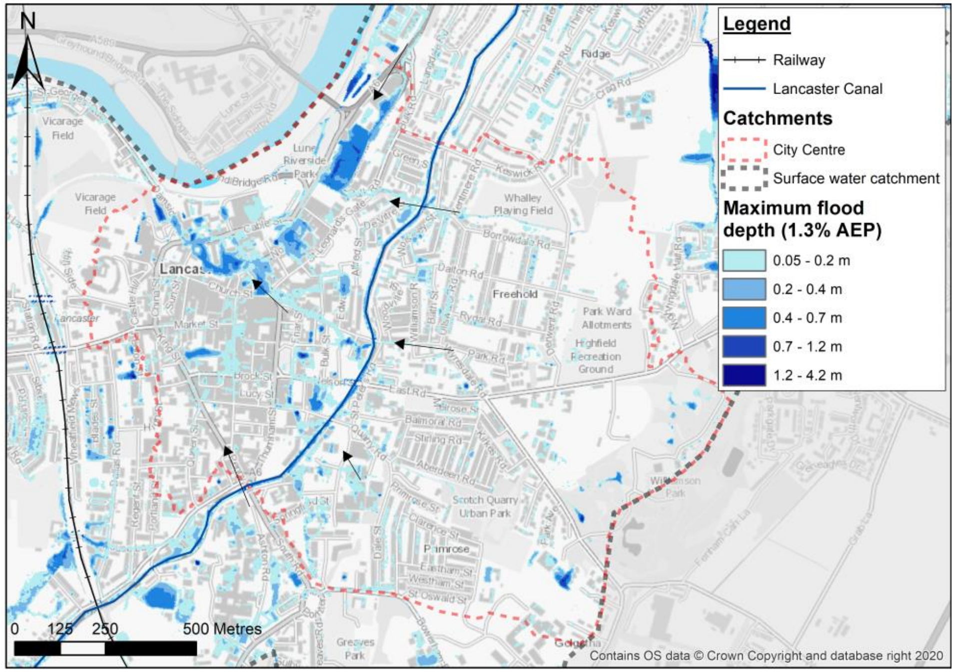
In mapping and historical borehole records, superficial deposits are shown to be absent from the Primrose, Moorlands and Freehold areas, as well as from Williamson Park in the east. Where superficial deposits are shown, they predominantly comprise alluvium, glacio-fluvial sands and gravels, and / or river terrace deposits, typically located in the lowest lying areas in the west of the catchment, with glacial till elsewhere. Sands and gravels were generally proven to depths of between 5-12 mbgl in historical boreholes, over till or bedrock. The glacial till is described as a variably silty sandy clay with gravel. The shallowest groundwater level encountered whilst drilling the historical boreholes was 2.2 mbgl. Available groundwater level monitoring data collected between 24th February and 12th June 2012, however, show groundwater levels of between 0.2-3.1 mbgl during this period, in the area around Damside Street. Bedrock underlying the catchment is the Pendle Grit Member, comprising interbedded sandstone and siltstone. In the north of the catchment, bedrock was proven at depths of between 9-12 mbgl.

3.6.2 Flood Mechanisms

Surface water flooding due to direct rainfall runoff

- Similar mechanisms for significant surface water runoff generation in the east as the Caton Road catchments; however, limited degree of natural attenuation for surface water flows, due to absence of topographic depressions and increased areas of hard standing. The hydraulic modelling outputs show the main areas of flooding are around Parliament Street and Bridge Lane / Cable Street (Figure 3-10).

Figure 3-10: City Centre surface water flood risk map



- The Lancaster Canal likely acts as a partial barrier to surface water flows from the east, but the hydraulic modelling outputs show that runoff is routed along Quarry Road, Nelson Street, and Moor Lane, providing connectivity to the west of the catchment. Model outputs also show a prominent surface water flow path along Caton Road (which enters from the Lower Caton Road catchment) and is conveyed to the industrial area to the south of Parliament Street. Inflows also occur from the Upland catchment, via Penny Street and King Street.

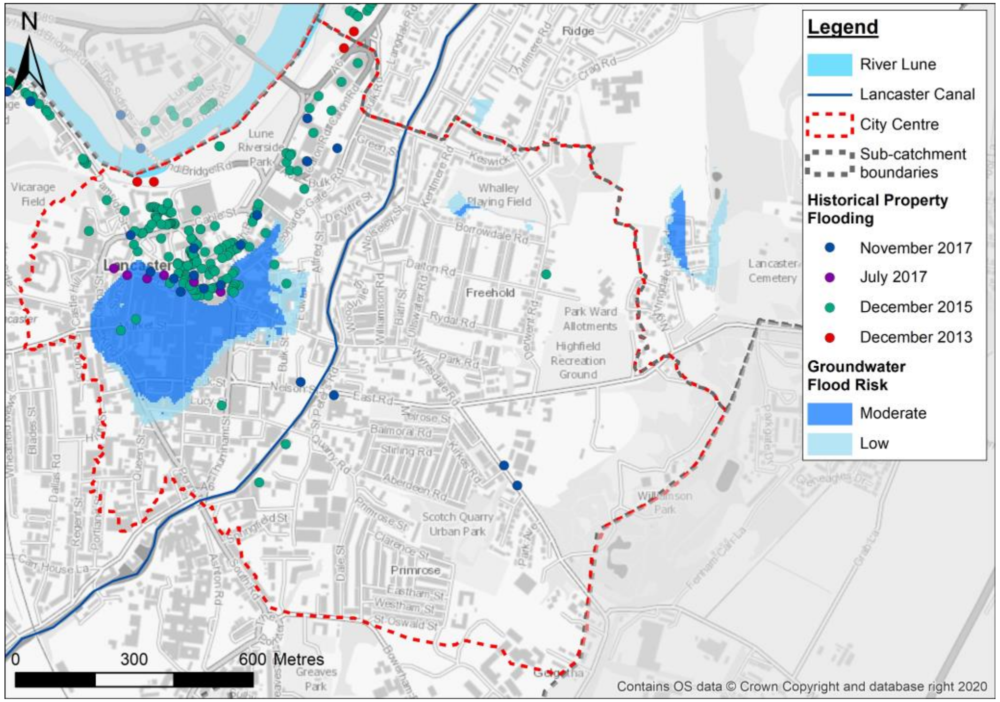
Fluvial flooding from unnamed Ordinary Watercourse

- The watercourse that flows through Whalley Playing Field may cause localised flooding when the Kentmere Road culvert surcharges during pluvial events greater than the 20% AEP.
- A historical watercourse used to exist beneath Rosemary Lane and connect to the Mill Race. This flow path may still exist.

Direct groundwater flooding

- Similar geology and groundwater level responses expected in the west of the catchment as that described for the west / north of the Caton Road catchments.
- There is a moderate risk of groundwater flooding in the northwest of the catchment[18], with a probability of greater than the 1% AEP (Figure 3-11). This confirms the current understanding of groundwater flooding mechanisms within the catchment.
- The Mill Race may present a semi-impermeable barrier to groundwater flows, and generally lies perpendicular to the main groundwater flow direction in the catchment. There is potential for groundwater levels to be artificially raised on the upgradient side of the asset, increasing localised groundwater flood risk. This may also be an issue due to local building foundations, below ground chambers etc.
- In addition, below-ground infrastructure associated with recent development around Damside Street and Rosemary Lane has been constructed below the level of the water table, and within the alluvial aquifer. There is potential for these to act as a barrier to groundwater flows, causing groundwater levels on their upgradient side to rise and increase groundwater flood risk to adjacent properties.

Figure 3-11: City Centre groundwater flood risk map



Groundwater contribution to other flood sources

- A shallow water table in parts of the catchment may limit rainfall infiltration, increasing the rate of runoff and surface water flooding.
- In addition to direct ingress into drainage and sewer systems, groundwater ingress into the Mill Race through misconnections, culverts, shafts, cracks etc. could reduce its capacity to convey surface water and sewer flows out of the catchment, causing the Mill Race, and associated surface water and sewer systems to surcharge at an earlier onset.

- In addition, natural springs are known to issue at Calkeld Street and Rosemary Lane, which are understood to drain into the existing surface water drainage network, i.e. further reducing its capacity to convey surface water.

Highway drainage and sewerage infrastructure

- The drainage and sewer network in the west of the catchment generally starts to surcharge during the 5% AEP pluvial event, with the greatest flood depths occurring at Parliament Street and Bridge Lane / Cable Street.
- If water levels in the River Lune rise above soffit level of surface water outfalls, flows could become locked, leading to networks surcharging and flooding during more frequent pluvial events.

Mill Race

- A combination of inflows to the asset, from surface water drainage, CSO connections, and foul and surface water sewers, likely cause the Mill Race to surcharge during frequent pluvial flood events. This could lead to increased groundwater flood risk adjacent to the asset.
- In addition, the outfall for the Mill Race is located within the City Centre catchment and is pumped during low flows. Once the pump rate is exceeded (potentially during low magnitude pluvial flood events), the Mill Race discharges into the River Lune.
- Water levels within the River Lune rise above the top of the Mill Race outfall during at least the 50% AEP fluvial flood event, which would likely cause hydraulic locking of the asset. This would potentially increase risk of surcharging upgradient.

Other

- The hydraulic modelling identifies a risk of flood water overtopping the Lancaster Canal embankments at certain locations along its reach during heavy rainfall and strong winds. Flood flows would be routed westwards by the topography, and either cause direct flooding or enter drainage and sewerage systems (where possible).

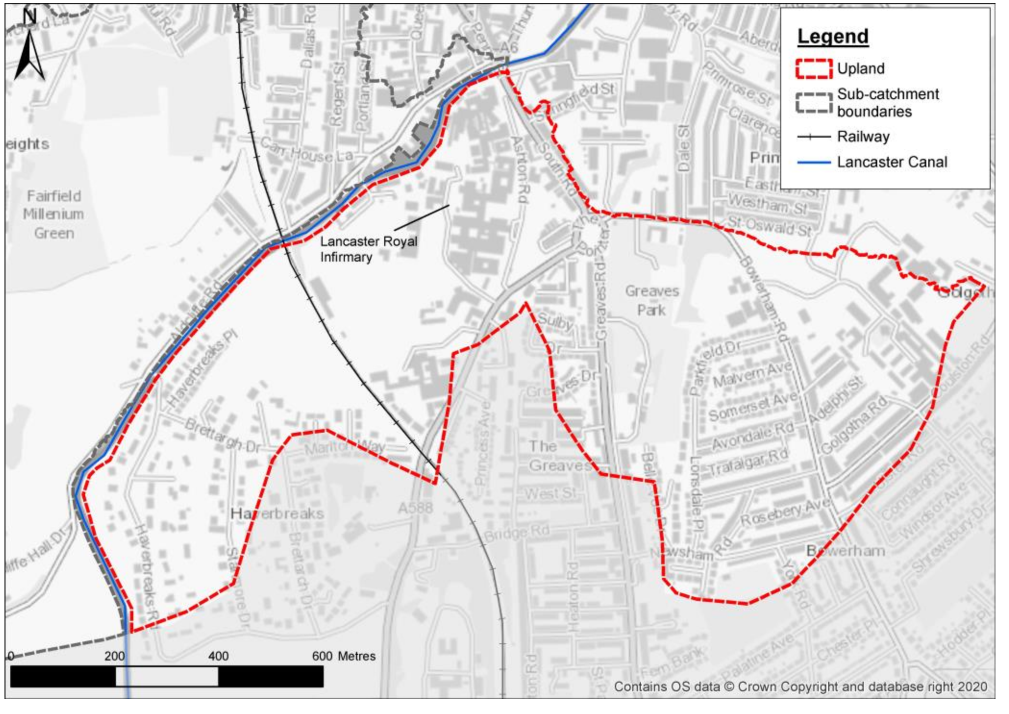
Figure 3.12: Surface water flooding Church Street – July 2017

3.7 Catchment D: Upland

3.7.1 Catchment Characteristics

The Upland catchment lies at the southernmost extent of the Lancaster surface water catchment. The Lancaster Canal runs along the entire western catchment boundary (Figure 3-13), whilst high ground forms the northern, eastern and southern catchment boundaries. The City Centre catchment borders the catchment to the north and east.

Figure 3-13: Upland Catchment



The head of the pluvial catchment lies in the far east of the catchment, around Golgotha, and reaches an elevation of 84 mAOD. The topography slopes steeply westwards towards the Lancaster Canal, with the upgradient canal embankment situated at an elevation of between 22-25 mAOD. A second area of high ground exists in the southwest (around Haverbreaks), which peaks at 50 mAOD. The Lancaster railway line runs north-south through the west of the catchment and its embankments would likely influence local topography and corresponding surface water routing within its vicinity.

The primary land uses within the catchment include residential areas, at Bowerham, The Greaves and Haverbreaks, as well as public buildings, such as the Royal Lancaster Infirmary (situated in the north of the catchment). Green spaces include Greaves Park, as well as areas east of the Lancaster Canal and either side of the railway line. In the far south of the catchment, to the south of Wellington Road, lies a playing field which used to contain a large fishpond and Greaves Quarry.

There are no watercourses present within the Upland catchment. The catchment is drained by a combined sewer system, which drains north, and passes water into the City Centre catchment. The hydrological catchment could also contribute water to Lucy Brook (located 150 m west) via surface water runoff and / or groundwater (as baseflow).

Freely draining loamy soils are present across most of the catchment, with low permeability loam and clay soils in the far east of the catchment[16]. Made ground is mapped in the southeast corner of the catchment, although its extent is likely to be larger given the residential land use throughout the catchment. Glacial till, comprising a silty sandy gravelly clay, is thought to be present across most of the area, except for two small patches in the east, around Greaves Park, and in part of the Bowerham residential area[17]. Glacio-fluvial sands and gravels are mapped in the lowest lying part of the catchment, in the west, adjacent to the Lancaster Canal. Within a slight topographic depression in the Bowerham residential area, lies a thin strip of lacustrine deposits, comprising clays and silts.

Bedrock underlying the entire catchment comprises interbedded sandstone and siltstone, belonging to the Pendle Grit Member. A cluster of historical borehole records located immediately south of the catchment boundary show that bedrock was reached at depths of between 4-9 mbgl.

3.7.2 Flood Mechanisms

Surface water flooding due to direct rainfall runoff

- Similar mechanisms as for the Caton Road and City Centre catchments, with potential for significant surface water runoff generation in the east of the catchment.
- A minor degree of natural attenuation for surface water flows predicted in the localised topographic depression within the Bowerham residential area.
- The hydraulic modelling outputs show two main flow paths during the 1.3% AEP pluvial event (Figure 3-14). One flow path originates to the south of the Bowerham residential area and conveys runoff northwards through the topographic depression within which the properties are located. Runoff is shown to spill onto Bowerham Road, and at this point separates into the two main flow paths. Flows are either conveyed northwards through the City Centre catchment, or are diverted west, and flow through the western half of the catchment towards the canal.

Direct groundwater flooding

- Groundwater levels are not expected to be particularly shallow across the catchment, due to the presence of generally low permeability glacial till. The exception is the area to the east of the railway bridge, and upgradient of the canal. In this location, the water table may approach the ground surface following direct recharge to the glaciofluvial aquifer (underlain by till).

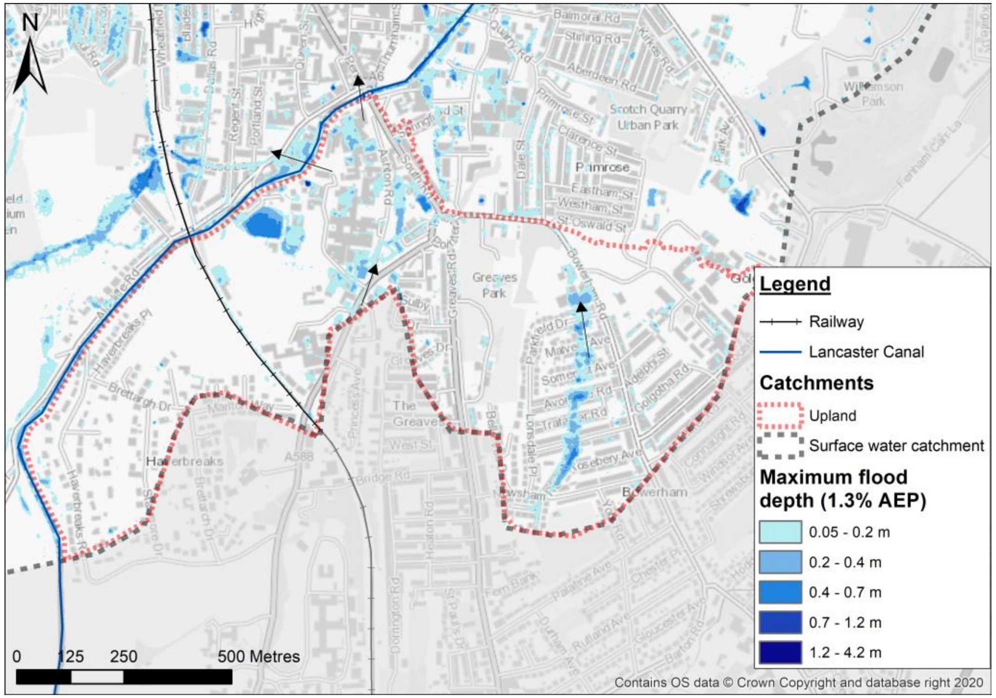
Groundwater contribution to other flood sources

- A potentially shallow water table (at times, i.e. following periods of intense or sustained rainfall/recharge saturating the ground) in the area described above, may limit rainfall infiltration rates, and increase the risk of localised surface water ponding in this area. This may increase volumes of surface water entering the drainage network.

Highway drainage and sewerage infrastructure

- The drainage and sewer network generally start to surcharge during the 10% AEP pluvial event and contributes to the main surface water flow paths described above.

Figure 3-14: Upland surface water flood risk map

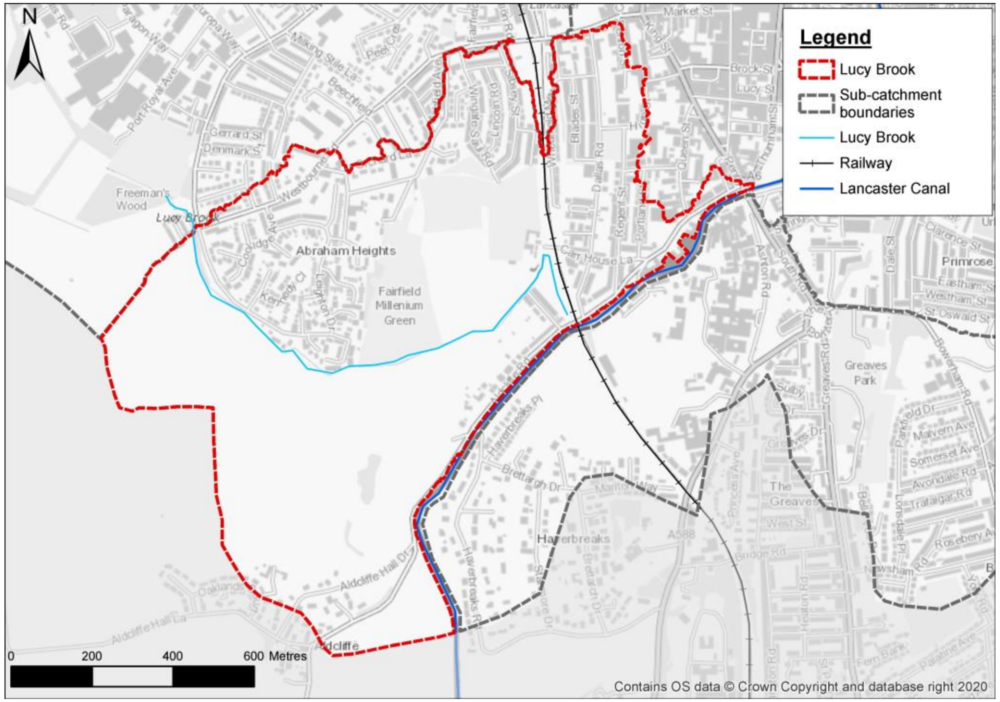


3.8 Catchment E: Lucy Brook

3.8.1 Catchment Characteristics

Further west lies the Lucy Brook catchment, with the Lancaster Canal running along the entire south-eastern catchment boundary (Figure 3-15). High ground (and the heads of the hydrological catchment), extends to the north, south and west, in the form of small raised hillocks. These localised areas of high ground peak at an elevation of between 31-36 mAOD.

Figure 3-15: Lucy Brook sub-catchment



The small ridge of high ground along the north-eastern catchment boundary, and that separates the sub-catchment from the City Centre, reaches a maximum elevation of around 27 mAOD. Elsewhere within the catchment, the ground surface broadly lies at an elevation of between 10-15 mAOD and forms a relatively flat low-lying valley. The railway embankment runs north-south through the east of the catchment and likely influences surface water mechanisms in this area.

Land use within the catchment is predominantly agricultural, with residential areas (Abraham Heights, Aldcliffe and areas to the east of the railway embankment) confined to the edges of the catchment; i.e. on slightly higher ground.

Lucy Brook Ordinary Watercourse is shown by Ordnance Survey maps to issue from an area immediately north of Aldcliffe Road, in the far southeast of the catchment. The brook flows north along the toe of the railway embankment, before turning west and entering culvert under Cromwell Road. The watercourse continues to flow west and then northwest through the catchment, predominantly in open channel, where it eventually exits the catchment via its western boundary into the adjoining Marsh sub-catchment. Two springs are shown on Ordnance Survey maps in the centre and southeast of the catchment, indicating potential for shallow groundwater conditions.

The area of Abraham Heights is served by a separate surface water / foul sewer network, with surface water discharged directly into the River Lune. The residential areas in the north and east of the catchment are served by a combined sewer network, which ultimately feeds into the Lancaster WwTW (via Willow Lane Pumping Station located in the Marsh catchment).

Freely draining loamy soils dominate the catchment[16]. The presence of made ground is confirmed by historical borehole data in the north and east of the catchment[17]. Generally, tarmacadam was encountered, overlying topsoil and sand to depths of 1-2 mbgl. Superficial deposits comprise glacial till underneath most of the catchment, with drumlins identified in the west, north and east, including the area known as Abraham Heights. The till is described as a sandy silty clay with gravel and sandstone fragments in historical boreholes in the north and east of the catchment, proven to depths of around 3-7 mbgl. Generally, no groundwater was encountered at the time of drilling the historical boreholes.

Glacio-fluvial sands and gravels are shown in the centre and east of the catchment and are recorded as underlying the glacial till in historical boreholes in the east and northeast, reaching depths of more than 12 mbgl in places. Alluvium is mapped along the course of Lucy Brook and its historical tributaries, with adjacent patches of peat. Bedrock across most of the catchment comprises interbedded sandstone and siltstone, belonging to the Pendle Grit Member, but the Roeburndale Member, comprising interbedded siltstone, mudstone and sandstone is expected to be present, at depth, in the west.

3.8.2 Flood Mechanisms

Surface water flooding due to direct rainfall runoff

- Potential for significant surface water runoff generation within the catchment is likely to be low due to the limited catchment extent. But the presence of localised mounds of high ground are expected to route runoff towards the low-lying, flat basin areas, where surface water attenuation is possible.
- The Lancaster Canal acts as a partial barrier to surface water flows from the east, but the hydraulic modelling show that runoff originating from the Bowerham residential area, could be routed along Aldcliffe Yard and crosses the canal; i.e. providing connectivity between the two catchments.
- The hydraulic modelling shows that the main flow path created is associated with Lucy Brook Ordinary Watercourse (Figure 3-16). This is formed by one flow path that originates to the east of Abraham Heights and conveys runoff southwards to join Lucy Brook and a second flow path from the south, originating from the residential area of Aldcliffe. There is potential for the Brookholme Farm culvert to surcharge and cause out of bank flooding, although is unconfirmed due to hydraulic model data gaps.

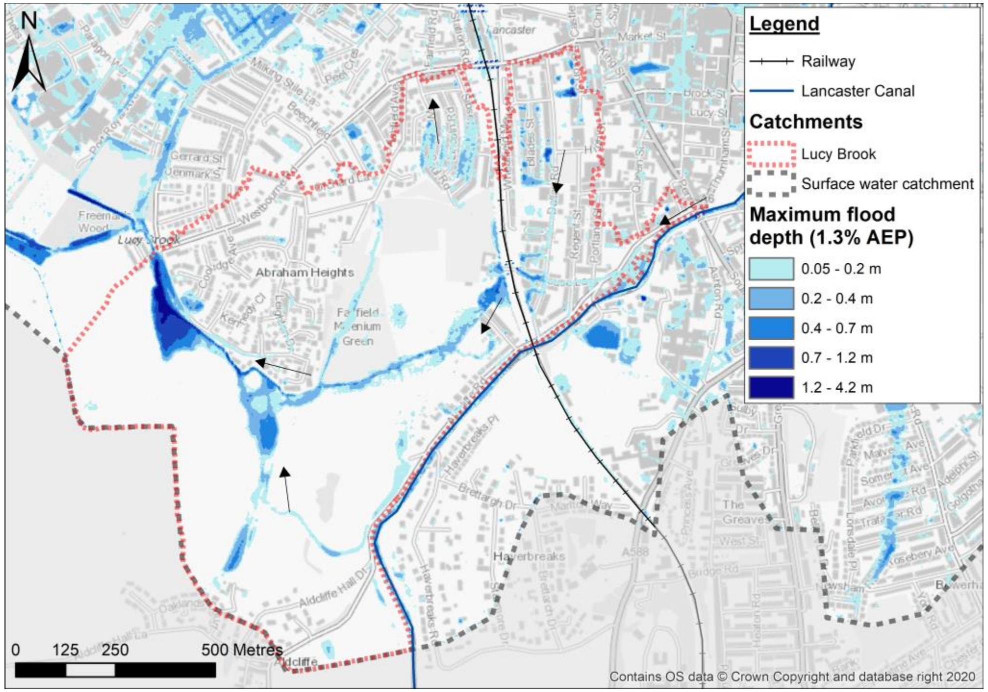
Direct groundwater flooding

- In the low-lying areas within the catchment, which correspond well with the mapped extent of unconfined sand and gravel superficial aquifers, as well as peat deposits, the water table may approach the ground surface following periods of prolonged or intense rainfall (evidenced by the presence of springs). Elsewhere, groundwater is likely to be confined by glacial till.

Groundwater contribution to other flood sources

- A potentially shallow water table (at times) in the low-lying areas, as well as the presence of glacial till elsewhere, may limit rainfall infiltration rates and increase the risk of localised surface water flooding in the catchment. This may increase volumes of surface water entering the drainage network.

Figure 3-16: Lucy Brook surface water flood risk map



Highway drainage and sewerage infrastructure

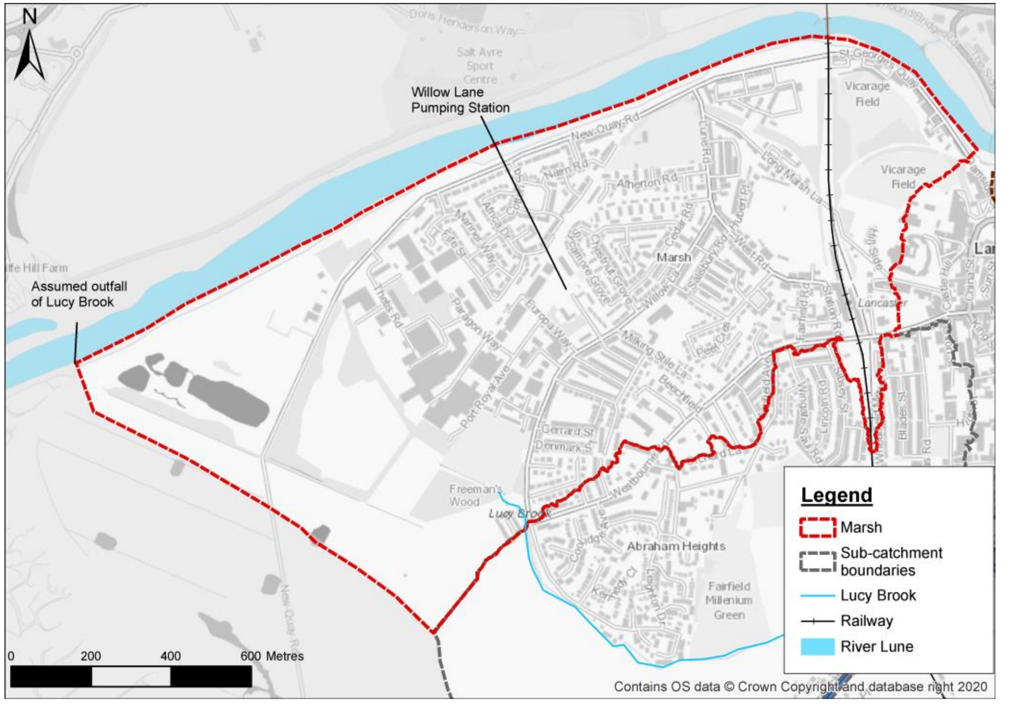
- The risk of flooding associated with drainage and sewer systems is generally thought to be low in the catchment, with little evidence of sewer surcharging from the hydraulic model results. The exception is the area around Carr House Lane / railway underpass, where the network starts to surcharge during the 10% AEP pluvial event.

3.9 Catchment F: Marsh

3.9.1 Catchment Characteristics

The Marsh catchment comprises a predominantly flat, low-lying area of land that forms part of the River Lune floodplain and estuary. The catchment is bounded to the south and east by the Lucy Brook and City Centre catchments respectively, and the River Lune to the north (Figure 3-17). The western catchment boundary broadly correlates with the mapped extent of linear fluvial and tidal flood defences.

Figure 3-17: Marsh sub-catchment



Most of the catchment lies at an elevation of between 5-7 mAOD, lying 1-2m higher than the banks of the River Lune (around 4-5 mAOD in this location). There are several localised areas of high ground, present along the southern and eastern catchment boundaries, where the ground surface reaches an elevation of between 30-35 mAOD. These small hillocks likely control surface water, fluvial, and shallow groundwater flow paths entering the catchment from areas of high ground to the south. Lancaster train station and the railway line are situated on a north-south trending embankment in the east of the catchment, which likely also influences hydrological inputs from the surrounding area.

Land use in the catchment is varied and includes the residential areas of Marsh and Abraham Heights in the centre, while the Lune Industrial Estate and Willow Business Park lie to the east of New Quay Road. Agricultural grazing land dominates the catchment in the west, adjacent to the Lune estuary. In the northeast (around Lancaster Castle), lie multiple recreation areas, as well as St George's Quay.

The Marsh sub-catchment marks the southernmost extent of the River Lune within the overarching Lancaster study area. The potential tidal influence experienced along this section of the river will be greater than the City Centre and Caton Road catchments, due to its proximity to the Lune Estuary. The linear flood defences present along the entire length of this sub-catchment's western boundary, (constructed as part of the Lancaster Phases 1 and 2), are thought to provide a 0.1% AEP SoP against tidal flooding.

Lucy Brook Ordinary Watercourse enters the catchment from the southeast and flows in a north-westerly direction, parallel to Willow Lane. The watercourse is thought to flow northwest, in and out of culvert, until it eventually discharges into the Lune Estuary in the far southwest corner of the catchment. In a field, immediately upgradient of the outfall, are several ponds which appear to be natural in origin. In addition, it appears that several drainage ditches connect into Lucy Brook along its reach throughout the catchment.

A combined sewer system serves most of the catchment, although the residential area of Abraham Heights and St George's Quay in the north are served by a separate foul and surface water network. The Marsh sub-catchment includes one of the main outflow points for the Lancaster surface water catchment, with the Willow Lane Pumping Station conveying flows to Lancaster WwTW.

Most of the catchment comprises loamy and sandy soils, with naturally high groundwater and a peaty surface[16]. Freely draining loamy soils are thought to be present in the south and east. Made ground is expected across large parts of the catchment, but particularly in the industrial areas close to the River Lune. Historical borehole data confirms the presence of made ground to depths of between 1-3 mbgl in the centre and north of the catchment, comprised of sand, clinker gravel and concrete[17]. Mapped superficial geology shows alluvium overlying glaciofluvial sands and gravels throughout most of the catchment, except in the south and east. Historical borehole data shows significant thicknesses of gravel deposits, reaching depths of between 17-48 mbgl in the north of the catchment. Elsewhere, glacial till comprising sandy silty clay with gravel is mapped in the south, with drumlins shown to be present along the southern and eastern catchment boundaries. During drilling of historical boreholes within the catchment, groundwater was reportedly struck at a depth of up to 2.3 mbgl.

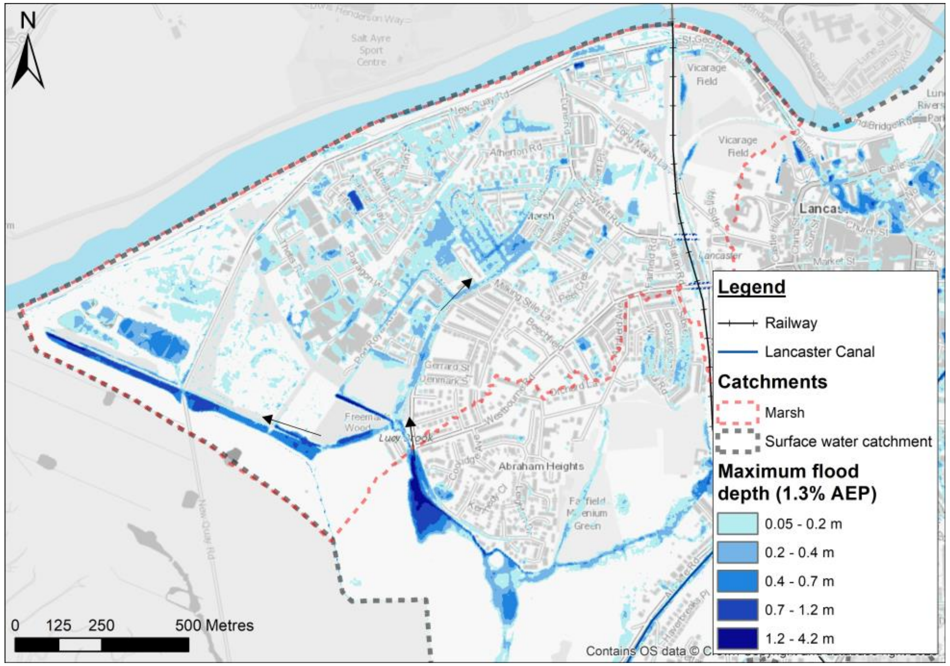
Bedrock underlying most of the catchment is the Roeburndale Member, comprising interbedded siltstone, mudstone, and sandstone, with a single sandstone unit present in the centre of the catchment. A north-south trending fault cuts across the bedrock in the west and separates the Roeburndale Member from the Collyhurst Sandstone Formation, and the adjoining Cumbrian Coast Group. The Pendle Grit Member sandstone is mapped in the far eastern edge of the catchment.

3.9.2 Flood Mechanisms

Surface water flooding due to direct rainfall runoff

- Like the Lucy Brook catchment, there is limited potential for significant surface water flow paths to be created due to the flat topography.
- The hydraulic modelling shows three main flow paths during the 1.3% AEP pluvial event (Figure 3-18). However, these are mainly associated with flooding from Lucy Brook. At Freeman's Wood, the flooding splits, with a proportion of flows conveyed north along Willow Lane that spills into the adjacent business park.

Figure 3-18: Marsh surface water flood risk map



Direct groundwater flooding

- Made ground deposits and superficial geology are expected to be highly permeable in the north and west of the catchment, giving rise to rapid responses in groundwater levels following recharge events (either directly or from being in potential hydraulic continuity with the Lune). At times, groundwater levels may be shallow, and approach the ground surface in the low-lying parts of the catchment. This may cause flooding to below ground infrastructure, such as basements, cellars etc. where present.
- Where there are no significant sub-surface barriers, there is potential for water levels within the River Lune and the alluvial / sand and gravel aquifers to be in hydraulic continuity. When river levels are high, pressure heads could recharge the aquifer(s), and cause groundwater levels to rise away from the flood defences, even when the river flows remain in bank.

3.10 Surface Water Flood Consequences

3.10.1 Quantifying flood risk

Using the outputs of the 1D-2D integrated hydraulic model it is possible to quantify current and future risk of surface water flooding across the City centre by considering the potential impacts on:

- Properties, including residential and businesses, and resulting direct, indirect and intangible economic damages that could be incurred should those properties flood internally;
- Vulnerable and critical infrastructure such as electricity substations, police stations, hospitals etc.; and the
- Environment, such as impacts on water quality in the receiving and downstream watercourses either directly through surface water runoff, or indirectly via combined sewer overflows.

Section 4 of the Catchment Study provides further detail on the methodology adopted to estimate properties at risk and resulting economic damages with detailed results provided at sub-catchment level. The following sections provide an overview of the results. All figures stated assume a present-day (Do-Minimum) scenario unless otherwise stated.

Do-Minimum scenario

The Do-Minimum scenario is defined as the minimum amount of action or intervention necessary to deliver the legal requirement or sustain the standard of service of the asset. It therefore assumes that maintenance is carried out and culverts and gullies remain clear of blockages over the full appraisal period. Blockages are however still assumed along the Mill Race as it is known that there is currently no maintenance carried out on this asset. For present day, the impact of climate change over epoch 1 (5% uplift) on rainfall intensity is still considered, with a MHWS tidal level assuming free flow of surface water discharges.

3.10.2 Properties at Risk

Table 3-2 and Table 3-3 illustrate the cumulative number of properties at risk of surface water flooding across the city for various rainfall events during the present-day scenario.

Table 3-2: Residential properties at risk of flooding

Sub-Catchments	AEP / Number of Properties						
	50%	20%	5%	3.33%	1.3%	1%	0.5%
A: Upper Caton Road	2	3	3	4	4	4	5
B: Lower Caton Road	21	35	50	51	74	83	100
C: City Centre	40	62	112	129	194	224	281
D: Upland	28	40	64	77	100	105	117
E: Lucy	38	43	55	69	86	92	126
F: Marsh	23	42	96	119	261	304	362

Table 3-3: Non-residential properties at risk of flooding

Sub-Catchments	AEP / Number of Properties						
	50%	20%	5%	3.33%	1.3%	1%	0.5%
A: Upper Caton Road	9	14	28	30	38	39	41
B: Lower Caton Road	15	23	40	45	61	68	101
C: City Centre	49	70	106	127	171	183	216
D: Upland	5	10	13	13	16	16	18
E: Lucy	3	4	12	12	14	15	15
F: Marsh	3	5	15	18	29	30	38

3.10.3 Economic flood damages

The consequence of flooding in monetary terms is estimated through the calculation of economic flood damages using standardised guidelines and figures provided in the Environment Agency's Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG)[20], and the Middlesex University's Flood Hazard Research Centre's Multi-Coloured Manual (MCM)[21].

The calculation of flood damages considers:

- Residential and non-residential direct damages resulting from flood water inundating a property;
- Vehicle damages;
- Indirect non-residential damages;
- Emergency service costs; and
- Costs associated with evacuation and providing temporary accommodation.

Flood damages estimates are then calculated for:

- A single, specific storm event i.e. a 1% AEP rainfall event;
- Average annual damages (AAD) i.e. the annual average damages expected to be incurred each year considering the probability of each storm event occurring; and
- Total present value (PV) damages over a longer appraisal period (in this case 100-years) i.e. considers the impact of climate change and discounted rates on the AAD over the appraisal period.

Each stage of the calculation process provides a useful insight into flood risk.

Damages incurred during a single storm event

Figure 3-19 illustrates the split of damages incurred due to surface water flooding across a range of single storm events modelled.

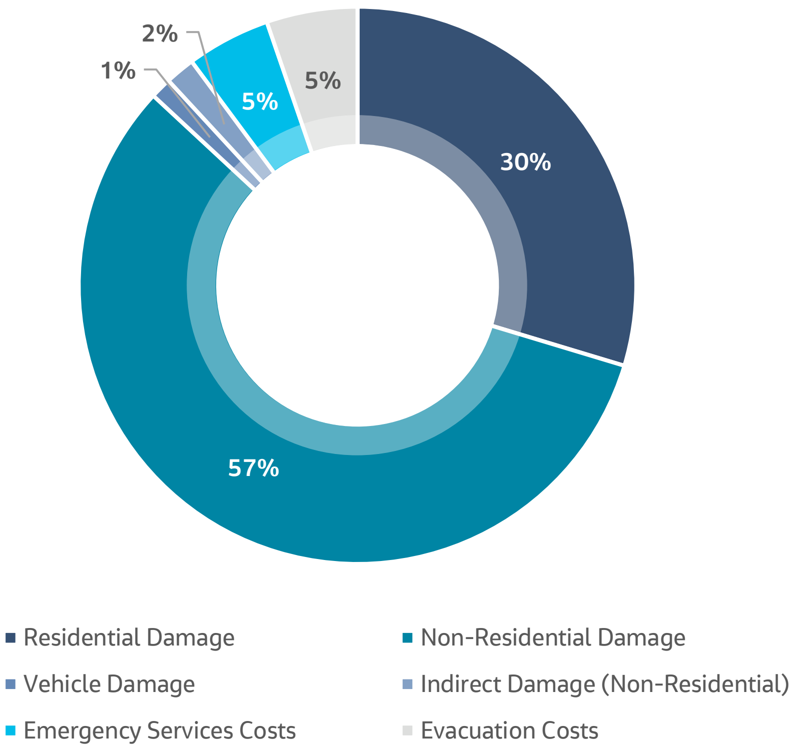
This includes total damages across the six sub-catchments (Upper Caton, Lower Caton, City centre, Upland, Lucy Brook and Marsh catchments).

Figure 3-19: Damages per AEP event

As shown in Table 3-2, more residential properties are at risk across the six sub-catchments in total. However, as shown in Figure 3-19, non-residential damages account for the largest proportion (approx. 60%) of direct damages, in comparison to residential direct damages (approx. 30%). Other indirect or intangible damages account for approximately 10% of the total damages incurred.

This is observed across all storm events modelled, although the percentage on non-residential damages does increase with more extreme rainfall events. Figure 3-20 helps to illustrate this percentage split for the 3.33% AEP event.

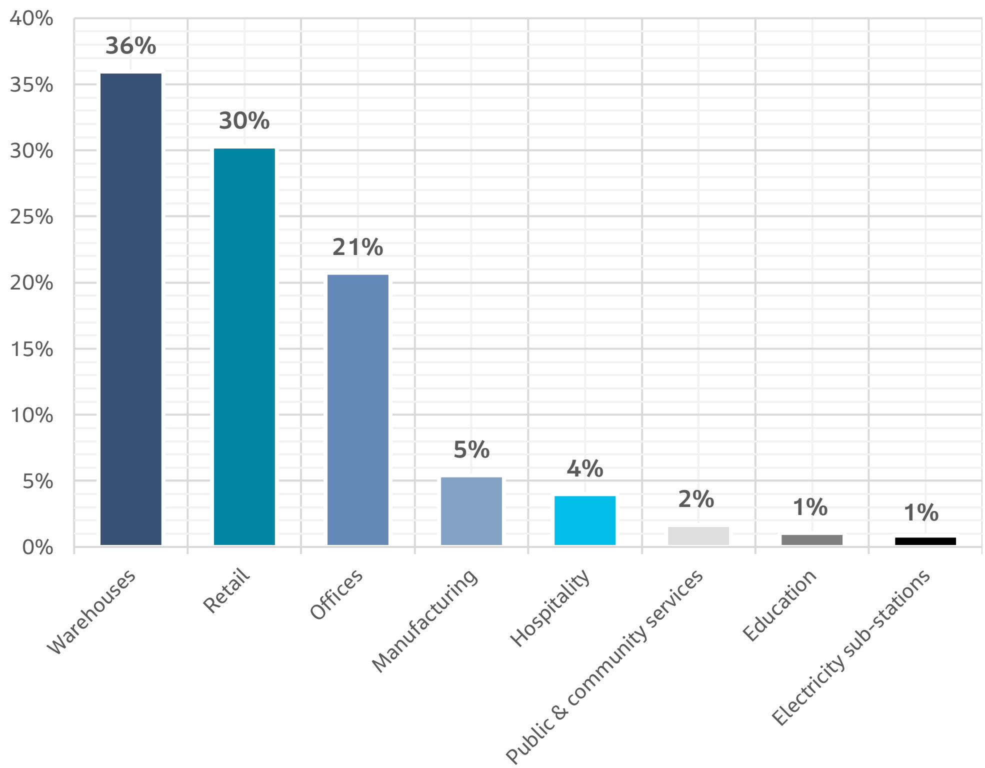
Figure 3-20: Damages (3.33% AEP event)



It can also be observed from Figure 3-19 that non-residential damages significant increase from the 5% AEP and again and the 1.33% AEP. A similar step is also present in residential properties at risk. This may indicate exceedance thresholds where surface water drainage networks become overloaded or when flood depths exceed residential properties thresholds at scale.

Figure 3.21 helps to illustrate the type of non-residential property at risk. As can be seen, there is a large proportion of warehouses, offices, and manufacturing properties potentially as expected within the industrial estates along Caton Road. Retail, offices and hospitality are more expected within the city centre.

Figure 3.21: Type of non-residential property at risk (1.33% AEP event)



Effects of climate change of future flood damages

The likelihood and intensity of summer rainfall events is predicted to increase in the North West of England as a result of climate change. Consequently, surface water flooding may become more frequent and severe in the future.

To assess the effects of climate change, UKCP09 projections associated with the central estimate on rainfall intensity allowances have been modelled across the full range of storm events. A climate change uplift allowance for peak tidal levels has also been applied to understand the impact on surface water discharges. The climate change uplifts have been applied in line with the 2016 Environment Agency guidance for Flood risk assessments[22] as outlined in Table 3.4. Further details of the approach are outlined in the Catchment Study.

Table 3.4: Climate change allowances (total potential change anticipated).

Source	Epoch 1: '2020s' (2018 to 2039)	Epoch 2: '2050s' (2040 to 2069)	Epoch 3: '2080s' (2070 to 2115)
Rainfall	5%	10%	20%
Tidal levels	108.5mm	343.5mm	870.5mm

Figure 3-22 illustrates to total direct damage that could be incurred across each storm event as well as the impact of climate change across each of the three epochs.

The figure shows a relatively minor increase in direct damages between Epoch 1 and Epoch 2, suggesting a lack of sensitivity to an additional 5% in rainfall over the next 20 to 40 years. This could also suggest that during the present-day scenarios (Epoch 1), most of the urban drainage network would already be overwhelmed during high frequency events and the additional rainfall is unlikely to change the pattern of flooding.

However, the figure also shows that during Epoch 3, there is a considerable increase in damages predicted, particularly during high magnitude/lower frequency events. This shows the catchment is sensitive to an increase in rainfall of 20% which could suggest a tipping point either further overloading of critical drainage infrastructure, additional flood hotspots or property thresholds being exceeded.

Figure 3-22: Effects of climate change on damages per AEP event

Present value damages

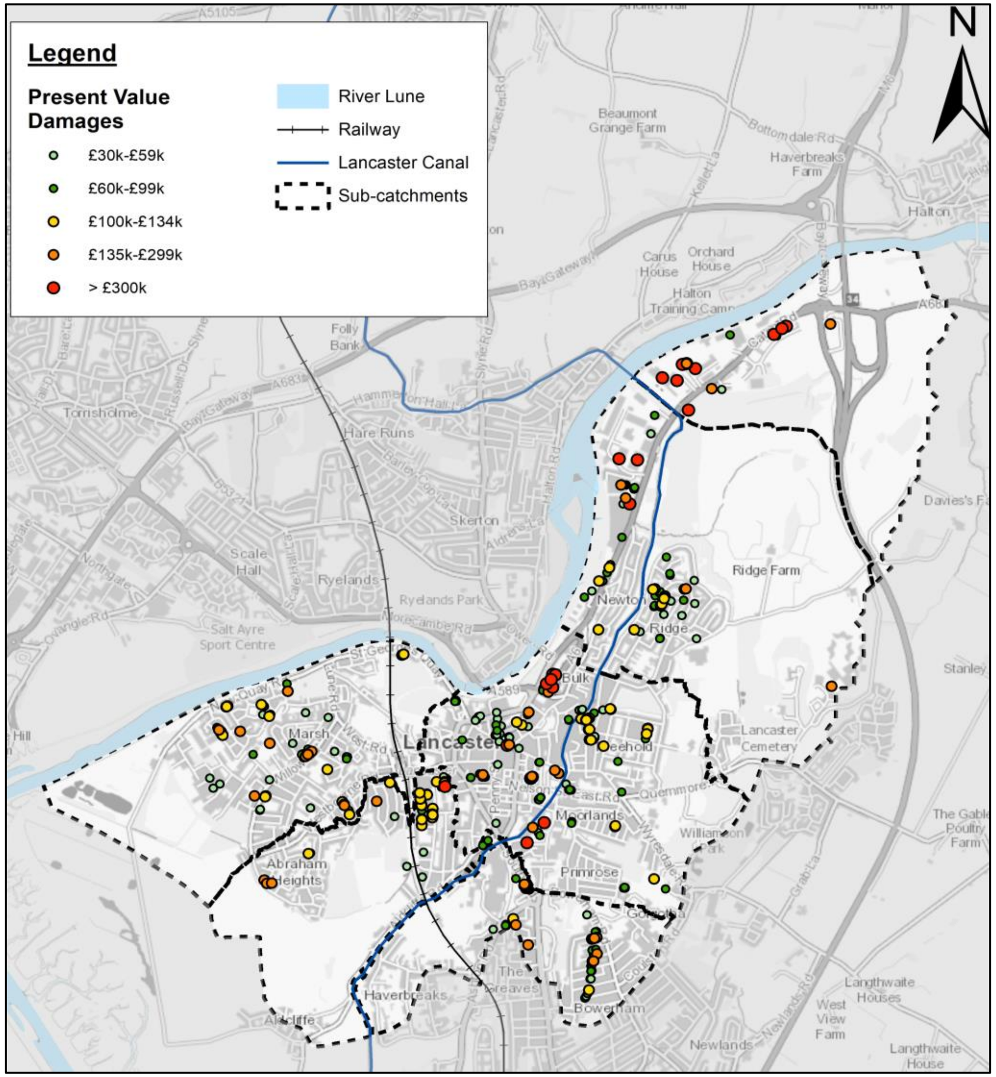
Table 3-5 provides an overview of the total PV damages incurred over the full 100-year appraisal period. These have been provided on a sub-catchment basis for both residential and non-residential properties.

Figure 3-23 illustrates the distribution of properties at risk of flooding and their associated PV damages.

Table 3-5: Total PV damages

Sub-Catchment	Residential	Non-Res	Other	Total
A: Upper Caton Road	£0.49 m	£28.08 m	£1.50 m	**£30.07 m**
B: Lower Caton Road	£3.41 m	£8.11 m	£0.69 m	**£12.21 m**
C: City Centre	£8.37 m	£11.57 m	£1.79 m	**£21.73 m**
D: Upland	£4.94 m	£0.17 m	£0.70 m	**£5.81 m**
E: Lucy Brook	£6.30 m	£1.04 m	£0.45 m	**£7.79 m**
F: Marsh	£8.34 m	£0.95 m	£1.83 m	**£11.12 m**
Total	**£31.85 m**	**£49.92 m**	**£6.96 m**	**£88.73 m**

Figure 3-23: Present Value damages per property



3.10.4 Infrastructure at risk

Flooding of vulnerable or critical infrastructure can have a significant impact on the communities that they serve. Not only is there a potential direct impact or damage associated with the infrastructure becoming inundated (e.g. damage to road surface), the loss of service can also have wider reaching impacts. For example, the flooding of the Caton Road substation during Storm Desmond resulted in the loss of power for 61,000 properties. This resulted in far reaching impacts including the loss of mobile phone coverage, the internet and household lighting and heating[23].

The serviceability of an infrastructure also plays an important role in post-flood recovery and response. If hospitals or fire stations, which need to remain operational during times of flood are unable to, impacts associated with flooding can be prolonged and intensified. This could result in further social and economic impacts which are not considered when calculating property damages.

Figure 3-24 helps to illustrate the immediate response required to the substation flooding in Lancaster including generators brought into Lancaster from as far away as the West Country and Northern Ireland and re-laying of high voltage cables outside the substation. Table 3-6 provides an overview of vulnerable or critical infrastructure at risk of surface water flooding in Lancaster based on the hydraulic modelling results.

Figure 3-24: Response required due to substation flooding[23]

Table 3-6: Vulnerable and critical infrastructure and services at risk

Infrastructure	Onset	Comments
Royal Lancaster Infirmary	20% AEP	Approximately 50% of the site is at risk from shallow (<250mm) flooding predicted to approximately up to 1% AEP event. Flood depths are predicted increase in some areas of the site up to 400mm during events >1% AEP.
Lancaster Community Fire & Ambulance Station	20% AEP	The site at Cable Street is at risk of shallow (<250mm) flooding during the 5% AEP event. The site will become surround by floodwater of up to 200mm during 1% AEP event. Flood depths in excess of 500mm are predicted along surrounding roads during 1.33% AEP, which could impede access.
Lancaster Police Station	> 0.2% AEP	The station at Thurnham Street would remain free from floodwater up to the 0.2% AEP event.
Lancaster City Bus Station	1% AEP	The station at Cable Street is at risk of shallow (<250mm) flooding during the 1% AEP event. Flooding to surrounding roads is predicted up to 500mm during the 1.3% AEP event.
Mannin Way substations	10% AEP	Onset of flooding during the 10% AEP event to depths of approximately 250mm. These increase through various flood events to a maximum of 350mm during the 1% AEP event.
Lansil Way substations	5% AEP	Early onset of flooding, however, depths are predicted to be shallow (<100mm) across all modelled return periods.
Kingsway Retail Park	1.3% AEP	Flooding to the site would likely occur from the 1.3% AEP event onwards, with maximum flood depths anticipated to be 150mm (1.33% AEP event) to 250mm (1% AEP event)
Spring Garden Street substations	20% AEP	Primary substation for Lancaster (along with Caton Road), flooding of the site onsets at 20% AEP event to a depth of approximately 150mm. This increases to a maximum of 250mm up to the 1% AEP event.
Caton Road substation	10% AEP	Model results suggest that the substation is at risk of flooding during a 10% AEP event. However, this substation flooded during Storm Desmond and measures have since been taken to protect the site against a 0.1% AEP event.

3.10.5 Resilient Route Network

The Resilient Route Network is conceptualised as the minimum road network Lancashire County Council will strive to be keep continuously open, as far as is practicably possible, in severe weather to protect essential economic activity and provide access to key services. It ensures continuity of travel across neighbouring local authority boundaries by providing access to the strategic road network.

Figure 3-25: Resilient Route Network in and around Lancaster

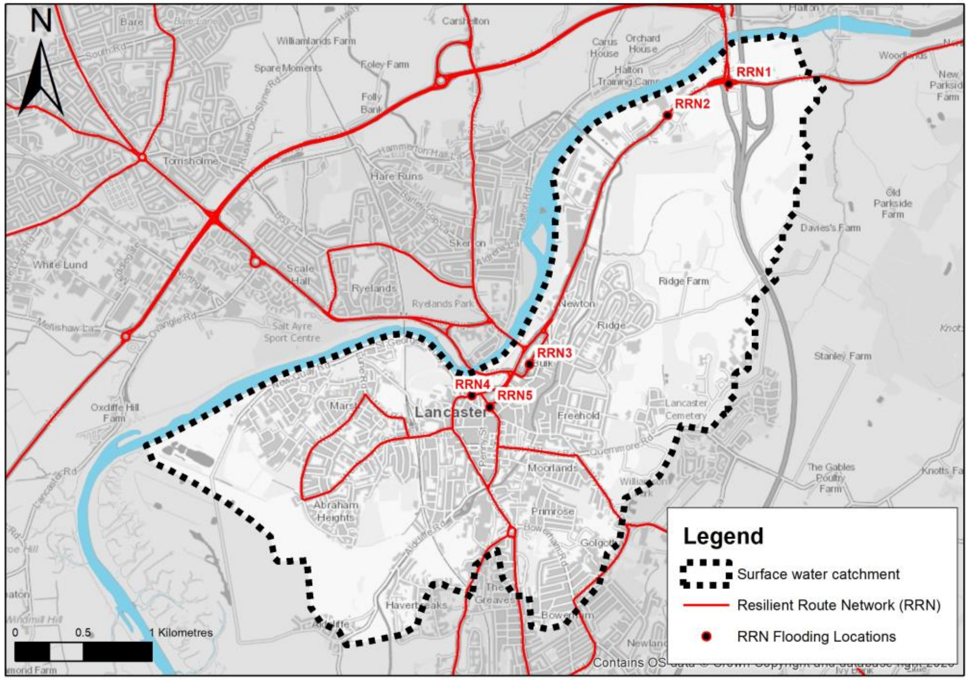


Figure 3-25 shows the resilient route network identified through the City centre. According to the results of the hydraulic modelling, much of the network is predicted to experience either no or shallow (<250mm[iii]) surface water flooding during all rainfall events modelled. However, there are five locations that could experience deeper (>250mm) surface water flooding. Flooding at these locations could impact on emergency service responses, and general use by the public, during and after a flood event.

These locations are shown in Figure 3-25, with information on predicted flood depths presented in Table 3-7. Flooding at PRN1 and PRN2 would cause major disruption for commuters entering / leaving to city from Junction 34 of the M6. Due to Lancaster's one-way system, flooding at RRN3, RRN4 and RRN5 would also prevent people and services moving through the city centre with very few alternative routes available.

Table 3-7: Flooding depths at locations along the Resilient Route Network

Figure Reference	Location	AEP / Flood Depth (mm)		
		5%	1.33%	1%
RRN1	Bay Gateway Junction	400	500	600
RRN2	Caton Road/Mannin Way	400	400	500
RRN3	Caton Road (Lawsons Quay)	500	750	800
RRN4	Cable Street	500	800	900
RRN5	Rosemary Lane/Chapel Street	205	400	400

[iii] 250mm has been chosen to demonstrate where use of roads could become difficult based on Defra research[24] into flood hazards, where depths of less than 250mm usually represent a low hazard unless high velocities (>2m/s) are encountered.

Flood hazards (combining flood depths and velocities), as defined by the Defra and the Environment Agency methodology[24], provides a useful alternative dataset for assessing flood risk. This is particularly useful dataset to understand the risk of flooding along the road network especially where fast flowing water (like those observed in Lancaster) can cause significant disruption even if flood depths are shallow.

Table 3-8 provides the flood hazards across the Resilient Route Network, using the following definitions:

- **Low (Caution) -** flood zone with shallow flowing water or deep standing water
- **Moderate (Dangerous for some (i.e. children)) -** flood zone with deep or fast flowing water
- **Significant (Dangerous for most people) -** a flood zone with deep, fast flowing water
- **Extreme (Dangerous for all (including emergency services)) -** flood zone with deep, fast flowing water

Table 3-8: Hazard ratings for flooded locations along the Resilient Route Network

Figure Reference	Location	AEP / Hazard Rating		
		5%	1.33%	1%
RRN1	Bay Gateway Junction	Moderate	Significant	Significant
RRN2	Caton Road/Mannin Way	Moderate	Moderate	Significant
RRN3	Caton Road (Lawsons Quay)	Significant	Significant	Significant
RRN4	Cable Street	Significant	Significant	Significant
RRN5	Rosemary Lane/Chapel Street	Low	Significant	Significant

Whilst no "extreme" flood hazards on the Resilient Route Network have been identified, the findings presented in Table 3-8 suggest that parts of the network would be hazardous during relatively low magnitude events i.e. 5% AEP around the City centre. Much of the network within the whole catchment would experience enough flooding during higher magnitude events i.e. greater than 1.33% AEP to make travel difficult and dangerous. This would likely hinder the day to day activities of the general public, whilst making emergency operations such as evacuations more challenging.

3.10.6 Risk to future development

Lancaster City Council have implemented several strategic initiatives designed to regenerate disadvantaged areas, remove barriers to investment and enable sustainable economic growth[25]. Across the City Centre, these include:

- **Lancaster Square Routes -** public realm improvement works (between 2011-12 and March and November 2014) to rejuvenate the important historic city centre and included Market Square, Market Street, Cheapside, Horseshoe Corner and Penny Street.
- **Beyond the Castle –** improvement works of a 14 ha of urban green space around Lancaster Castle and down to St George's Quay.
- **The Canal Quarter –** redevelopment of a 6.69 ha derelict and under-used site with a mix of uses including 1,000 new dwellings and business and retails opportunities before 2023.
- **Luneside East Regeneration Project –** regeneration of a new quarter of the city with a mix of residential, commercial space, high quality open spaces and walking and cycling routes. This is located on a 7ha site located on the south banks of the River Lune on Lancaster's historic St George's Quay.

The City Centre is also expanding. The largest proposed development includes:

- **Land at Ridge Farm and Cuckoo Farm –** an existing 120 ha undeveloped site, consisting of pastoral farmland, pockets of woodland and copse and areas of Lansil Golf Course, to deliver in the region of 1,000 new homes over the course of the plan period and beyond into the next plan period[26].

Strategic approach to development and flood risk

Managing and reducing flood risk throughout the city can play an important role in supporting the area's regeneration and growth prospects by making it more attractive to businesses and putting it on a par with other potential locations. This includes managing the risk of flooding to transportation links, making access more resilient along with potentially positive impacts on insurance costs.

Reducing flood risk may also provide scope to broaden the economic base and resilience of the area by allowing types of businesses to locate there that might otherwise not have been permitted due to planning regulations and restricted land use due to the level of flood risk.

The recently adopted Local Plan (adopted Summer 2020[iv]) has identified several Strategic and Development Management policies that should support sustainable management of surface water through the City, including:

- Strategic Policy 8: Protecting the natural environment (particularly the expectation that development should be designed in such a way as to not create new flooding issues in future or exacerbate current problems)
- Development Management 29: Key design principles (particularly consideration of SuDS and Green Infrastructure)
- Development Management 34: Surface water run-off and sustainable drainage (particularly consideration of Surface Water Drainage hierarchy, attenuation measures and biodiversity)
- Development Management 36: Protecting water resources and infrastructure (particularly capture of 'grey water' and use of SuDS)
- Development Management 43: Green infrastructure (particularly extension of existing green space/corridor frameworks)

Site-specific approach to development and flood risk

At a site level, regeneration and new development also provide an opportunity to reduce existing flood risk or to create capacity in the downstream drainage system through careful master-planning and the implementation of sustainable drainage systems (SuDS).

Whilst the risk of surface water flooding to these sites has not been explicitly assessed within this SWMP. It will therefore be important that Lancaster City Council and individual developers consider the surface water flood risk identified within this study at the earliest stage of the planning process.

It is recommended that these developments adhere to specific policy relating to surface water management in this document in addition to the requirements of the National Planning Policy Framework (NPPF).

3.10.7 Water quality

The Water Framework Directive (WFD) requires all water bodies (defined as "a discrete and significant element of surface water" including part/all of a river, canal or stream) in Europe to achieve both good chemical status and good ecological status. The Environment Agency are the competent authority in England for delivering WFD targets, as well as assessing Ecological and Chemical status of all water bodies.

Ecological status is based on biological, physico-chemical and hydromorphological quality elements which assessed as being High, Good, Moderate, Poor or Bad. High status means no or very minor human alterations, and Bad status means a severe deviation in biological quality elements from reference conditions. Chemical status is determined by assessing compliance with environmental standards for chemicals that are listed in the Environmental Quality Standards (EQS) Directive. To achieve

[iv] The Local Plan is currently undergoing review, following the declaration of a Climate Emergency by Lancaster City Council in January 2019. This includes a further look at the role green-blue infrastructure plays in the planning process

Good status requires every EQS to be met, with a single failure resulting in a status of Fail.

Within the Lancaster City, there are three WFD water bodies:

- **Lune** transitional water body, which covers the River Lune downstream of Skerton Weir to Glasson (approximately 6km downstream of Lancaster)
- **Lune confluence Wenning to tidal** surface water body, covers the River Lune from Skerton Weir to Hornby (approximately 6km upstream of Lancaster)
- **Lancaster Canal (cruising section)**, an artificial water body which runs through Lancaster but runs from Carnforth to Preston (approximately 71.5km)

Table 3-9 summarises the baseline conditions for these WFD water bodies Cycle 2 (2019) data collected by the Environment Agency[27].

Table 3-9: Baselines WFD water body classifications

Water body name	Water body ID	Ecological status	Chemical status
Lune	GB531207212100	Bad	Fail
Lune confluence Wenning to tidal	GB112072065980	Moderate	Fail
Lancaster Canal	GB71210228	Moderate	Fail

Whilst the Environment Agency are responsible for compliance with WFD targets and overseeing delivery of WFD mitigation measures, it is recognised that all the RMAs can assist in the improvement of WFD status and water body quality through sustainable management of surface water.

Impact on water quality from surface water flooding

Surface water flooding, particularly in urban areas, can significantly impact on water quality in receiving water bodies, in this case the River Lune and the Lancaster Canal. This can include direct and indirect impacts such as:

- Urban surface water runoff, which can wash pollutants and contaminates (e.g. from roads) directly into watercourses or via surface water drainage systems;
- Structural deficiency and misconnections in drainage systems; and
- Indirect impacts, such as discharges from combined sewer overflows.

This is particularly relevant to the Lune transitional water body, which is failing to achieve good status largely on account of diffuse source pollution from urban developments (including transport) and sewage discharge (point discharge)[27].

Management

River Basin Management Plans (RBMPs) provide a framework for protecting and enhancing the benefits provided by the water environment. The RBMP for the North West sets out seven significant water management issues, with the issues most likely being faced in Lancaster being pollution from wastewater, pollution from towns, cities and transport and physical modifications. Future aims of the RBMP for the Lune catchment include expanding the Lower Lune Restoration Project to enhance riparian (riverside) habitats and use of SuDS in Lancaster to combat urban pollution.

4. Options

4.1 Introduction

This section of the SWMP discusses how surface water flooding across these sub-catchments could be managed in the future by considering a range **of structural, non-structural and adaptation measures**, with those suitable and deliverable measures taken forward into the SWMP Action Plan found in Table 5.1 in Section 5.

The measures identified and options developed have been informed by the findings presented in Section 2 (Risk Assessment) of this SWMP including local knowledge of the catchment, historical flood records, the perceived understanding of flooding mechanism, and the location of at-risk properties.

Given this understanding, this section focuses on four sub-catchments where the greatest risk of surface water flooding has been identified, including:

- Catchment A: Upper Caton Road
- Catchment B: Caton Road
- Catchment C: City centre; and
- Catchment D: Upland

Measures and Options

In this SWMP, a measure is defined as a proposed individual action or procedure intended to minimise current and future surface water flood risk or wholly or partially meet other agreed objectives of the SWMP. An option (or options) is made up of either a single, or a combination of previously defined measures.

4.2 Surface Water Flood Risk Management Strategy

Prior to identifying suitable measures, it is first necessary to define the overall surface water flood risk management strategy, which includes:

- The overall **goal** of what we are aiming to achieve; and
- **Specific objectives** to address the flood risk and associated problems.

By defining a strategy collaboratively with relevant stakeholders and partners will also improve the way adaptation measures (identified later in this section) are eventually integrated into daily activities, projects, long-term strategic investment plans, and strategies for places and catchments.

As acknowledged in the National Flood and Coastal Erosion Risk Management Strategy, a strategic approach will allow RMAs and partners to work together to:

- *Deliver practical and innovative actions that help to bolster resilience to flood in local places;*
- *Make greater use of nature-based solutions that take a catchment led approach to managing the flow of water to improve resilience to floods;*
- *Maximise opportunities to work with farmers and land managers to help them adapt their businesses and practices to be resilient to flooding;*
- *Develop adaptive pathways in local places that equip practitioners and policy makers to better plan for future flood and adapt to future climate hazards;*
- *Put greater focus on providing timely and quality planning advice that helps avoid inappropriate development in areas at risk of flooding;*
- *Leave the environment in a better state by contributing to environmental net gain for new development proposals;*

  Ensure that spending on flood resilience contributes to job creation and sustainable growth in local places;
- *Mainstream property flood resilience measures and to 'build back better' after flooding to reduce damages and enable faster recovery for local communities*

- *Provide expert advice on how infrastructure providers (road, rail, water and power supplies) can ensure their investments are more resilient to future flooding avoiding disruption to peoples' lives and livelihoods;*
- *Support communities to better prepare and respond to flooding, including transforming how people receive flood warnings;*
- *Ensure people and businesses receive the support they need from all those involved in recovery so they can get back to normal quicker after flooding;*
- *Help support communities with managing the long-term mental health impacts from flooding;*
- *Develop the skills and capabilities needed to better support communities to adapt to future flooding; and*
- *Become a world leader in the research and innovation of flood risk management to better protect current and future generations.*

4.2.1 SWMP Workshop

Using the framework set out in the SWMP Technical Guidance and guiding principles within the National Flood and Coastal Erosion Risk Management Strategy, a workshop was held with the multi-agency Steering Group (Figure 2-3) to:

- Share the findings of the Risk Assessment to provide a common understanding of surface water flood risk across the City centre;
- Discuss RMA statutory responsibilities and duties with regards to flood risk management and their specific priorities within the City of Lancaster;
- Understand what partners are doing or have planned in the City centre that may directly or indirectly influence future flood risk;
- Discuss how surface water flood risk can be managed collectively in the future.

Appendix B contains findings of the SWMP Workshop including an overview of individual RMA flood risk management objectives identified. These findings have then been used to define the Goal and Strategic Objectives.

Flood Risk Management Goal

The goal of the strategy is to reduce the risk of surface water flood risk in Lancaster City.

However, it must be acknowledged that it will be impossible to completely eliminate the possibility of flooding. Therefore, an adaptive approach is required to bolster resilience to flooding, both now and in the face of climate change, with all stakeholders and partners continually working together over the long-term to:

- Making the right investment and planning decisions to secure sustainable growth and environmental improvements, as well as infrastructure resilient to flooding; and
- Ensuring that 'at risk' businesses, residents and visitors in the City understand what is required to be adequately prepared for, and resilient to, extreme flood events.

To help deliver this goal across the City, the follow five strategic objectives have been defined. Further detail on what these mean for the City centre is provided on the following page.

Strategic Objectives

- **SO1: Provide a collective understanding of existing and future surface water flood risk**
- **SO2: Reduce the vulnerability and cost to City businesses, residents and visitors from flooding**
- **SO3: Respond effectively in the event of flooding by providing emergency assistance to those in need**
- **SO4: Assist in recovery enabling the City residents and businesses to resume normal activities promptly**
- **SO5: Monitor and review appropriateness of strategies, plans and actions**

SO1: Provide a collective understanding of existing and future surface water flood risk

1 Building relationships with 'at risk' businesses and residents to improve awareness of the risks they face by sharing information in consistent and digestible way;
2 Communicating changes in risk to those who are most likely to be affected; and
3 Establish community/flood action groups to facilitate exchange of information between the public and RMAs.

SO3: Respond effectively in the event of flooding by providing emergency assistance to those in need by:

1 Maintaining emergency response plans that:
  - provide clear roles and responsibilities;
  - identify higher risk properties and more vulnerable communities; and
  - identify safe access and egress routes.

2 Maintaining a Resilient Route Network.

SO4: Assist in recovery enabling the City residents and businesses to resume normal activities promptly by:

1 Understanding the critical needs of 'at risk' communities to allow for prioritisation of resources post-flood event.
2 Supporting affected businesses and residents in obtaining / providing emergency funding to affect repair work.
3 Offering guidance on the actions and measures that can be taken to improve resilience to future flood events, for example selection of Property Level Protection measures.

SO5: Monitor and review appropriateness of strategies, plans and actions by:

1 Collecting and sharing of flood data and information.
2 Undertaking Section 19 Investigations.
3 Reprioritizing schemes and works as necessary to meet changing priorities.

SO2: Reduce the vulnerability and cost to City businesses, residents and visitors from flooding

1 Adopting a partnership approach to the delivery of schemes and works that:
  - reduce the likelihood and/or impact of surface water flooding to residential and commercial properties;
  - improve property resistance and resilience;
  - have low maintenance costs and are adaptable to the impacts of climate change;
  - reduce unsatisfactory discharges (permitted and non-permitted, as well as direct and indirect) into the River Lune;
  - reduce internal and external sewer flooding;
  - relieve pressure on the highway and combined sewerage network; and,
  - enhance the resilience of critical infrastructure.

2 Prioritising interventions that deliver multiple benefits, specifically:
  - low carbon / carbon neutral measures;
  - improvements to air and water quality;
  - amenity and biodiversity enhancements;
  - creating new, and maintain existing, ecological corridors; and,
  - enhancements to the public realm which allow people to connect with the natural environment through greening of urban space.

3 Ensuring that early in the design and master planning process (within the City catchment), City centre regeneration, development and transportation plans:
  - adopt sustainable drainage techniques (SuDS) to capture and attenuate surface water runoff, and follow the hierarchy of surface water discharge to limit discharge to the public sewer network;
  - consider the retrofit of nature-based solution (e.g. urban green parks, walls and roofs);
  - provide betterment (not just 'no impact'); and,
  - embody the principle of environmental net gain.

4 Supporting businesses in the development of continuity and preparedness plans.

4.3 Identify Measures and Options

4.3.1 Structural, non-structural and adaptation measures

Given the understanding of flood mechanisms outlined in Section 2 (Risk Assessment) of this SWMP, a long list of structural, non-structural and adaptation measures have been identified (Table 4-1) to help deliver the five strategic objectives.

These measures have been identified using the source-pathway-receptor model. Each measure will provide different levels of resilience from surface water flooding, have a range of benefits and costs associated with them, and could be delivered by multiple stakeholders and partners.

Source-pathway-receptor model:

- **Source control** measures aim to reduce the rate and volume to surface water runoff through infiltration or storage reducing the impact on receiving drainage catchments. Within an urban environment, source control of surface water runoff can be achieved using the Sustainable Drainage Systems (SUDS) approach to drainage. Within rural upper catchments, these could include Natural Flood Management (NFM) techniques.
- **Pathway measures** seek to manage overland and underground flow pathways of water. Within an urban environment, they include traditional hard engineering solutions to increase pipe capacities to remove pinch points or provide additional storage or measures along roads to contain or redirect overland flows. Measures along more natural watercourses could include enhanced maintenance or reconnecting the floodplain; and
- **Receptor measures** which can help reduce the impact (consequence) of flooding on receptors such as people, property and the environment. Measures such as property level resilience is often considered as a last resort but can be beneficial when focusing on individual high-risk properties, especially where no other measures or scheme is viable.

4.3.2 Shortlisting measures

Given the findings of the risk assessment and using professional judgement and experience, the longlist of measures identified has been qualitatively assessed in terms of their suitability to manage or reduce flood risk across each of the four main surface water sub-catchments in Lancaster.

Each measure has been scored using the following system:

✓✓ These measures on their own will help to reduce the number of properties flooded, or a reduction in the depth of flooding (or duration) to a length of road. These measures can be delivered (and funded) by one or a combination of the RMAs.

✓ These measures can help reduce the overall level of risk but may form part of a wider option or strategy across the study area as whole. They may require buy-in from landowners and require partnership funding to deliver. They may be best delivered through other planning and infrastructure investment programmes.

✘ These measures are unlikely to be cost beneficial or may be difficult to deliver due to one or several social, political, economic or environmental barriers and constraints.

✘✘ These measures are not applicable given the understanding of surface water flooding mechanisms and the location of properties at risk.

4.3.3 Options

Using the measures identified in Table 4-1, a **shortlist of options** has been developed for each sub-catchment. These options are considered as technically viable in achieving Strategic Objective 2 (reduce the vulnerability and cost to City businesses, residents and visitors from flooding). In addition, **further considerations and opportunities** are identified for each sub-catchment which may help achieve Strategic Objective 1 (further improving the collective understanding of flooding mechanisms) as well as minor improvements to local risk issues.

Table 4-1: Sub-catchment suitability and deliverability

	Structural, non-structural, resilience and resistance measures	Upper Caton Road	Lower Caton Road	City Centre	Upland
Source	Green roofs	✖✖	✓	✓✓	✓
	Soakaways	✖✖	✖✖	✖✖	✖✖
	Swales	✖✖	✓	✓	✓
	Permeable paving	✖✖	✓	✓✓	✓
	Rainwater harvesting	✖✖	✓	✓	✓
	Detention basins	✓✓	✖✖	✓✓	✓
	Underground attenuation tanks	✖✖	✖✖	✖✖	✖
	Natural Flood Management	✓✓	✖✖	✖	✖✖
Pathway	Increasing capacity in highway and surface water sewers	✓	✓	✓	✓✓
	Separation of foul and surface water sewers	✖✖	✓✓	✓✓	✓✓
	Offline storage	✖✖	✓	✓	✓
	Efficient use of the Mill Race	✖✖	✓	✓✓	✖✖
	Utilise Lancaster Canal	✖✖	✖✖	✓	✓
	Increased channel capacity	✖✖	✖✖	✖✖	✖✖
	Increased culvert capacity	✓	✖✖	✓✓	✖✖
	Reviewed maintenance regimes	✖✖	✓	✓	✓
	Managing overland flows	✓	✖✖	✓✓	✓
	Floodwalls or embankments	✓	✖✖	✓	✓
	Land management practices	✓	✖✖	✖✖	✖✖
Receptor	Improved flood warnings	✓	✓	✓	✓
	Pumping stations	✓✓	✖✖	✓✓	✓
	Temporary flood defences	✖✖	✖✖	✖✖	✖✖
	Social change, education and awareness	✖✖	✓	✓	✓✓
	Property Level Protection	✓	✓✓	✓✓	✓✓
	Flood and contingency planning	✓	✓	✓✓	✓
	Community engagement programmes (businesses)	✓✓	✓	✓✓	✖
	Community engagement programmes (homeowners)	✖	✓	✓	✓✓
Plans and Policies	Strategic planning	✓	✓✓	✓✓	✓✓
	Development control	✓	✓	✓✓	✓
	Enhanced surface water drainage design criteria and policy	✖✖	✖✖	✓✓	✖✖
	Sub-catchment flood recovery plans	✓	✓	✓	✓

4.4 Catchment A: Upper Caton Road - Options

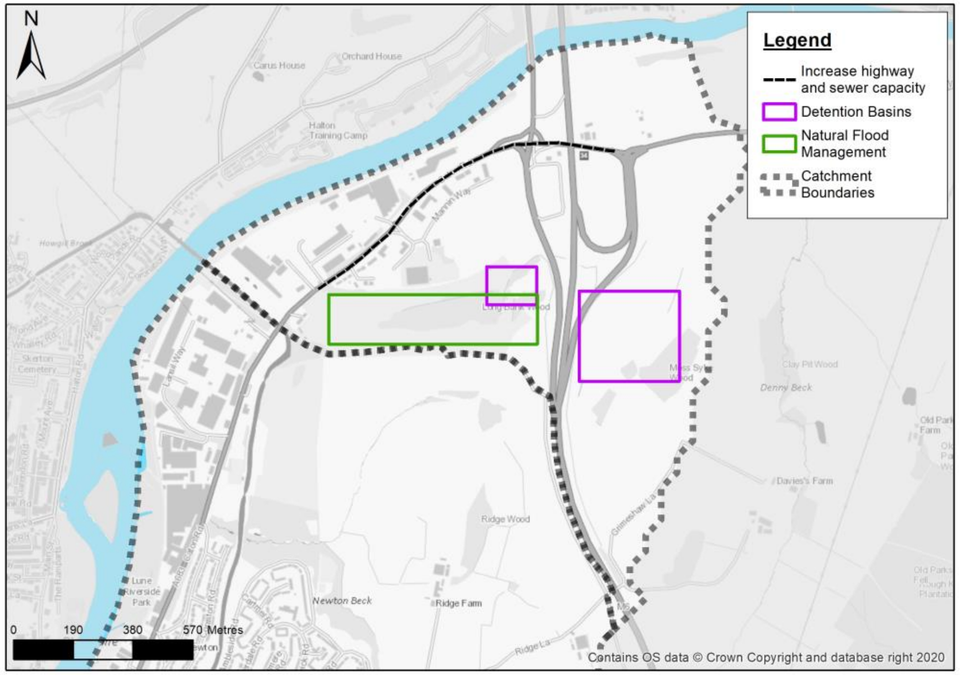
Shortlisted options for this catchment are listed below, with indicative locations shown in Figure 4-1.

- **Upstream flood storage (e.g. detention basins)** would capture and attenuate surface water runoff generated upstream of the M6 during extreme rainfall events to alleviate pressure on existing capacity issues downstream along the watercourse, culverts at Bay Gateway Junction and through Lansil Golf Course.
- **Natural Flood Management (NFM)** would help to re-naturalise of parts of the catchment and slow the speed with which surface water runoff passes through the catchment. This could be coupled with de-culverting of the watercourse through Lansil Golf Course to increase capacity and capture additional overland flows, whilst other measures such as tree planting in the upper catchment would reduce runoff volumes and rates once they have matured.
- **Increasing capacity in highway drainage and surface water sewers** would allow more surface water to be drained from Caton Road, reducing the level and extent of surface water flooding occurring along the highway, as well as surface water runoff entering Riverside Industrial Estate.
- **Pumping stations** could be used to address residual risks associated with surface water outfalls to the River Lune becoming hydraulically locked by high water levels, preventing a surcharging of the upstream surface water network.

Considerations and Further Opportunities

- Ground Investigation (GI) data from Lancaster Phase 3 could be used to better characterise the ground and groundwater conditions and confirm the contribution of groundwater to the current flooding mechanisms. This could also help design and implement appropriate mitigation measures, such as targeted pumping or addressing any drainage / sewerage asset condition issues to prevent groundwater ingress.
- Future sub-surface structures within the alluvial aquifer should be avoided due to potential impacts on groundwater levels. Where possible efforts should be made to reclaim aquifer storage by altering sub-surface land uses within the western part of the catchment.

Figure 4-1: Upper Caton Road - indicative option locations



Alignment with Stakeholder Objectives

- SuDS would support Lancaster City Council (Planning) and Lancashire County Council (FRM) objectives in enhancing ecological corridors as well as local biodiversity and environmental conditions.
- NFM and SuDS would align with United Utilities objectives by reducing runoff volumes entering their networks and improving water quality.
- Reducing the probability and depth of surface water flooding along Caton Road would help Lancaster City Council (Civil Contingency) maintain their Resilient Road Network.

4.5 Catchment B: Lower Caton Road - Options

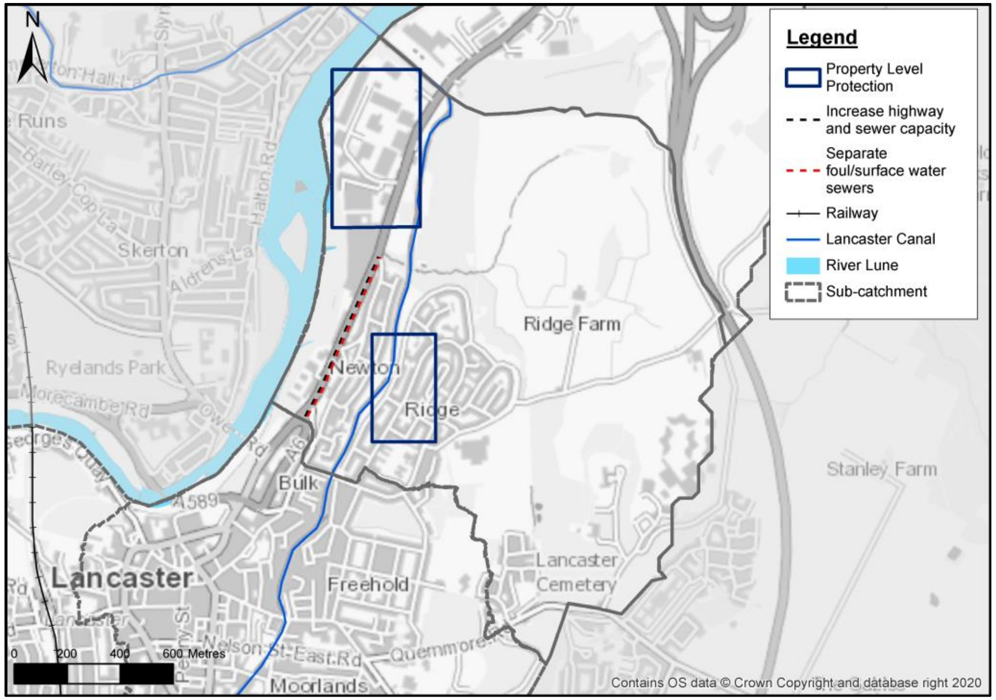
- Shortlisted options for this catchment are listed below, with indicative locations shown in Figure 4-2.
- **Increasing capacity in surface water drainage network** by installing separate foul and surface water sewers, increasing sewers capacity, or retrofitting SuDS along the highway. These measures would aim to improve efficiency in the network and reduce residual surface water flows along Caton Road (which acts a critical flow path). Separation could provide the opportunity to discharge surface water runoff directly to the River Lune instead of pumping to United Utilities WwTW, relieving pressure on the downstream networks and the City centre catchment.
- **Retrofitting SuDS** (such as green roofs and rainwater harvesting) would complement this approach and generally help to reduce runoff entering the network downstream.
- **Property Level Protection (PLP)** targeted at specific areas in Ridge and the Lansil Industrial Estate, where localised flooding is anticipated, could improve overall flood resilience during extreme rainfall events. Through the Lansil Industrial Estate PLP should be consider along with any residual fluvial flood risk following completion of the Phase 3 FAS.

Considerations and Further Opportunities

- NFM measures have already been delivered along Newton Beck. As the fluvial catchment generally presents a low flood risk given its natural attenuation, there is little value in implementing further measures along the beck.
- Hydraulic modelling suggests that the Lancaster Canal may overtop between Ridge and Newton during an extreme rainfall event. Further investigation and engagement with the Canals and Rivers Trust should be considered in order to better understand this potential flooding mechanism.

GI would help to better characterise the ground and groundwater conditions in the catchment, to confirm the contribution of groundwater to the current flooding mechanisms identified, and to design and implement appropriate mitigation measures, such as re-instatement of aquifer storage by removal of sub-surface structures (such as basements or old foundations), targeted pumping, etc.

Figure 4-2: Lower Caton Road - indicative option locations



Alignment with Stakeholder Objectives

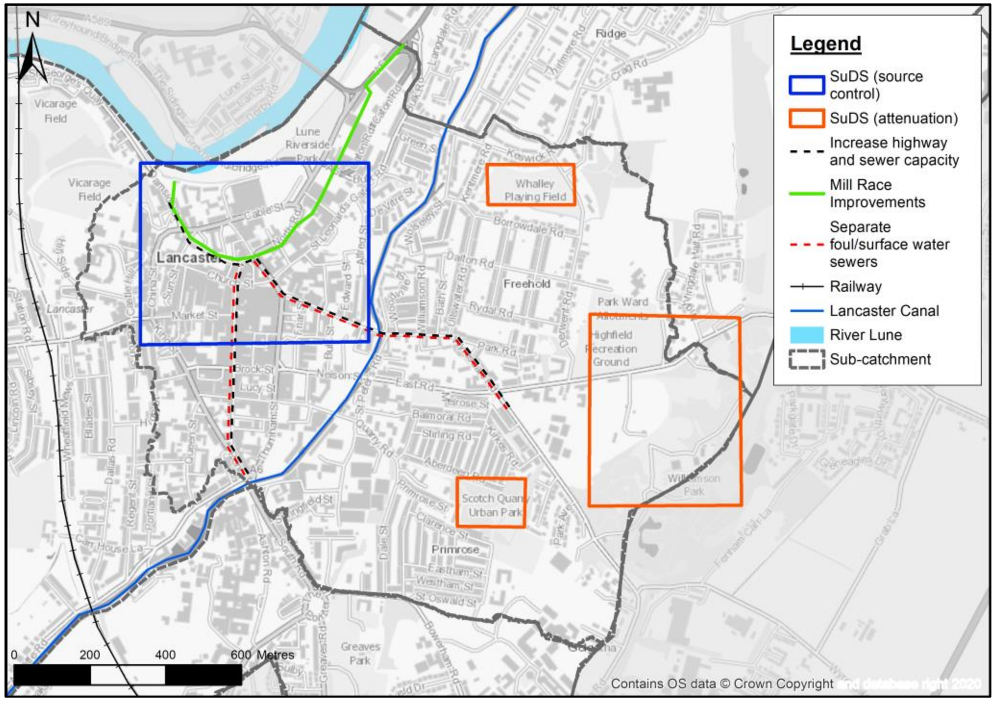
- Reducing the probability and depth of surface water flooding along Caton Road would help Lancaster City Council (Civil Contingency) maintain their Resilient Road Network.
- Delivery of PLP would help Lancaster City Council improve overall community resilience to surface water flooding (along with residual fluvial risks) and the impacts of climate change.

4.6 Catchment C: City Centre - Options

Shortlisted options for this catchment are listed below, with indicative locations shown in Figure 4-3.

- **Retrofitting SuDS** within the dense city centre would help to capture and attenuate urban runoff and alleviate pressure on the combined sewer network. These measures would be particularly beneficial in existing green areas such as Whalley Recreation Ground, Scotch Quarry Urban Park and Williamson Park, and through the creation of new 'pocket parks' throughout the city to replace existing brownfield sites (such as existing car parks). Uptake of source control measures within the west of the catchment (e.g. green roofs, rainwater harvesting, permeable paving) and the removal of sub-surface features such as basements and redundant foundations (known to increase risk of groundwater flooding) could also help to reclaim aquifer storage.
- **Improving capacity of the existing surface water network** is likely to be critical long-term option in reducing risk of surface water flooding though the City centre. This could require the uptake of several complementary measures:
  - **Exploiting the Mill Race** as a surface water drainage asset. This could provide significant benefits to high risk areas around Parliament Street and Cable Street. This would require a significant long-term investment from multiple stakeholders and partners to deal with condition issues, misconnections and removal of foul networks.
  - **Increasing pumping capacity** at the two United Utilities pumping stations would improve the ability to pump water from the Mill Race to Lancaster WwTW during wet weather conditions, would reduce levels in the Mill Race (and risk of surcharging), the risk posed by hydraulic locking of the outfall, and provide water quality benefits by reducing CSO spills in to the Lune Estuary.
  - **Separation of foul and surface water sewers** and **increasing capacity in highway drainage** along key flow paths, such as Moor Lane and Penny Street, would likely provide significant benefit to downstream receptors.
- **Delivering strategic city centre regeneration sites** at Lawsons Quay and Lune Industrial Estate and the Canal Quarter provide excellent opportunities to deliver Nature Based Solutions (inc. SuDS) that help to reduce flood risk and multiple benefits including water quality. Regional SuDS located in strategic sites also provide alterative drainage locations for neighbouring developments or infrastructure improvements.
- **Developing location specific surface water drainage policy or design criteria** would help to ensuring that developers manage surface water runoff in line with the NPPF and/or provide overall betterment by applying stricter discharge criteria. This should also acknowledge the risk posed by groundwater flooding, particularly in the west of the catchment, and could be used to restrict subsurface structures.

Figure 4-3: City Centre - indicative option locations



Considerations and Further Opportunities

- Future sub-surface structures, such as basements or building foundations, within the alluvial aquifer should be avoided due to potential impacts on groundwater flooding. Where possible efforts should be made to reclaim aquifer storage by altering sub-surface land uses (for example through the removal of redundant basement walls) within the western part of the catchment.
- Retrofitting SuDS in existing topographic depressions within Scotch Quarry Urban Park and Williamson Park could provide additional enhancement of pre-existing quarry locations.
- New 'Pocket Parks' would provide wider visual and amenity benefits, tackle air quality issues and help to reduce the long-term impacts associated with climate change in a densely urban environment. These could also support strategic planning policies including a cohesive strategy to address car park use.
- Addressing sewer and Mill Race condition issues would provide additional water quality improvements. This may increase the number of different funding sources available for future measures.
- Given the lack of open watercourses in the catchment, the Lancaster Canal could be considered as a strategic asset for managing surface water runoff, giving some control over the volumes of surface water which are passed through the catchment from east to west. Consultation with the Canal and Rivers Trust, as well as consideration of the Canal Quarter redevelopment scheme would be required.
- There is potential for groundwater flooding to occur within the more permeable deposits of the River Lune Floodplain, which may be masked by fluvial / pluvial flood events. Ground investigation is therefore recommended to better characterise the ground and groundwater conditions in the catchment, to confirm the contribution of groundwater to the current flooding mechanisms identified, and to design and implement appropriate mitigation measures. Such measures may include (but are not limited to) re-instatement of aquifer storage by removal of removal of sub-surface structures e.g. redundant basements, targeted pumping, etc.

Alignment with Stakeholder Objectives

- The options identified would help Lancaster City Council (Regeneration and Planning) and Lancashire County Council (FRM) achieve key objectives, including:
  - Improving amenity value and air quality within the urban realm
  - Enhancing biodiversity
  - Providing new ecological corridors and maximise opportunities for green space in the city centre
  - Improving water quality
- By reducing overall flood risk issues in the city centre, it will drive economic growth by removing potential barriers for investment.

4.7 Catchment D: Upland – Options

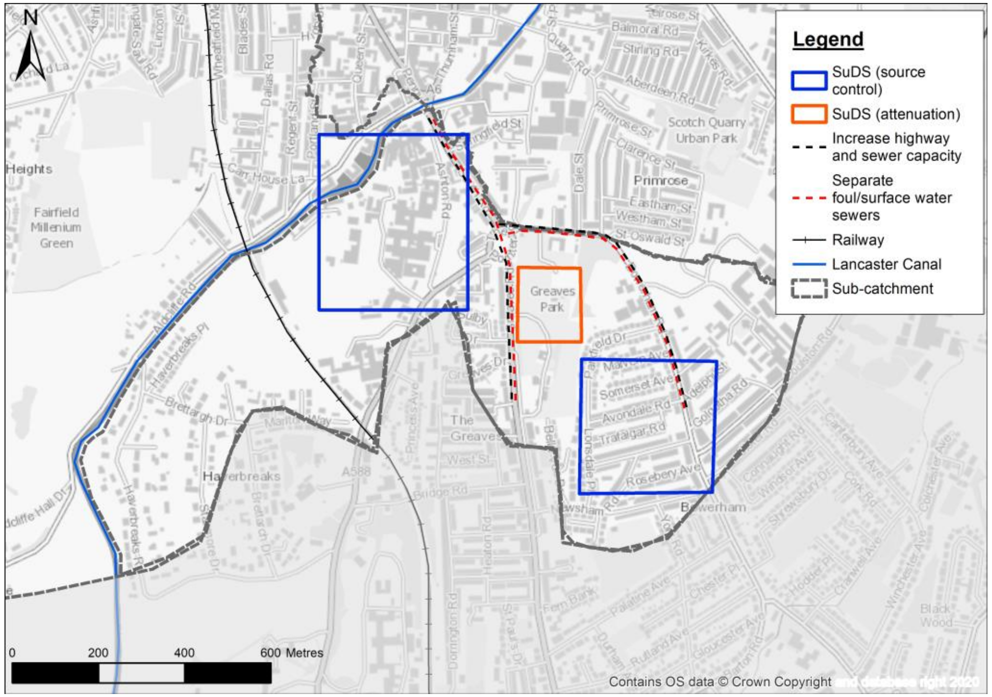
Shortlisted options for this catchment are listed below, with indicative locations shown in Figure 4-4.

- **Delivering small- and large-scale SuDS** would have local benefits as well as attenuate flows entering the surface water drainage network, draining towards the City centre and Lucy Brook. Areas where SuDS would provide the greatest benefit are:
    - Bowerham residential area for widespread, small-scale SuDS measures such as rainwater harvesting, permeable paving, and rain gardens. Delivery of initiatives to drive social change, through education and awareness could help to improve uptake and acceptance of these measures.
    - Greaves Park could be used to deliver large-scale SuDS measures such as swales or storage areas/ponds, which could be landscaped to complement and enhance the existing green space.
    - Lancaster Royal Infirmary could be used to deliver various small-scale measures such as green roofs (following a structural survey) and rain gardens. These would provide other opportunities such as rainwater harvesting and visual amenity enhancement for positive health benefits.
- The uptake of SuDS would help to reduce surface water runoff entering the drainage system; however, a lack of capacity in the highway drainage / sewer network also contributes to flooding in the catchment. **Separating foul and surface water sewers** and/or **increasing capacity in highway drainage and surface water sewers** would be appropriate measures to consider along two main flow paths through the catchment on Bowerham Road and Greaves Road. This would also help reduce the amount of surface water being passed downstream into the City Centre catchment.

Considerations and Further Opportunities

- Options delivered in this catchment would likely provide in-direct benefits to both the City Centre and Lucy Brook catchments, by slowing runoff rates/reducing runoff volumes.

Figure 4-4: Upland - indicative option locations



Alignment with Stakeholder Objectives

- SuDS would support Lancaster City Council (Planning) and Lancashire County Council (FRM) objectives in enhancing ecological corridors as well as local biodiversity and environmental conditions.
- Co-investment in SuDS at catchment scale could reduce the need for hard engineering solutions and/or could provide additional benefits through a natural capital approach to ensure these solutions are cost beneficial.

5. Implementation & Review

5.1 Action Plan

Based on the findings of the risk assessment, this SWMP has identified a wide range of actions, that when delivered over time, would help to reduce the risk of surface water flood risk in Lancaster City.

An Action Plan has been developed to outline the responsibilities and recommendations of structural, non-structural and adaptation measures identified (Table 4-1) and shortlisted. The final SWMP Action Plan is shown in Table 5.1 on the following page.

5.2 Implementation

Proposed actions have been classified into the following categories of priority:

- **Short term:** Actions to be undertaken within the next one to three years;
- **Medium term:** Actions to be undertaken within the next one to five years; and
- **Long term:** Actions to be undertaken beyond five years

The actions will be led by one of the RMAs linking to their role and responsibilities as set out in Appendix B. Some of these actions will be a continuation of activities already undertaken or planned, whilst others challenge the RMAs to improve existing process or procedures.

Whilst the actions have been reviewed and agreed upon by the RMAs, timing and deliverability is still dependent on other factors, such as the capital budgets and other local or regional priorities.

5.3 Review

The actions outlined within the Action Plan have been agreed to by all parties, it is therefore the responsibility of the various authorities to ensure these are undertaken.

Lancashire County Council, as LLFA, should undertake a minimum annual review of the High and Medium priority actions to ensure actions are being implemented and progress is being made by relevant partners and stakeholders. This allows forward financial planning in line with external partners and internal budget allocations. The local Making Space for Water Groups may provide the opportunity for this discussion. Low priority actions should be reviewed on a two to three-year cycle.

5.4 Monitoring

The Multi-agency Steering Group should continue beyond the completion of this SWMP, in order to discuss the implementation of the proposed actions, review opportunities for operational efficiency and any legislative change.

As a minimum, the SWMP Technical Guidance recommends that the whole Action Plan should be reviewed and updated once every six years, but there are circumstances which might trigger a review and/or an update of the Action Plan in the interim or in some cases annually:

- Occurrence of flood incident (an event that might trigger a Section 19 Investigation);
- Additional data or modelling becoming available, which may alter the understanding of risk within the study area;
- Outcome of investment decisions by partners is different to the preferred approach, which may require a revision to the action plan; and
- Additional development or other changes in the catchment which affect the surface water flood risk.

Table 5.1: SWMP Action Plan

Ref	Action	Type	Description	Outcome	Opportunities	Stakeholders	Priority
A.1	Publish SWMP	Engagement	Sharing the information and findings of the SWMP with: ▪ Multi-agency steering group ▪ Key stakeholders and partners ▪ At risk communities and businesses	▪ Build a collective understanding of surface water flooding risk. ▪ Ensure ownership of this Action Plan. ▪ Increase uptake of local measures.	▪ Engagement could help to identify further partnership working opportunities and similarities between different programmes of work.	**Action Owner:** Lancashire County Council	Short-term
B.1	Caton Road Foul Sewer Works	Quick Win	The existing foul sewer has been laid through the culverted watercourse that links the catchment upstream of Lansil Golf Course with the River Lune. This currently restricts flows through the culvert. The foul sewer pipe should be moved in this section and the watercourse culvert repaired.	▪ Reinstate culvert capacity and reduce the risk of surface water flooding to Golf Course and Caton Road.	▪ Reduces risk of flooding to Resilient Road Network.	**Action Owner:** United Utilities	Short-term
B.2	Upper Caton Road Surface Water Management Scheme	Quick Win	Develop and implement scheme to address residual surface water flooding risks following completion of the River Lune Phase 3 FAS. The scheme should focus on reducing surface water runoff reaching Caton Road with a focus on upstream attenuation, via small scale capital works, and local highway improvements.	▪ Reduce surface water flood risk to Caton Road. ▪ Support delivery of the Lancaster Phase 3 FAS fluvial defences.	▪ Delivery NFM in the upper catchment. ▪ Biodiversity enhancement via SuDS.	**Action Owner:** Lancashire County Council **Stakeholder Support:** Environment Agency Lancaster City Council River Lune Trust	Short-term
C.1	River Lune Outfall Survey	Survey	A survey of the River Lune outfalls was undertaken by ANDIDRAIN in 2017 with a location plan developed and photographs taken. A second survey should be undertaken to collect invert/soffit levels of outfalls, which can then be used to update the 1D-2D integrated model of the city centre and assess residual risk associated with hydraulic locking.	▪ Collecting additional data and information to develop understanding of flood risk mechanisms. ▪ Inform need for local measures such as pumping stations.	▪ Improved understanding could inform future operation and maintenance plans.	**Action Owner:** Lancashire County Council **Stakeholder Support:** Environment Agency Lancaster City Council United Utilities	Short-term
C.2	River Lune Ground Investigation and Groundwater Assessment	Investigation and Study	A ground investigation in the more permeable deposits of the River Lune floodplain should be undertaken to better characterise the ground and groundwater conditions. This should include a: ▪ Ground investigation and groundwater monitoring plan ▪ Data collection exercise ▪ Detailed groundwater level and flow assessment ▪ Conceptual understanding of groundwater contributions to flooding problems	▪ Confirm the contribution of groundwater to the current flooding mechanisms identified; and to ▪ Design and implement appropriate mitigation measures.	▪ Inform future blue / green infrastructure strategies. ▪ Inform strategic development policies. ▪ Inform Mill Race Strategy ▪ Inform Flood Risk Assessments for future development applications.	**Action Owner:** Lancashire County Council **Stakeholder Support:** Environment Agency Lancaster City Council	Short-term
E.1	Mill Race Strategy	Strategy	The Mill Race is an existing drainage asset, but this SWMP has shown there is a potential for enhancement opportunities to help reduce surface water flood risk. However, several existing and future constraints would need to be addressed. Using the findings of the Catchment Study and Mill Race survey, it is recommended that a strategy for the Mill Race is developed to define: ▪ Existing function and ownership of the Mill Race ▪ Stakeholder objectives / priorities (short to long term) ▪ Opportunities and constraints ▪ Potential benefits available ▪ Likely options to achieve benefits ▪ Capital costs and long-term operational and maintenance costs ▪ Next steps	▪ Define the purpose of the Mill Race to support complementary future capital work and investment. ▪ Improved efficiency of operation to support surface water management. ▪ Clear ownership responsibilities.	▪ Improved water quality in Lune Estuary. ▪ Potential to reduce treatment and operational costs for United Utilities. ▪ Reduced risk of asset failure.	**Action Owner:** Lancashire County Council **Stakeholder Support:** Environment Agency Lancaster City Council United Utilities	Medium-term

Ref	Action	Type	Description	Outcome	Opportunities	Stakeholders	Priority
E.2	Lancaster Integrated Drainage Area Strategy (IDAS) and Drainage & Wastewater Management Plans (DWMPs)	Strategy	Over the current and next asset management plan (AMP) period, United Utilities will be developing strategies and plans to identify and prioritise flood and pollution risks, as well as long-term solutions to manage risk and ensure long term network resilience. This will include the preparation on Integrated Drainage Area Strategy (IDAS) and Drainage & Wastewater Management Plans (DWMPs). It is critical that these strategies and plans consider the findings the 1D-2D integrated hydraulic modelling, and how the shortlisted options and actions presenting in this SWMP can help United Utilities achieve their business plan goal and objectives. This should include an integrated catchment management and natural capital approach, which is well aligned to the opportunities presented in this SWMP.	Delivery of a resilient drainage network by supporting a combination of measures across the City centre, including: ▪ Action E.1: Mill Race Strategy ▪ Action F.2: Retrofit SuDS feasibility assessment ▪ Action G.1: Increased sewer capacity	▪ Help tackle future demands from city centre growth and climate change. ▪ Reduction in capital and operating costs. ▪ Environmental improvements.	**Action Owner:** United Utilities **Stakeholder Support:** Lancashire County Council Lancaster City Council Environment Agency	Short-term
F.1	City Centre Pocket Park Feasibility Assessment	Feasibility Assessment	As part of the Lancaster District Parking Strategy there is a need to review the use of existing parking places to ensure the best use of space over the long term. Many of the city centre car parks are located on derelict brownfield sites with potential future development pressures. There is an opportunity to consider changing to use of these sites to pocket parks within the urban area including the use of SuDS to manage better surface water runoff. This feasibility assessment should consider the suitability and viability of pocket parks with the aim of identify those worth taking forwards as part of the wider city centre regeneration and transport strategy.	▪ Pocket parks would help to reduce the amount of surface water entering the combine sewer network and overland flows reaching the City centre. ▪ Removing existing subsurface structures will help to reclaim aquifer storage.	▪ Improved urban realm. ▪ Help to manage long term impacts associated with climate change (e.g. urban heat island effects and air quality)	**Action Owner:** Lancaster City Council **Stakeholder Support:** Lancashire County Council Environment Agency United Utilities	Medium-term
F.2	Lancaster City Retrofit SuDS Feasibility Assessment	Feasibility Assessment	Feasibility assessment to identify opportunities for retrofit SuDS projects and to develop outline designs. Feasibility assessment should consider: ▪ Open green space and urban areas across Upland and City centre catchment ▪ Street and neighbourhood level SuDS ▪ Locations and measures that help to provide multiple benefits and could attract co-investment ▪ Community engagement. This would lead into a business case for a catchment wide SuDS project or individual retrofit schemes.	▪ Viable SuDS schemes to reduce volumes of surface water reaching sewers and therefore risk of existing sewer capacity being exceeded.	▪ Reduce frequency and volume of discharges CSOs and therefore improved water quality in Lune Estuary. ▪ Reduce treatment and operational costs for WwTWs and pumping stations. ▪ Improved urban realm. ▪ Link green spaces within catchments and improve biodiversity.	**Action Owner:** Lancashire County Council **Stakeholder Support:** Lancaster City Council United Utilities	Medium-term
F.3	Lancaster Canal Feasibility Assessment	Feasibility Assessment	Feasibility assessment to understand whether the Lancaster Canal could be used for capturing, storing and transporting surface water throughout the city. This should consider: ▪ Canal infrastructure and condition ▪ Historical and predictive flood risk issues ▪ Technical viability of using the canal as surface water discharge location and/or flood storage. This should consider a range of factors such as length of pond, proximity to controlled and uncontrolled inflows, amount that upstream and downstream locks are being used, navigable depth and canal freeboard, as well as discharge locations and volumes. ▪ How the system could be operated and maintained including opportunities for smart systems to inform real time management; ▪ Any engineering, environmental and legal implications to overcome	▪ To reduce surface water runoff entering the City centre catchment from east of the canal. ▪ Possibility to address other residual flood risk associated with the canal which are currently unknown.	▪ Support regeneration of Canal Quarter. ▪ Enhance aesthetics of Lancaster Canal.	**Action Owner:** Canal and Rivers Trust **Stakeholder Support:** Lancashire County Council Lancaster City Council Environment Agency	Long-term

Ref	Action	Type	Description	Outcome	Opportunities	Stakeholders	Priority
G.1	Lancaster Sewer Capacity Improvements	Capital Scheme	Implement a dedicated programme to address capacity issues by implementing several activities including, but not limited to, sewer upsizing, surface water removal and the construction of more surface water capacity and the use of SuDS. Where found to be cost beneficial this should include traditional hydraulic solutions along combined sewers within the Lower Caton Road, City Centre and Upland sub-catchments. This should consider: ▪ Identifying significant physical blockers, such as services, and operational blockers, such as pumping station capabilities; and ▪ Whole life cost benefit of separation. This should be informed by the IDAS and DWMP programme and completed in time to inform the next UU price review for the next Asset Management Plan (AMP) cycle if not already included.	▪ Focus on reducing flood risk at properties that have experienced flooding multiple times.	▪ Traditional hydraulic solutions should be considered in combination with catchment scale solutions such as SuDS to provide wider benefits.	**Action Owner:** United Utilities **Stakeholder Support:** Lancashire County Council Lancaster City Council Environment Agency	Long-term
H.1	Lancaster Property Level Protection Planning, Incentivizing and Implementation Programme	Programme	Both businesses and properties in Lancaster received central government grants to implement property level protection (PLP) measures following the December 2015 floods. There was only partial uptake and the process / advice could have been improved. PLP can help to build second or third lines of physical defence as one of a combination of community-level measures. A Lancashire wide or city centre guidance document and procedure would help improve awareness, ensure the right products are selected, standardize operating procedures around implementation including 'resilient reinstatement' or 'building back better' procedures (including incentivization) following an event.	▪ Understand the best types / locations of PLP measures. ▪ Improve communication to raise, build and maintain individuals flood risk awareness and to encourage community ownership and action. ▪ Provide better independent advice about how to implement PLP and integrate them into overall flood resilience measures.	▪ Standard operating procedures on how such a resilient reinstatement process will look and function operationally ▪ This could involve training of those undertaking surveys or conducting the reinstatement	**Action Owner:** Lancaster City Council **Stakeholder Support:** Lancashire County Council Environment Agency United Utilities	Short-term
H.2	Community Emergency Plan	Plan	A community emergency plan should be prepared covering the City centre using information and findings of this SWMP. This would likely include identification of local buildings that can act as community emergency centres and location of emergency equipment stock to assist residents in emergency situations.	▪ Enhance community resilience by improving preparedness and recoverability to flooding.	▪ Engagement could help to identify further partnership working opportunities.	**Action Owner:** Flood Action Groups **Stakeholder Support:** Lancaster City Council	Short-term
H.3	Local surface water drainage policy and design standards	Policy	The use of local surface water and groundwater policy within the Local Plan or subsequent Spatial Planning Documents supported SuDS design standards could be used to ensure uptake in SuDS that aim to provide betterment and reduce flood risk (rather than aiming to achieve no impact).	▪ Policies should inform strategic and local planning decisions. ▪ Stricter control over how surface water and groundwater is investigated and managed to ensure risk is not overlooked and is effectively addressed.	▪ Policies could attract central government funding for further investigations and modelling. ▪ Tighter management of surface water can also lead to improved water quality and reduction in water entering sewer network.	**Action Owner:** Lancaster City Council **Stakeholder Support:** Lancashire County Council Environment Agency United Utilities	Short-term

Appendix A. Existing datasets, plans, studies and investigations

Table A.1: Existing datasets

Dataset	Data Owner	Description	Use in SWMP Study
Flood Map for Planning	Environment Agency	National dataset identifying locations at risk from fluvial and tidal flooding along Main Rivers.	Used to identify locations at risk from fluvial flooding from Main Rivers.
Main Rivers	Environment Agency	National dataset showing locations of watercourses designated as Main Rivers.	Used to identify Main Rivers.
Detailed Rivers Network	Environment Agency	National dataset showing locations of all watercourses.	Used to understand surface water networks and the identification on Ordinary Watercourses, as well as define surface water drainage catchments.
Sewerage Asset Data	United Utilities	United Utilities GIS assets database showing public sewer network, pumping stations and wastewater treatment works.	Used to understand the surface water networks, define drainage catchments and inform the detailed hydraulic model.
Sewer network	United Utilities	GIS data showing the foul, surface and combined sewer network and assets within Lancaster	Used to support construction of hydraulic model, as well as understanding of how the sewer network operates
National Receptor Database (NRD)	Lancashire County Council	National property dataset detailing property specific information and locations.	Used to calculate economic flood damages and identify vulnerable infrastructure
Canal Asset Data	Canal & Rivers Trust	Details of Canal & Rivers Trust assets including canal locations, embankments, locks and culverts	Used to identify assets owned by the Canal & Rivers Trust.
Gully locations	Lancashire County Council	GIS dataset detailing the location of highway gullies.	Used to inform the detailed hydraulic model.
Soilscapes	Cranfield University	Provides information on soil type as well as soil drainage e.g. infiltration.	Used to understand infiltration potential of land within and surrounding Lancaster City.
Superficial and bedrock geology/ borehole records	British Geological Survey	Details the extent, type, and composition of superficial and bedrock geology.	Used to understand local geology to aid in assessing the potential for groundwater emergence at the surface.

Dataset	Data Owner	Description	Use in SWMP Study
Superficial and bedrock aquifer designation	Environment Agency	Provides information on superficial and bedrock aquifer designations.	Used to understand local aquifers to aid in assessing the potential for groundwater emergence at the surface.
Flooded property locations	Environment Agency	GIS data showing properties which flooded during the Nov 2017, July 2017, Dec 2015 and Dec 2013 events	Identifying historically flooded properties to help understanding of flood mechanisms
December 2015 flood extents	Environment Agency	GIS data showing December 2015 flood extents	Understand historical flood extents, and how these compare to modelled flood extents
Historical flood maps	Environment Agency and Lancashire County Council	Datasets detailing reported incidents of flooding.	Used to support anecdotal evidence and validate detail hydraulic modelling results.
Integrated Catchment Model	United Utilities	1D hydraulic model of Lancaster combined and surface water network	Basis of 1D-2D integrated hydraulic model built during the Catchment Study.
Geosmart Groundwater Flood Risk Map	Geosmart	Groundwater Flooding Risk Map	To support understanding of where groundwater may be contributing to flooding issues alongside surface water
Mill Race survey data	Lancashire County Council	3D topographic survey, 360 colour HDR imagery, 3D surface mesh datasets and CCTV survey of the Mill Race	Provide understanding of Mill Race condition and function
Lune Outfall Locations Study	Environment Agency/Lancaster City Council	Description of various outfalls along the River Lune from the M6 to Millennium Bridge	Identify outfall locations to the River Lune
Bay Gateway junction drainage as built design	Lancashire County Council	As built design drawings showing highway drainage of the Bay Gateway/M6 Junction	Understanding how the surface water drainage network in Upper Caton Road sub-catchment operates
Resilient Route Network (RRN)	Lancashire County Council	GIS data showing the Resilient Route Network within Lancaster	Understanding critical highways within Lancaster and how these could be impacted by flood events
Phase 3 as built drawings	Lancaster City Council	As built drawings of the Phase 3 flood wall	Understanding of dimensions, including footings and how this may affect groundwater flow

Table A.2: Previous plans, studies and investigations

Study	Purpose	Main Findings	Recommendations
Lancaster FAS: Phase 1 and 2 [28]	Business case developed for investment in the tidal defences downstream of the City centre.	The preferred option was a floodwall along the southern bank of the River Lune extending as far upstream as St. George's Quay. This has been demonstrated to provide a 0.1% AEP standard of protection to the City from tidal flooding.	Environment Agency constructed Phases 1 and 2 of the Lancaster Flood Alleviation Scheme (FAS) in 2008.
Lancaster City Council Strategic Flood Risk Assessment[29]	Strategic assessment of flood risk to inform the planning process locally.	The report did not identify significant constraints to development.	Future investment in maintenance, and possibly the raising of defences, to combat the potential impacts of climate change will be imperative to ensure that defences and other flood management assets represent a sustainable solution for the District in the long term.
Lune Catchment Flood Management Plan[30]	This CFMP identifies flood risk management policies to assist all key decision makers in the catchment.	Lancaster was identified as an area of low to moderate flood risk where fluvial risk is generally being managed effectively.	Continue to resist inappropriate development in areas of flood risk.
December 2015: Section 19 flood investigation report[4]	Investigation of the December 2015 flood events with a particular focus on the statutory responsibilities and duties of flood risk management authorities during those storms.	332 properties flooded internally, and electricity substation impacted resulting in 61,000 properties without power for 48 hours.	It was recommended that a bid should be made to access DEFRA funding for flood risk management studies and schemes.
Lancashire and Blackpool Local Flood Risk Management Strategy [31]	Outlines how LCC intend to manage the risk from local sources of flooding over the assessment period.	Identifies the strategic objectives for managing flood risk across the area including: Identification of RMAs and definition of responsibilities; Development of the understanding of local flood risks; Identifying funding opportunities for flood risk management works; and To deliver flood risk management schemes	Recommendations are linked to the implementation of the strategic objectives.

Study	Purpose	Main Findings	Recommendations
November 2017: Section 19 flood investigation report[15]	Investigation of the November 2017 flood events with a particular focus on the statutory responsibilities and duties of flood risk management authorities during those storms.	Flooding occurred in 39 streets across the city of Lancaster with 16 properties flooded internally. All local surface water drainage systems including local watercourses, public sewers and highway drainage systems, were overwhelmed by heavy rainfall leading to flooding of roads, homes, businesses and open space.	It is noted that the EA Phase 3 scheme is underway, as is this SWMP which includes a survey of the Mill Race.
Lancaster FAS: Phase 3 Strategic Outline Case (SOC)[32]	Business case developed for investment in fluvial defences upstream of the city centre.	It was found that there was an economic and strategic to support the development of flood walls along the River Lune.	Construction of the scheme was recommended and is ongoing as of August 2020.
Lancaster City Council Multi-Agency Flooding Plan[33]	Outlines Flood Warning Areas and surface water flooding hotspots around Lancaster. Defines the responsibilities of agencies and available resources during flood events.	1455 properties lie within the Lancaster Quay Flood Warning Area which contains two surface water ‘hot-spots’.	Recommendations are linked to the response of agencies and residents during flood events.

Appendix B. Roles and responsibilities

B.1 Introduction

The Flood and Water Management Act 2010 (FWMA) defines the role of each RMA including within the multi-agency Steering Group and their responsibilities for managing flooding in the UK. RMAs have powers and duties to manage the different forms for flooding that can occur. Those relevant to Lancaster are discussed in further detail below.

Under the FWMA, all RMAs have a duty to co-operate with each other and to share data. A key theme of the Pitt Review was for flood risk management authorities to work in partnership to deliver flood risk management better to the benefit of their communities.

B.2 Lancashire County Council

Lead Local Flood Authority

As LLFA, the Council has several duties and powers as laid out under the FWMA and Land Drainage Act (1991). They lead in managing local flood risks (i.e. risks of flooding from surface water, groundwater and Ordinary Watercourses). This includes ensuring co-operation between the RMAs in their area. Under the Act, LLFAs are required to:

- Develop, maintain, apply and monitor a strategy for local flood risk management in its area;
- Investigate significant local flooding incidents and publish the results of such investigations;
- Develop and maintain a register of structures or features that might impact on flood risk; and
- Manage the consenting process for works that are likely to affect the flow characteristics of Ordinary Watercourses in accordance with the requirements of the Land Drainage Act 1991.

LLFAs also have powers to:

- Undertake works for managing flood risk from surface runoff or groundwater;
- Designate structures and features that affect flooding or coastal erosion; and
- Take enforcement action where there is an obstruction to an Ordinary Watercourse.

Highways Authority

The County Council also holds the position as the local highway authority and under the Highways Act 1980 has a duty to maintain highways that are maintainable at public expense. This includes responsibility for highway drainage, as well as for the condition and safety of all highway assets including bridges and culverts.

Lancashire County Council also have responsibilities under the Civil Contingencies Act 2004 which include identifying potential emergency incidents, as well as co-ordinating incident response and recovery.

B.3 Lancaster City Council

Lancaster City Council is a RMA and also a key partner with regard to planning and local flood risk management. They have a duty to:

- Exercise their flood risk management functions in a manner consistent with local and national strategies, and to have regard to those strategies in their other functions; and
- To co-operate with other relevant authorities in the exercise of flood risk management functions, which may include the sharing of information with other relevant authorities.

They also have powers to:

- Designate structures and features that affect flooding or coastal erosion; and
- Do works on Ordinary Watercourses.

Other departments within the City Council with direct or indirect responsibilities relevant to the management of surface water flooding include:

- Planning and Development Control
  - Responsible for strategic initiatives designed to regenerate the city and surrounding areas; and
  - Responsible for reviewing planning applications and delivery of planning policy (including Local Plan).
- Civil Contingencies
  - Responsible for identifying potential emergency incidents, as well as co-ordinating incident response and recovery.

B.4 United Utilities

Under Section 94 of the Water Industry Act 1991, United Utilities as the water and sewerage company serving Lancaster, have a duty as sewage undertaker, to provide and maintain sewers for the drainage of buildings and associated paved areas within property boundaries. They are also responsible for transferred sewers under the 'Transfer of Private Sewer Regulations 2011' and lateral drains, which communicate with the public sewers.

With regards to local flood risk management, under the Flood and Water Management Act 2010, they have a duty to manage the risk of flooding to water supply and sewerage facilities and flooding which is directly caused by its assets (i.e. water or sewerage pipes). They also must maintain a register of properties that have flooded due to hydraulic incapacity of the sewerage network.

B.5 Environment Agency

The Environment Agency is responsible for taking a strategic overview of the management of all sources of flooding and coastal erosion. This includes, for example:

- Setting the direction for managing the risks through strategic plans;
- Providing evidence and advice to inform Government policy and support others;
- Working collaboratively to support the development of risk management skills and capacity; and
- Providing a framework to support local delivery.

The Agency also has operational responsibility for managing the risk of flooding from main rivers, reservoirs, estuaries and the sea, as well as being a coastal erosion risk management authority.

As part of its strategic overview role, the Environment Agency has published a National Flood and Coastal Risk Management Strategy for England. The strategy provides a lot more information designed to ensure that the roles of all those involved in managing risk are clearly defined and understood.

B.6 Riparian landowners

The legal term riparian is applied to landowners who own land adjoining or containing a river or watercourse. They have certain rights to use the water flowing across their land for their own purposes, and regarding flood risk management they also have several responsibilities, including the following:

- To maintain the bed and banks of the watercourse, and the trees and shrubs growing on the banks;
- To clear any debris (natural or man-made), even if it did not originate from their land; and
- To keep any structures (culverts, trash screens, weirs and mill gates) within their ownership clear of debris.

B.7 SWMP Workshop

Table B.1: Stakeholder objectives

Stakeholder / Department	Objectives
Lancashire County Council / Flood Risk Management	▪ Reduce current flood risk levels ▪ Lower asset maintenance costs ▪ SuDS to provide betterment, not just "no detriment" ▪ Manage flood risk from new developments through the surface water drainage hierarchy ▪ Incorporate surface water drainage through appropriate management techniques, maximising the opportunity to deliver amenity and biodiversity enhancements ▪ Use viable, sustainable and coordinated approaches to better manage the risk of local flooding ▪ Separation of foul and surface water drainage networks
Lancashire County Council / Highways	▪ Consider whole life costs of assets, and maintainability of structures/assets ▪ SuDS to provide betterment, not just "no detriment"
Lancashire County Council / Transport Planning and Policy	▪ Major ambition for sustainable transport, including sustainable routes ▪ Development of a cohesive strategy concerning car park use and requirements ▪ Promote use of 'greenways' (multi-user off-road routes)
Lancaster City Council / Regeneration	▪ Developing solutions which provide multiple benefits ▪ Improving the public realm ▪ Remove barriers to investment ▪ Enable sustainable economic growth across Lancaster
Lancaster City Council / Planning	▪ Make the Council's activities net zero carbon ▪ Increase local resilience to climate impacts ▪ Encourage above ground SuDS to enhance biodiversity, provide betterment, reduce flood risk and limit discharge to sewers ▪ Develop a master plan and delivery strategy for implementation of Canal Quarter Regeneration Scheme ▪ Provide new and maintain existing ecological corridors, and maximise opportunities for green space in the city centre ▪ Create sustainable waterway neighbourhoods ▪ Improve air quality in the city centre (currently failing to meet national objectives)
Lancaster City Council / Civil Contingencies	▪ Keep key transport routes open during flood events ▪ Critical infrastructure to be resilient to flooding
United Utilities	▪ Reduction in internal and external flooding to properties in the next investment period (April 2020 – March 2025) in line with regulatory targets ▪ Encourage developers to follow the surface water hierarchy ▪ Promote Natural Flood Risk Management and Partnership Working to help mitigate, reduce and alleviate flood risk. ▪ Ensure that no detriment is experienced on the current level of service requirements across the public sewerage network and Wastewater Treatment Works.

Appendix C. References

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