

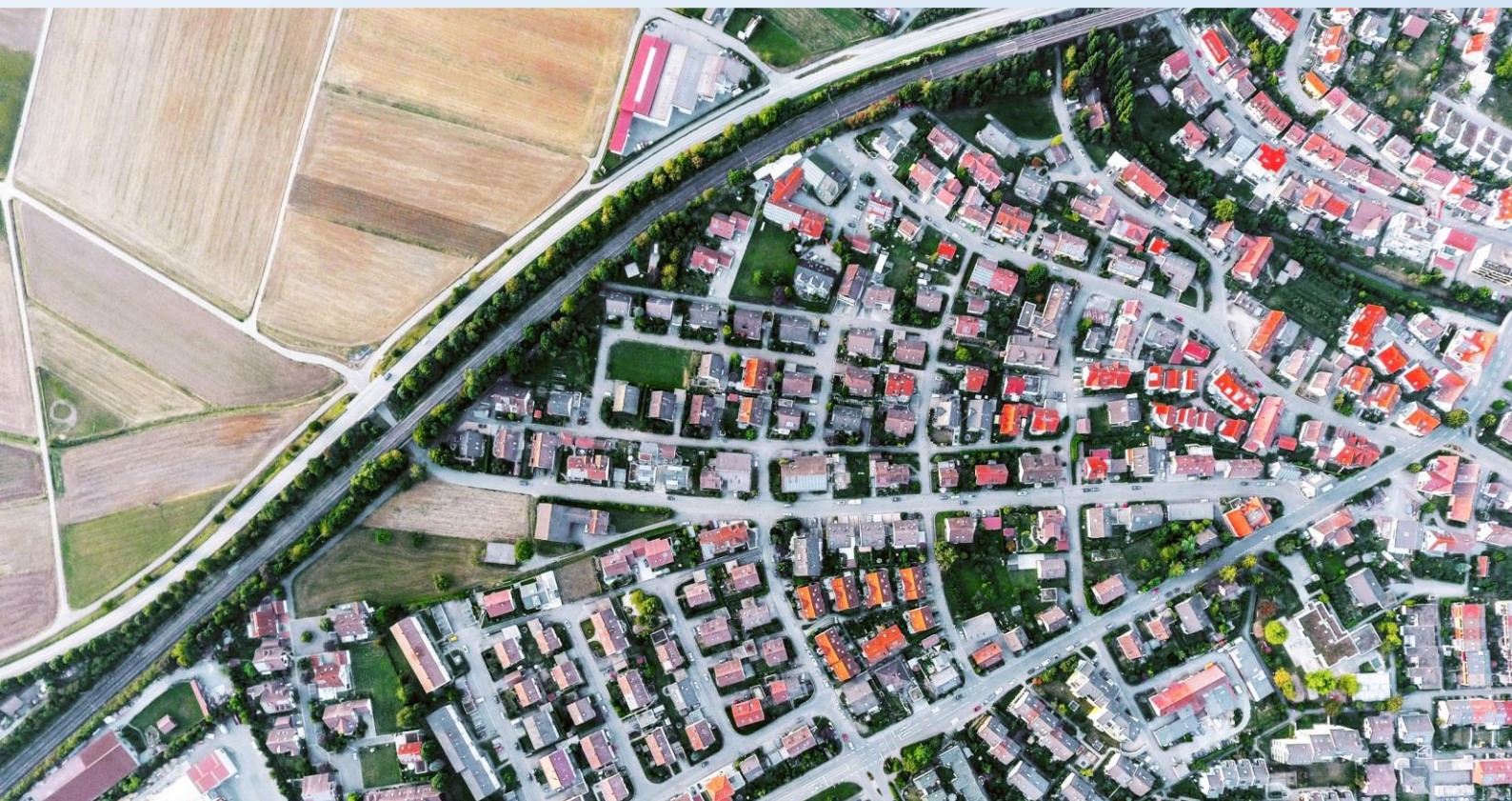


North Yorkshire County Council

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# UPPER DALES DISPERSED VILLAGES FLOOD ALLEVIATION STUDY

Option Investigation Report - Arkengarthdale





North Yorkshire County Council

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Option Investigation Report - Arkengarthdale

**OPTION INVESTIGATION REPORT (001) CONFIDENTIAL**

**PROJECT NO. 70074075**

**OUR REF. NO. 002**

**DATE: JUNE 2021**

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# 1 INTRODUCTION

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In the previous phase of work, described as the 'Upper Dales Flood Studies', WSP carried out an investigation into flood risk and described key locations where North Yorkshire County Council should consider interventions to mitigate flood risk.

Building on this initial phase of flood investigation, this report will explore potential interventions that could reduce risk at the previously identified key flood locations. This optioneering process will take place across the following two stages.

**Stage 1** – Identify the problem: assumption of flood mechanism based on the previously issued report<sup>1</sup> and high-level estimate of flood frequency, properties affected and economic damages.

**Stage 2** – Identify potential solutions: description of intervention based on assumed flood mechanism, high-level estimate of benefits and disbenefits, identification of unknowns and indicative cost estimates for construction and identification of likely maintenance activities.

The results of the assessments carried out in these two stages have been presented in a summarised option description table toward the end of the report (Table 4-2).

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<sup>1</sup> Upper Dales Flood Studies: Leyburn Assessment Report, WSP, 2020



## 2 FLOOD MECHANISMS AND KEY LOCATIONS

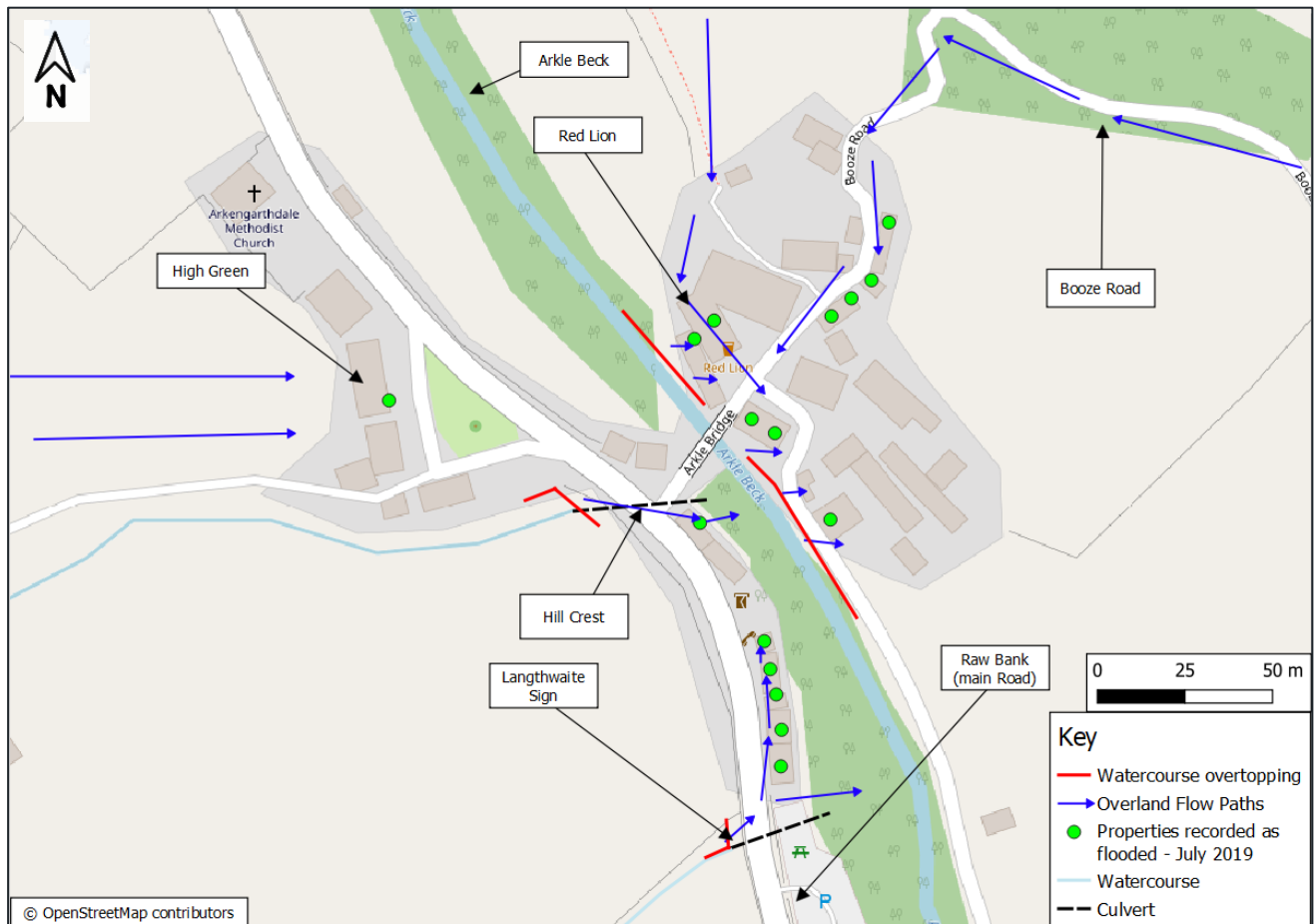
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A previous flood investigation was undertaken that examined the 30th July 2019 flood event at settlements in Arkengarthdale. This highlighted a number of flooding problems that affected properties in Langthwaite and Whaw. Reeth and Fremington, which were also included in the Arkengarthdale flood investigation have been assessed separately and presented under separate cover.

Flooding in Langthwaite during the event was caused by both fluvial flood flows and surface water runoff, affecting properties on both banks of Arkle Beck. Significant volumes of hillslope runoff affected properties at the bottom of Booze Road and on High Green, where fluvial flood risk is not a primary concern. Figure 2-1 shows the flooding mechanisms that affected properties during the 2019 event, as well as the individual properties which reported flooding following the incident. Properties on the left bank of Arkle Beck were affected by surface water runoff from the north routing through the town, via the Red Lion. Water levels in Arkle Beck are also believed to have overtopped the left bank affecting properties along the watercourse bank.

A consultation meeting was held between WSP, North Yorkshire County Council and Arkengarthdale Parish Council on 1st March 2021. The parish council highlighted that additional properties in Langthwaite have flooded in the past relating to a condition issue with a culvert under Raw Bank (main road). A minor unnamed watercourse flows under the main road, via a culvert of unknown size, adjacent to the Langthwaite sign at the southern side of the village. Dates and information relating to the extent of flooding could not be provided. The assumed flooding mechanisms and properties affected are shown in Figure 2-1.

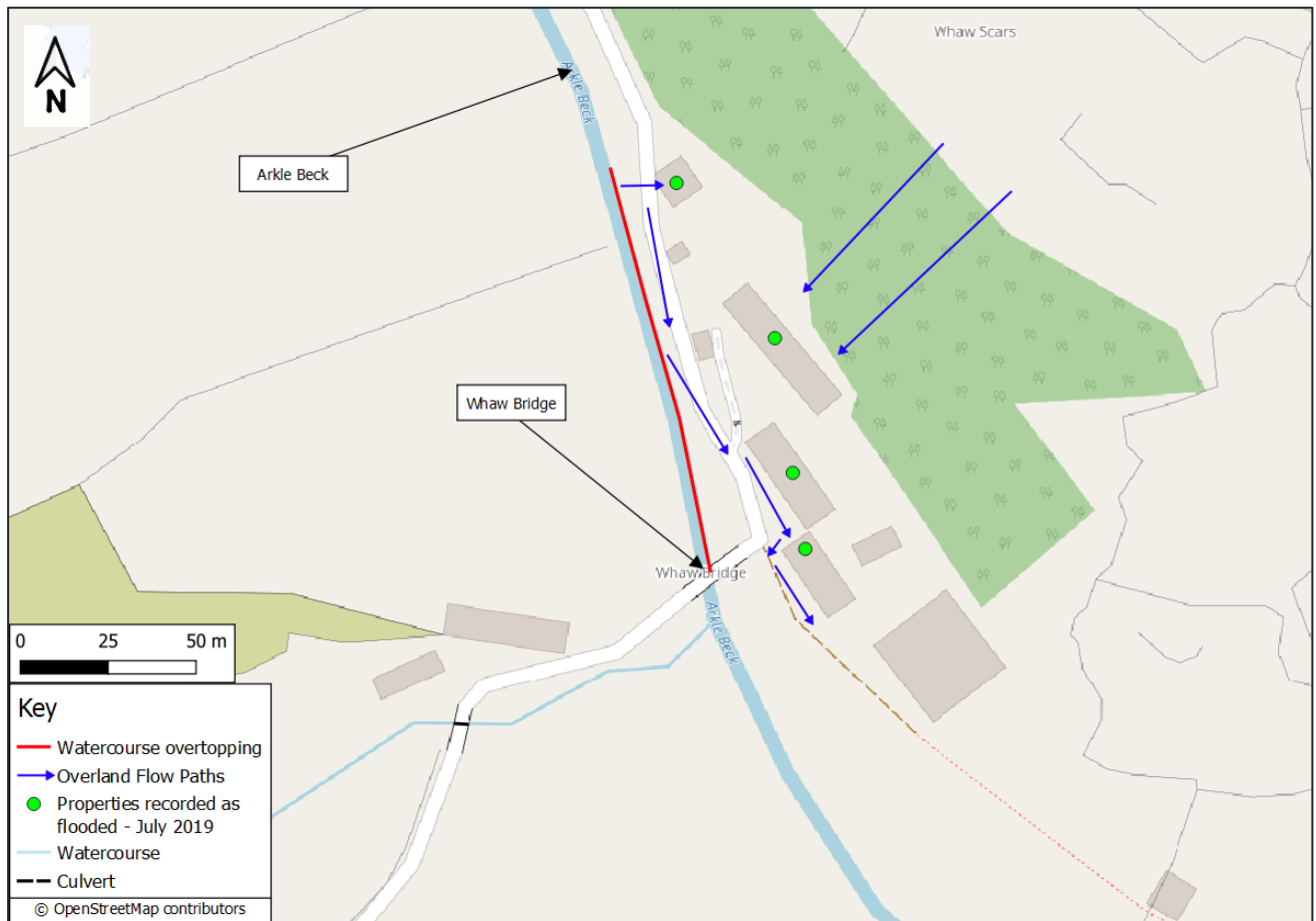
**Figure 2-1 - Overview of identified flooding mechanisms - Langthwaite**



Flooding in Whaw resulted from similar fluvial and surface water flooding mechanisms to those which occurred in Langthwaite. Arkle Beck overtopped the left bank, primarily due to a blockage at Whaw Bridge. The blockage occurred when an upstream footbridge was destroyed and debris was conveyed downstream, becoming trapped against the upstream face of the bridge. Flows in Arkle Beck overtopped the left bank due to the constriction. Photographs of the incident show that depths of flooding exceeding 1m on the left bank. Surface water runoff from the north east also affected properties during the event. Figure 2-2 shows the flooding mechanisms that affected properties during the 2019 event, as well as the individual properties which reported flooding following the incident.



**Figure 2-2 - Overview of identified flooding mechanisms - Whaw**



The earlier phase of investigation found that flooding was widespread across Arkengarthdale with several properties flooded to a significant depth during the 2019 event. At least 10 properties were reported as flooded in Langthwaite with a further 4 reporting flooding in Whaw; however, there was not enough detail to distinguish the severity of flooding, so this number could include incidents of internal flooding to residences, as well as flooding to outbuildings, gardens and driveways. Based on the information provided by Arkengarthdale Parish Council at least one additional property in Langthwaite was affected during the 2019 flooding incident and five additional properties may be at risk of fluvial flooding from the unnamed watercourse which flows under the main road at the Langthwaite sign.

Using the findings of the initial flood investigation, the following key locations were identified to be at significant risk of flooding:

- A) Langthwaite – Arkle Beck Left Bank,
- B) Langthwaite – Booze Road,
- C) Langthwaite – High Green,
- D) Langthwaite South, and
- E) Whaw.

## 3 PROPERTIES AT RISK AND DAMAGES

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### 3.1 PROPERTIES AT RISK

An assessment was undertaken to improve the definition of flood risk at each of the flood locations. It included a review of the total number of properties at risk at each flood location to include other properties likely to be at risk. It also included an estimate of flood frequency for the properties at the flood location. These assessments were made based on engineering-judgement informed by flood incident data, rainfall event analysis, Environment Agency (EA) flood risk mapping, topographic data and the flood mechanism.

As the majority of the locations experience flooding from different sources and/or at a range of return periods, the most representative source and flood frequency has been used for the assessment.

Flood frequency has been provided as a rough guide to indicate the order of flood risk at the location. Further study, such as hydraulic analysis or modelling would be required to confirm the results of the assessment.

For reference, the categorisation of flood risk according to EA surface water flood risk mapping is provided below:

- 1 in 30 years – the location has 3.3% or greater annual chance of flooding from surface water,
- 1 in 100 years – the location has 1% or greater annual chance of flooding from surface water,
- 1 in 1000 years – the location has 0.1% or greater annual chance of flooding from surface water, and
- < 1 in 1000 years – the location has less than 0.1% annual chance of flooding from surface water.

The categorisation of flood risk according to EA fluvial flood risk mapping is provided below:

- 1 in 100 (Flood Zone 3) – the location has 1% or greater annual chance of flooding from rivers,
- 1 in 1000 (Flood Zone 2) – the location has between a 0.1 and 1% annual chance of flooding from rivers, and
- < 1 in 1000 years (Flood Zone 1) – the location has less than 0.1% annual chance of flooding from rivers.

A summary of the findings of this assessment have been provided in Table 3-1.

**Table 3-1 – Definition of flood risk at Locations**

Location		Assumed main source of flooding	Recorded flood incidents provided by NYCC	Total properties assumed to be at risk by WSP*	Surface water flood frequency for 'total properties assumed to be at risk' from EA mapping		Fluvial flood frequency for 'total properties assumed to be at risk' from EA mapping		Flood frequency estimated by WSP (1 in x year return period)
A	Langthwaite Left Bank	Surface Water & Fluvial Flooding	5	11	1 in 30	0			1 in 100  All eleven properties thought to be at risk on Arkle Beck left bank lie within the EA's 1 in 100 year fluvial flood extent.
					1 in 100	0	1 in 100	11	
					1 in 1000	9	1 in 1000	11	
					< 1 in 1000	9	< 1 in 1000	11	
B	Langthwaite – Booze Road	Surface Water	4	4	1 in 30	0			<1 in 1000  None of the properties affected here are shown to be at risk on the EA surface water flood map. It is assumed the annual probability of flooding is less than 0.1%.
					1 in 100	0	1 in 100	0	
					1 in 1000	0	1 in 1000	0	
					< 1 in 1000	4	< 1 in 1000	0	

Location	Assumed main source of flooding	Recorded flood incidents provided by NYCC	Total properties assumed to be at risk by WSP*	Surface water flood frequency for 'total properties assumed to be at risk' from EA mapping		Fluvial flood frequency for 'total properties assumed to be at risk' from EA mapping		Flood frequency estimated by WSP (1 in x year return period)
C    Lanthwaite – High Green & Hill Crest	Surface Water (minor watercourse)	2	3	1 in 30	0			1 in 100  Two properties at Lanthwaite Bridge are shown to be at risk in a 1 in 100 year event due to surface water overtopping the main road. One of these properties was impacted during the 2019 incident; however, it is unknown whether any internal flooding occurred.  The other property flooded in 2019, High Green, lies out with the EA's surface water flood extents.  Additional properties are shown to be at risk on the EA's 1 in 100 year fluvial flood extent (from Arkle Beck). Given the elevation of the properties above the watercourse and the rest of Lanthwaite, it is thought that the flood map does not accurately represent fluvial flood risk on the right bank.  Given the relative frequency of risk for the two properties at Lanthwaite Bridge, the 1 in 100 year surface water flood has been
				1 in 100	2	1 in 100	5	
				1 in 1000	2	1 in 1000	5	
				< 1 in 1000	3	< 1 in 1000	5	

								adopted as the representative flood risk for this location.	
Location		Assumed main source of flooding	Recorded flood incidents provided by NYCC	Total properties assumed to be at risk by WSP*	Surface water flood frequency for ‘total properties assumed to be at risk’ from EA mapping		Fluvial flood frequency for ‘total properties assumed to be at risk’ from EA mapping		Flood frequency estimated by WSP (1 in x year return period)
D	Langthwaite South	Surface Water (minor watercourse)	5	5	1 in 30	0			1 in 1000
					1 in 100	0	1 in 100	5	None of these properties reported flooding during the 2019 event. However, Arkengarthdale Parish Council advised flooding has occurred here due to an issue relating to a culvert under the main road.  All five properties lie within the EA’s 1 in 1000 year surface water flood map.  All 5 properties are shown to be at risk on the EA’s 1 in 100 year fluvial flood extent (from Arkle Beck). Given the elevation of the properties above the watercourse and the rest of Langthwaite, it is thought that the flood map does not accurately represent fluvial flood risk on the right bank.
					1 in 1000	5	1 in 1000	5	
					< 1 in 1000	5	< 1 in 1000	5	
E	Whaw	Surface Water & Fluvial Flooding	4	7	1 in 30	0			< 1 in 1000
					1 in 100	0	1 in 100	1	Properties which reported flooding during the 2019 event all lie out
					1 in 1000	0	1 in 1000	1	

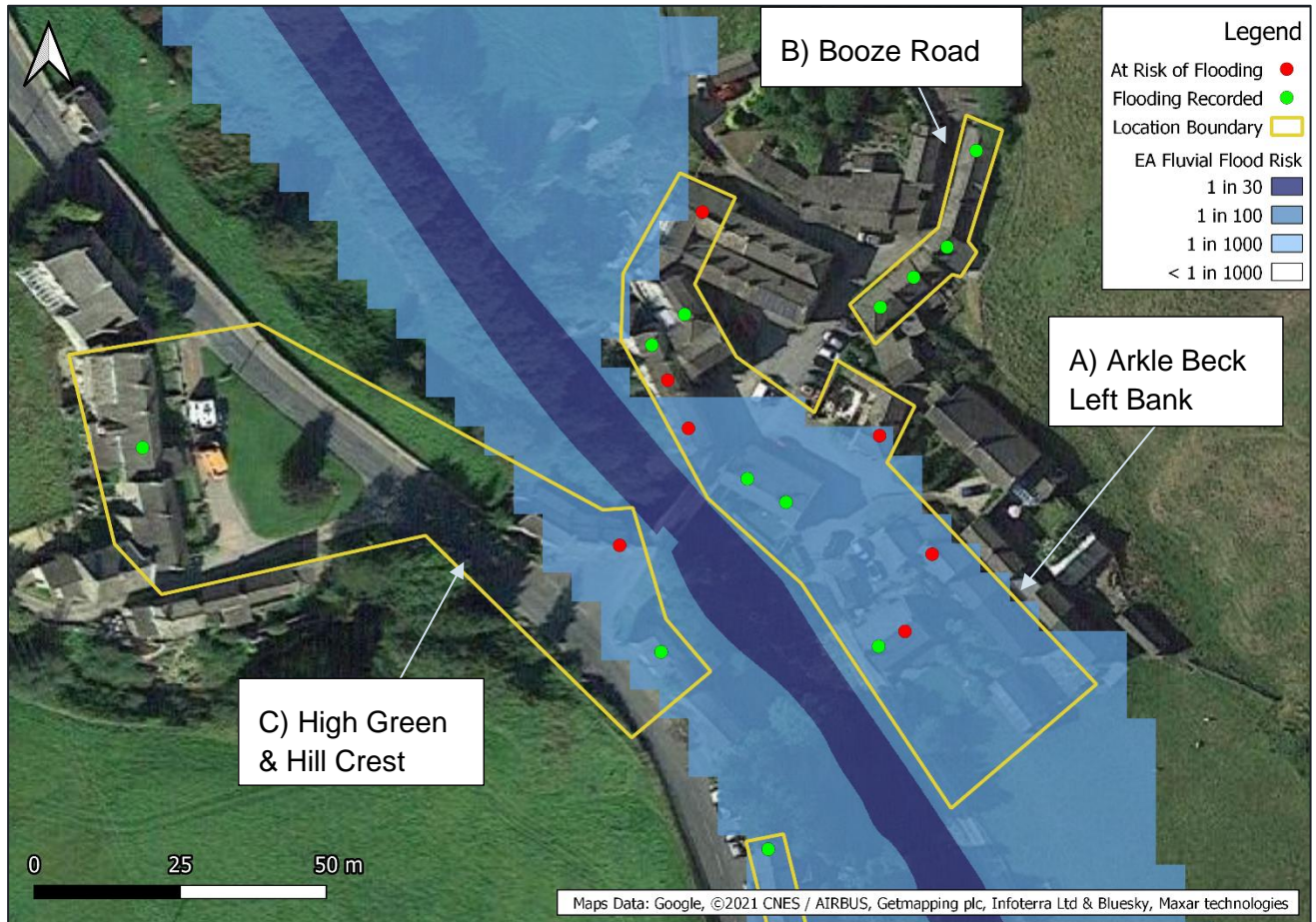
					< 1 in 1000	1	< 1 in 1000	7	<p>with the EA fluvial flood map extents except one.</p> <p>Four properties reported flooding in the 2019 event. Based on a review of historic data including photographs taken during the incident WSP considers it highly likely that 3 additional properties would have sustained internal flooding. These properties either adjoin or lie adjacent to two properties which reported flooding. Photographs of the event suggest external flood depths were around 1 m.</p>
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\*Includes recorded flood incidents provided by NYCC



Plans that show the relevant EA flood risk mapping datasets<sup>2,3</sup> alongside properties that were recorded as flooded, and estimated to be at risk of flooding by WSP have been provided from Figure 3-1 to Figure 3-7. A boundary polygon was drawn at each location (shown in yellow) to include all properties that were considered to be at flood risk for the assigned flood frequency.

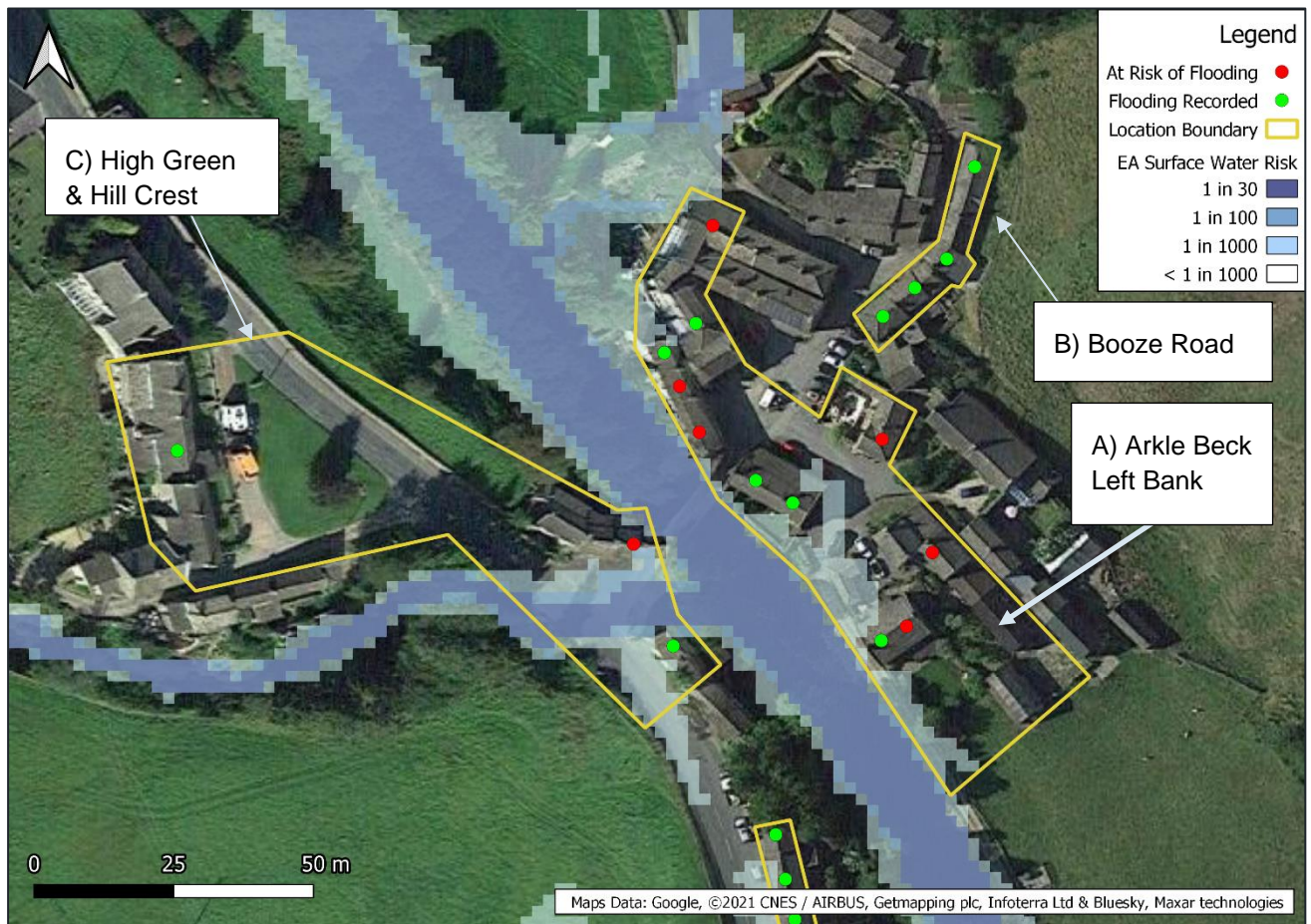
**Figure 3-1 – Flood risk to properties from rivers at Location A) Langthwaite – Arkle Beck Left Bank**



<sup>2</sup> Environment Agency, Flood Zone 2 and 3 Datasets. Available at: <https://data.gov.uk/dataset/cf494c44-05cd-4060-a029-35937970c9c6/flood-map-for-planning-rivers-and-sea-flood-zone-2>

<sup>3</sup> Environment Agency, Surface Water Flood Risk Datasets. Available at: <https://data.gov.uk/dataset/95ea1c96-f3dd-4f92-b41f-ef21603a2802/risk-of-flooding-from-surface-water-extent-3-3-percent-annual-chance>

**Figure 3-2 – Flood risk to properties from surface water at Location A) Arkle Beck Left Bank, B) Booze Road and C) High Green & Hill Crest**





**Figure 3-3 - Flood risk to properties from surface water at Location D) Langthwaite South**

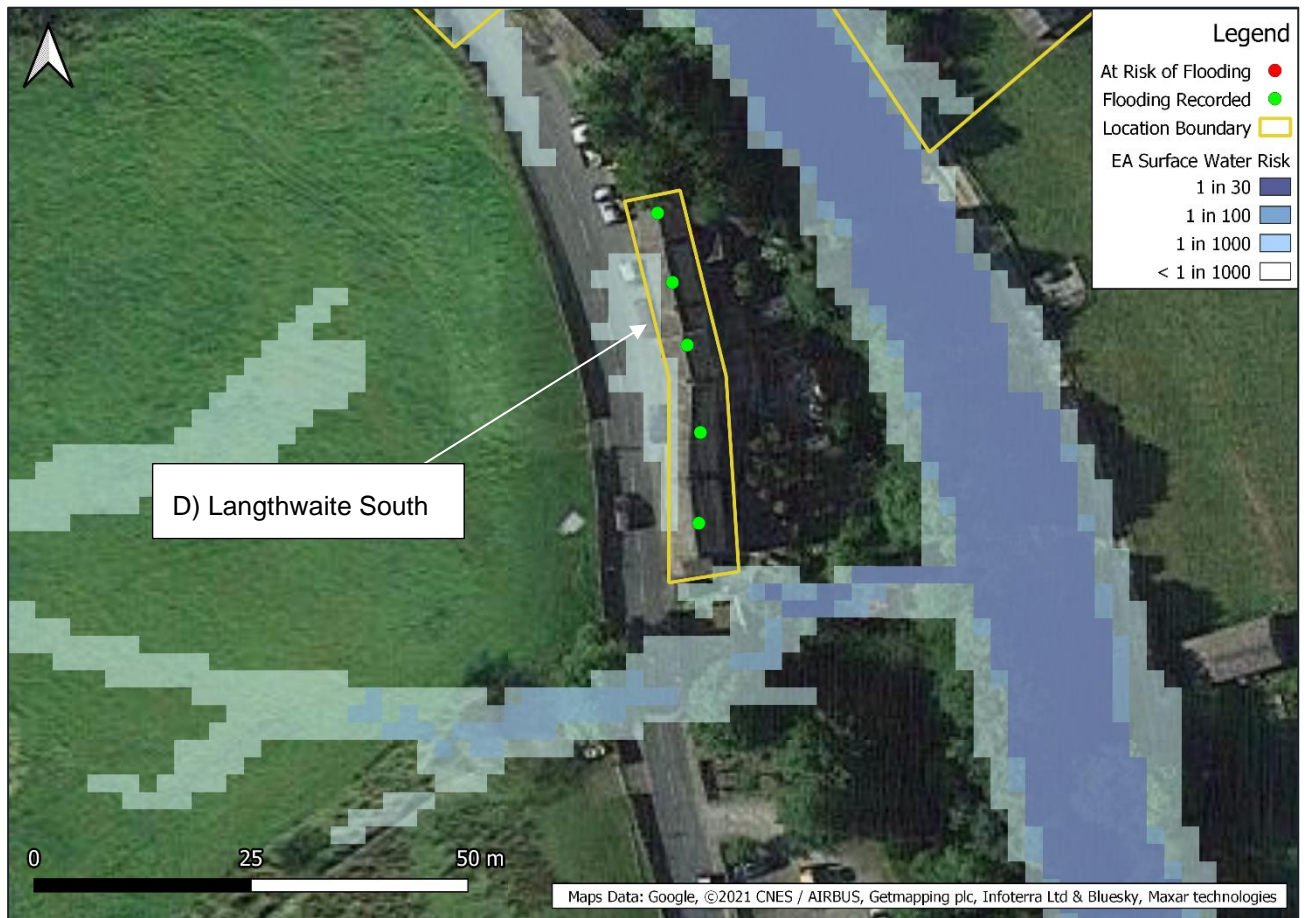


Figure 3-4 – Flood risk to properties from rivers at Location E) Whaw

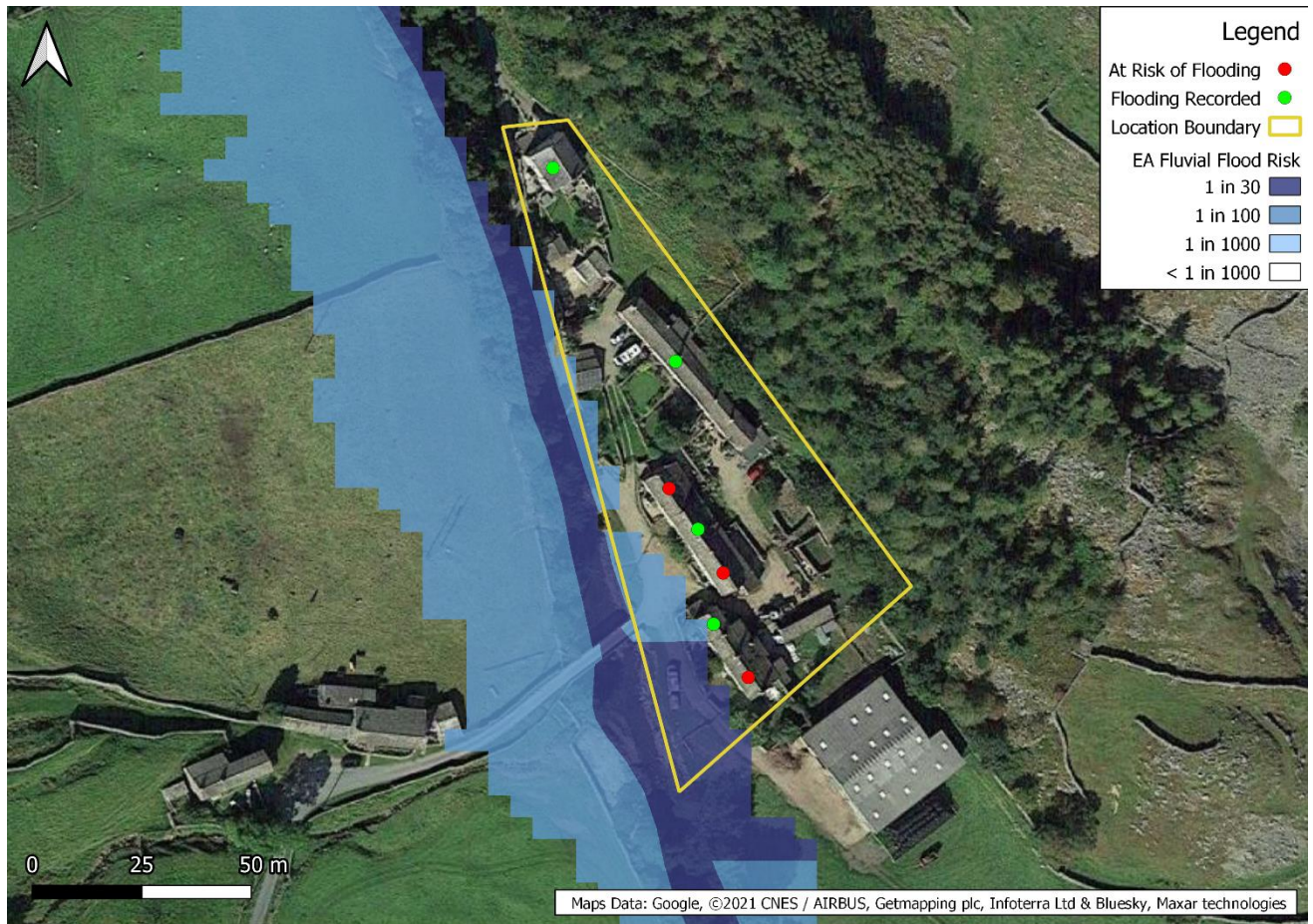




Figure 3-5 – Surface water flood risk at Location E) Whaw



## 3.2 PROPERTY DAMAGES ESTIMATE

Property damages were calculated to indicate the value of damages for the assigned flood frequency, where there is no intervention in place. These calculations were used to provide a broad approximation of flooding damages and do not include other economic damages associated with flooding, such as public health, services and infrastructure damages.

The total number of properties assessed to be at flood risk at each location from the assessment in Section 3.1 were used to calculate damages.

An estimate of damages to individual properties was obtained from 'Environment Agency (2018) *Estimating the Economic Costs of the 2015 to 2016 Winter Floods*<sup>4</sup>. This assigns an average cost of £18,000 per residential property (ranges from £12,000 to £24,000) and an average cost of £99,000 per commercial property. It should be noted that these values were estimated for a single flood event and may overestimate or underestimate the damages for the range of flood frequencies stated in this report. Furthermore, these costs do not consider total economic damages over the lifetime of an intervention that would allow whole-life benefit-cost ratios to be developed.

Table 3-2 describes property risk at each location alongside the estimated damages for the properties.

**Table 3-2 – Estimated Flood Damages**

Location	Flood frequency estimated by WSP (1 in x year return period)	Total properties assumed to be at risk by WSP	Comments	Estimated Property Damages (£)
A Langthwaite – Arkle Beck Left Bank	1 in 100	11	10 Residential Properties 1 Commercial Property	£279,000
B Langthwaite – Booze Road	<1 in 1000	4	Residential Properties	£72,000
C Langthwaite – High Green & Hill Crest	1 in 100	2	Residential Properties	£36,000
D Langthwaite South	1 in 1000	5	Residential Properties	£90,000
E Whaw	<1 in 1000	7	Residential Properties	£126,000

<sup>4</sup> Environment Agency (2018) Estimating the Economic Costs of the 2015 to 2016 Winter Floods. Available at: [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/672087/Estimating\\_the\\_economic\\_costs\\_of\\_the\\_winter\\_floods\\_2015\\_to\\_2016.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/672087/Estimating_the_economic_costs_of_the_winter_floods_2015_to_2016.pdf)



## 4 FLOOD RISK INTERVENTION OPTIONS

### 4.1 OPTIONS DEVELOPMENT

Opportunities for flood risk mitigation at the flood locations were explored based on the observations and assessments made in this report, and in previous work undertaken by WSP as part of the Upper Dales Flood Studies.

Potential interventions were identified through a desk-based opportunities assessment using engineering judgement on the information available, which also included some client input. A broad screening of options was undertaken based on a notional account of option applicability, likely buildability and associated indicative scheme costs, where such could be meaningfully derived.

The client requested that the following intervention types were considered when identifying opportunities for flood alleviation at each flood location:

- Modification of existing drainage,
- Flow attenuation,
- Exceedance planning,
- Working with natural processes i.e. land management, wetland creation, leaky dams etc., and
- Property level protection.

A description of the criteria examined for each of the intervention options identified has been presented in Table 4-1.

**Table 4-1 – Definition of criteria used to explore potential intervention options**

Criteria	Description	Derivation
Location	Locations the client identified for investigation	Identified groups of properties where incidents of flooding have been reported. Confirmed by comparing flood risk data during flood investigation reports by WSP.
Flooding Source	Source of flooding at the location	Identified by WSP by review of flood incident and flood risk data during flood investigation reporting
Flood frequency estimated by WSP (1 in x year return period)	Flood recurrence probability at the location estimated by WSP in Section 3.1	Estimated by WSP based on the common flood frequency of properties at the location based on EA flood risk maps and knowledge of the flood mechanism.
Total properties assumed to be at risk by WSP (No.)	Estimated number of properties at risk of flooding for the flood frequency identified.	Estimated based on flood incident records, historic flooding and flood risk datasets including risk of flooding from surface water and risk of flooding from rivers.
Estimated Property Damages (£)	Estimated property damages in £s for a single flood event at the location if no intervention is put in place	Calculated by multiplying the estimated number of properties at risk by average economic damages for the property type according to 'estimating the cost of 2015/16

Criteria	Description	Derivation
		winter storms', provided in Section 3.2 of the report.
Assumed flooding problem/s	Flood risk problem that the intervention addresses	Identified in preceding flood investigation reporting by WSP <sup>1</sup> . These problems typically require further site-based assessment to be confirmed.
Intervention Type	Classification of the type of the potential intervention	Intervention types described in Section 4.1 of the report
Intervention Description	Description of the design elements that may be able to reduce flood risk at the location	An assumption of the flood mechanism (or problem) has been made and an intervention has been proposed to address these factors. Design elements for the intervention have been assumed based on a limited desk-based assessment of engineering constraints. At this stage, these interventions remain potential strategies and both flood mechanism and intervention require further investigation.
Anticipated hydraulic benefits	Description of the assumed flood risk reduction of the potential intervention at the location	Engineering judgement based on likely effectiveness the potential interventions and assumptions of the flood mechanism.
Estimated Properties Benefiting (No.)	Total number of properties at risk for the flood frequency assigned to the location	Estimated based on the common flood frequency of properties at the location according to flood risk datasets produced by the EA. Described in Section 3.1 of this report.
Secondary Benefits (+) or Disbenefits (-)	Other benefits or disbenefits, including those outside flood risk, anticipated as a result of the potential intervention	Identified using the assumptions made about the potential intervention and its impacts on the catchment. These are key items to be considered in any further investigations.
Intervention Maintenance Requirements	A description of any activities required to maintain the as-designed operation of the potential intervention	Determined according to the design assumptions of the intervention.
Indicative Construction Cost (£)	An indication of total construction cost estimated by a Quantity Surveyor	Estimated costs based on assumed design details provided in Intervention Description. Further explanation is provided in Section 4.2 of this report.
Key Option Unknowns / Limitations	Highlight of any key unknowns or limitations that would significantly impact the viability of the potential intervention	Identified from datasets used during development of interventions.
Mitigation Sequence	An indication of the timescale for the proposed intervention to come	Includes a notional earliest timeframe for all necessary activities to support construction

Criteria	Description	Derivation
	into service; described as Short, Medium or Long term (3+, 6+, 12+ months respectively). Used to provide a comparison of timescales between interventions for sequencing purposes only.	after feasibility, business justification and funding allocation has taken place. This may include, but not be limited to, consultations, site investigations, surveys, hydraulic modelling, detailed design, and construction. It does not take into account the time of year these works are carried out and what impact that would have on the overall programme.

## 4.2 CONSTRUCTION COST ESTIMATES

Only where there is enough option detail to meaningfully derive an indicative quantum of typical construction costs, an outline estimate has been produced by a Quantity Surveyor with experience of flood alleviation scheme cost estimation. Sketches showing the arrangement of some potential interventions, including key design details, has been provided in Appendix B. As the design details have been provided for the purposes of providing outline costs, they are indicative only and are based upon a number of significant assumptions; these assumptions are provided as Appendix C.

The sketches and design assumptions are based on high-level design from a desk-based assessment of how the intervention can be built in the current environment given the assumptions made about the flooding problem.

Cost estimates have been calculated for each of the potential interventions and total costs for construction have been provided in Appendix A and are presented in Table 4-2. These totals also include for the following nominal additions:

- Basic construction costs,
- Uplift to account for other construction items,
  - Contingency for non-defined items (5%)
  - Preliminaries (15%)
  - Works by, and for, statutory undertakers and other authorities (5%)
  - Investigations, design and supervision (14%)
- Land requirements, such as purchase or compensation, and
- Optimism bias at 60%.

The following items are excluded from total construction costs:

- Operation and maintenance,
- Inflation from estimate date to construction phase,
- Local authority charges,
- Client costs, and
- VAT.

A standard optimism bias factor of 60% has been used in accordance with the EA FCERM Appraisal Guidance. This factor is typically reduced to 30% as further investigation and design work is undertaken to feed into an Outline Business Case.

Where Property Level Protection (PLP) is considered, this cost has been obtained from the Environment Agency (2015) '*Cost estimation for household flood resistance and resilience measures – summary of evidence*' guidance<sup>5</sup>.

A breakdown of intervention construction cost estimates according to the elements above is provided in Appendix A.

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<sup>5</sup> Environment Agency (2015) '*Cost estimation for household flood resistance and resilience measures – summary of evidence*'. Available at: [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\\_data/file/411182/Cost\\_estimation\\_for\\_household\\_flood\\_resistance\\_and\\_resilience\\_measures.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/411182/Cost_estimation_for_household_flood_resistance_and_resilience_measures.pdf) (Accessed: 25<sup>th</sup> January 2021).

### 4.3 INTERVENTION OPTIONS

Intervention options that were identified for each of the flood prone areas are presented on Table 4-2. Option arrangement sketches have been provided, as well as design assumptions that describe each intervention in Appendix B and C.

**Table 4-2 – Options identified to provide flood risk mitigation per flood location**

Ref.	Location	Flooding Source	Estimated Flood Frequency (1 in x years)	Properties estimated by WSP to be at risk for the flood frequency (No.)	Estimated Property Damages (£)	Assumed flooding problem/s	Option No.	Intervention Type	Intervention Description	Anticipated hydraulic benefits	Estimated Properties Benefiting (No.)	Secondary Flood Risk Benefits (+) or Disbenefits (-)	Intervention Maintenance Requirements	Indicative Construction Cost (£)	Key Option Unknowns/ Limitations	Mitigation Sequence
A	Langthwaite – Arkle Beck Left Bank	Surface Water/ Fluvial	1 in 1000	11	£279,000	Properties flooded during the 2019 event due to a surface water flow path which routes hillslope runoff towards the village. Additionally, properties on the left bank are at risk of flooding from Arkle Beck directly.	1a	Exceedance Planning 1	Implement a flood wall along the north-west and south-west of the village to provide a barrier to flows. This will effectively 'cut off' the flow path from the north, routing flows into Arkle Beck to the West.  Protection would be afforded to properties at risk of flooding from Arkle Beck.  A back drainage system would be required to provide drainage for surface water runoff flowing into the village from the north-east.  The section of wall at the west of the town would need to be constructed in residential gardens, which may not be acceptable for residents.	Properties in the north on the left bank of Arkle Beck would be protected to a higher standard, against surface water flows from the north and from fluvial flows in Arkle Beck.	11	(-) Would require back drainage system for surface water runoff from the north-east. Without this, flood risk may be increased upstream of the defence.	Regular inspections required to ensure defence is still fit for purpose.  Frequent inspection and clearance of back drainage system to ensure effective operation.	£1,424,500	Likely to require residential property owner buy-in.  Required wall height is unknown. Wall height shown in Appendix C has been used purely as an indicative figure for the purposes of providing outline cost estimates.	Long (12+ months)
						Properties flooded during the 2019 event due to a surface water flow path which routes hillslope runoff towards the village.	1b	Exceedance Planning 2	Implement a flood wall along the north-west of the town to provide a barrier to flows. This will effectively 'cut off' the flow path from the north, routing flows into Arkle Beck to the West.  It is assumed a back drainage system would not be required for this option.	Properties in the north west of the village would be protected against the overland flow path from the north (which is thought to have caused the greatest damage in the 2019 event).	11	(-) Limited protection offered to properties on the left bank of Arkle Beck.	Frequent inspection and to ensure effective operation.	£255,300	Likely to require residential property owner buy-in.  Required wall height is unknown. Wall height shown in Appendix C has been used purely as an indicative figure for the purposes of providing outline cost estimates.	Long (12+ months)
						Properties flooded during the 2019 event due to a	1c	Exceedance Planning 3	Implement a flood embankment along the north-west of the town to provide a barrier to flows. This will	Properties in the north west of the village would be protected against the	11	(-) Limited protection offered to properties on the left bank of Arkle Beck.	Inspection of the embankment for erosion, scour or other defects that may undermine its stability.	£51,200	Likely to require residential property owner buy-in.	Long (12+ months)



Ref.	Location	Flooding Source	Estimated Flood Frequency (1 in x years)	Properties estimated by WSP to be at risk for the flood frequency (No.)	Estimated Property Damages (£)	Assumed flooding problem/s	Option No.	Intervention Type	Intervention Description	Anticipated hydraulic benefits	Estimated Properties Benefiting (No.)	Secondary Flood Risk Benefits (+) or Disbenefits (-)	Intervention Maintenance Requirements	Indicative Construction Cost (£)	Key Option Unknowns/ Limitations	Mitigation Sequence
						surface water flow path which routes hillslope runoff towards the village.			effectively 'cut off' the flow path from the north, routing flows into Arkle Beck to the West.  It is assumed a back drainage system would not be required for this option.	overland flow path from the north (which is thought to have caused the greatest damage in the 2019 event).			Routine vegetation management and minor reinstatement works.		Required embankment height is unknown. Embankment height shown in Appendix C has been used purely as an indicative figure for the purposes of providing outline cost estimates.	
						Properties flooded during the 2019 event due to a surface water flow path which routes hillslope runoff towards the village.  Additionally, properties on the left bank are at risk of flooding from Arkle Beck directly.	2	Property Level Protection	The installation of measures that protect properties from flooding. A notional 'premium' installation per residential property (as per 2015 EA guidance) includes two flood-proof doors, two airbrick covers and external wall render/bricks.	Obstruct flow paths so that flood flows cannot enter property, mainly focused on preventing internal flooding of buildings.	8	(-) Residual flood risk remains as measures rely upon effective operation and maintenance to function.	Inspection and maintenance of measures carried out by property owner.	£70,315 (based on 2008 costs and accounting for inflation at 2.6%/year)	Properties may not be appropriate for proposed measures.  Property owners may reject due to perceived devaluation of property.	Short (3+ months)
B	Langthwaite – Booze Road	Surface Water	<1 in 1000	4	£72,000	Surface water runoff from north-east of the town is conveyed along Booze Road and internally floods residential properties in the north of the village.	3	Drainage Modification	Regrade area of Booze Road above the field in the east of the village in order to divert surface water flows along Booze Road into the field.  At the south-west boundary of the field a newly excavated collection channel would collect surface water flows and route water to the south-east, around the village.  The proposed collection channel as	Reduce peak flood flows downstream of this location, destressing drainage systems and reducing the risk of flooding from overflow of watercourse and drainage features.	4	(+) Improved drainage of Booze Road.  (-) Potentially increases flood risk at Chapel Lodge and Netherly.	Inspection and clearance of collection channel to avoid sediment build up and loss of channel capacity.	£35,500	No hydrological analysis has been undertaken at Booze Road. The volume of surface water runoff is therefore unknown.  Diverting flows through the field will route surface water towards Chapel Lodge and Netherly. In order to ensure flood risk to	Long (12+ months)

Ref.	Location	Flooding Source	Estimated Flood Frequency (1 in x years)	Properties estimated by WSP to be at risk for the flood frequency (No.)	Estimated Property Damages (£)	Assumed flooding problem/s	Option No.	Intervention Type	Intervention Description	Anticipated hydraulic benefits	Estimated Properties Benefiting (No.)	Secondary Flood Risk Benefits (+) or Disbenefits (-)	Intervention Maintenance Requirements	Indicative Construction Cost (£)	Key Option Unknowns/ Limitations	Mitigation Sequence
									outlined discharges to the field at the south-east of the village. However, alternative discharges, such as to Arkle Beck, SuDS pond or soakaway, should be examined.						these properties does not increase, the channel would need to be sized to accommodate a high magnitude return period event (exceeding 1 in 1000). It is not known whether the space available could accommodate a channel of this size.  Booze Road is the only road in and out of Booze. It is a narrow single track road. Closing the road for a significant period to undertake regrading works may not be possible.  The constructability of this option should be subject to further assessment.	
							4	Property Level Protection	The installation of measures that protect properties from flooding. A notional 'premium' installation per residential property (as per 2015 EA guidance) includes two flood-proof doors, two airbrick covers and external wall render/bricks.	Obstruct flow paths so that flood flows cannot enter property, mainly focused on preventing internal flooding of buildings.	4	(-) Residual flood risk remains as measures rely upon effective operation and maintenance to function.	Inspection and maintenance of measures carried out by property owner.	£24,180 (based on 2008 costs and accounting for inflation at 2.6%/year)	Properties may not be appropriate for proposed measures  Property owners may reject due to perceived devaluation of property.	Short (3+ months)
C	Langthwaite – High Green	Fluvial Flooding	1 in 100	2	£36,000	Fluvial flooding occurring where the unnamed	5	Drainage Modification	Replace the culvert under the road to accommodate a higher flow rate.	Reduce the restriction of flows and afflux associated with the culvert.	2	(+) Reduced risk of flooding to the main road.	Inspection of culvert to ensure free flowing conditions and no build-up of debris or sediment within the culvert barrel.	£56,000	No hydraulic assessment has been made when providing outline culvert	Medium (6+ months)

Ref.	Location	Flooding Source	Estimated Flood Frequency (1 in x years)	Properties estimated by WSP to be at risk for the flood frequency (No.)	Estimated Property Damages (£)	Assumed flooding problem/s	Option No.	Intervention Type	Intervention Description	Anticipated hydraulic benefits	Estimated Properties Benefiting (No.)	Secondary Flood Risk Benefits (+) or Disbenefits (-)	Intervention Maintenance Requirements	Indicative Construction Cost (£)	Key Option Unknowns/ Limitations	Mitigation Sequence
						watercourse flows under the road opposite Hill Crest. Culvert is estimated to be about 50% blocked (the Parish Council).			Investigate influence of Arkle Beck on the culvert outlet and if necessary, raise the culvert outlet to maintain free flowing conditions when water levels in Arkle Beck are high.	Reduced risk of flooding to the former Black Smith shop and adjacent properties.		(+) Single barrel precast concrete culvert should be less prone to blockage than the current masonry arch culvert.			dimensions for costing.  Culvert dimensions used for costing are based on residents' estimates of the current culvert dimensions, on the assumption that the culvert capacity would be sufficient if it was free flowing, and free of debris.	
							6	Drainage Modification 2	Undertake essential maintenance to clear culvert and implement modern trash screen to prevent future blockage.	Increased culvert capacity and reduced risk of blockage would reduce risk of flooding to the former Black Smith shop and adjacent properties.	2	(+) Reduced risk of flooding to the main road.	Frequent clearance of debris from trash screen. This would be required prior to and following major rainfall events when forecast.	£7,800	Residents attempts to remove the blockage have so far been unsuccessful. Clearance of the culvert may therefore not be possible without intrusive interventions.  This option assumes that the culvert dimensions are sufficient to convey high RP flows, provided the culvert is free from blockage. No hydraulic assessment has been undertaken to verify this assumption.  It is assumed there is sufficient space to install the trash screen and provide access for maintenance. This has not been confirmed on site. A	Medium (6+ months)

Ref.	Location	Flooding Source	Estimated Flood Frequency (1 in x years)	Properties estimated by WSP to be at risk for the flood frequency (No.)	Estimated Property Damages (£)	Assumed flooding problem/s	Option No.	Intervention Type	Intervention Description	Anticipated hydraulic benefits	Estimated Properties Benefiting (No.)	Secondary Flood Risk Benefits (+) or Disbenefits (-)	Intervention Maintenance Requirements	Indicative Construction Cost (£)	Key Option Unknowns/ Limitations	Mitigation Sequence
															survey of the culvert is required to confirm suitability for installation.	
		Surface Water/ Fluvial Flooding	<1 in 1000	3	£54,000	Fluvial flooding occurring where the unnamed watercourse flows under the road opposite Hill Crest. Culvert is estimated to be about 50% blocked (the Parish Council.)  High Green is affected by surface water runoff from the hills to the west.	7	Property Level Protection	The installation measures that protect properties from flooding. A notional 'premium' installation per residential property (as per 2015 EA guidance) includes two flood-proof doors, two airbrick covers and external wall render/bricks.	Obstruct flow paths so that flood flows cannot enter property, mainly focused on preventing internal flooding of buildings.	3	(-) Residual flood risk remains as measures rely upon effective operation and maintenance to function.	Inspection and maintenance of measures carried out by property owner.	£18,140 (based on 2008 costs and accounting for inflation at 2.6%/year)	Properties may not be appropriate for proposed measures.  Property owners may reject due to perceived devaluation of property.	Short (3+ months)
D	Langthwaite South	Fluvial Flooding	1 in 1000	5	£90,000	Fluvial flooding occurs where an unnamed watercourse surcharges the culvert under the main road (adjacent to the Langthwaite sign) placing properties at risk. No incident records are held for this location; however, this flood mechanism was	8	Drainage Modification	Replace the culvert under the highway with a culvert of equivalent or increased capacity.	Reduced risk of flooding to residential properties.	5	(+) Reduced risk of flooding to the main road.	Inspection of culvert to ensure free flowing conditions and no build-up of debris or sediment within the culvert barrel.	£99,000	No hydraulic assessment has been made when providing outline culvert dimensions for costing.  Culvert dimensions shown in Appendix C are indicative for costing purposes only.	Medium (6+ months)
							9	Property Level Protection	The installation measures that protect properties from flooding. A notional 'premium' installation per residential property (as per 2015 EA guidance) includes two flood-proof doors, two airbrick covers and	Obstruct flow paths so that flood flows cannot enter property, mainly focused on preventing internal flooding of buildings.	5	(-) Residual flood risk remains as measures rely upon effective operation and maintenance to function.	Inspection and maintenance of measures carried out by property owner.	£30,225 (based on 2008 costs and accounting for inflation at 2.6%/year)	Properties may not be appropriate for proposed measures.  Property owners may reject due to perceived	Short (3+ months)

Ref.	Location	Flooding Source	Estimated Flood Frequency (1 in x years)	Properties estimated by WSP to be at risk for the flood frequency (No.)	Estimated Property Damages (£)	Assumed flooding problem/s	Option No.	Intervention Type	Intervention Description	Anticipated hydraulic benefits	Estimated Properties Benefiting (No.)	Secondary Flood Risk Benefits (+) or Disbenefits (-)	Intervention Maintenance Requirements	Indicative Construction Cost (£)	Key Option Unknowns/ Limitations	Mitigation Sequence
						highlighted by members of the Parish Council. The Parish Council advised the culvert has fallen into disrepair and is the cause of the flooding issue.			external wall render/bricks.						devaluation of property.	
E	Whaw – Arkle Beck Left Bank	Surface Water	<1 in 1000	7	£126,000	Surface water runoff from hillside to the east of Whaw routes towards properties resulting in internal flooding to at least 1 property and possible impacts to 6 others.	10	Drainage Modification	A newly excavated collection channel would collect surface water runoff from hillsides and convey flows away from buildings.  Pipe outfalls would take water from the collection channel and discharge to Arkle Beck.	Reduced risk of surface water flooding to properties	6	(-) Discharge to Arkle Beck would be constrained by water levels in the watercourse.	Inspection and clearance of collection channel & drainage pipes to avoid sediment build up and loss of channel capacity.	£87,600	No hydrological analysis has been undertaken to estimate the volume of surface water runoff. The channel and pipe dimensions presented in Appendix C are indicative for the purposes of producing outline cost estimates for an option like this.  It is assumed that the drainage system would drain to Arkle Beck under gravity conditions. It is assumed that the inlet to the drainage pipes is sufficiently elevated above the watercourse to allow this. It is therefore assumed that risk of backflow is low, and flap valves have not been costed as part of this option.	Medium (6+ months)



Ref.	Location	Flooding Source	Estimated Flood Frequency (1 in x years)	Properties estimated by WSP to be at risk for the flood frequency (No.)	Estimated Property Damages (£)	Assumed flooding problem/s	Option No.	Intervention Type	Intervention Description	Anticipated hydraulic benefits	Estimated Properties Benefiting (No.)	Secondary Flood Risk Benefits (+) or Disbenefits (-)	Intervention Maintenance Requirements	Indicative Construction Cost (£)	Key Option Unknowns/ Limitations	Mitigation Sequence
		Fluvial Flooding	<1 in 1000	7	£126,000	Arkle Beck presents a risk of flooding to at least 6 properties on the left bank as evidenced during the 2019 flooding incident.	11	Exceedance planning	Implement a flood wall along the bank of Arkle Beck to protect against fluvial flooding.  A back drainage system would be required to provide drainage for surface water runoff flowing into the village from the north-east.	Reduced risk of fluvial flooding to properties.	6	(-) Would require back drainage system for surface water runoff from the north-east.	Regular inspections required to ensure defence is still fit for purpose.  Frequent inspection and clearance of back drainage system to ensure effective operation.	£430,000	Requires residential property owner buy-in.  Required wall height is unknown. Wall height shown in Appendix C has been used purely as an indicative figure for the purposes of providing outline cost estimates.  Residents have advised that they believe there is insufficient space available to implement this option due to the presence of the road, which is used by heavy farm plant. The potential wall height is therefore constrained.	Long (12+ months)
		Surface Water/ Fluvial Flooding	<1 in 1000	7	£126,000	Flooding caused by rapid hillslope runoff and high fluvial flows in Arkle Beck.	12	Property Level Protection	The installation of measures that protect properties from flooding. A notional 'premium' installation per residential property (as per 2015 EA guidance) includes two flood-proof doors, two airbrick covers and external wall render/bricks.	Obstruct flow paths so that flood flows cannot enter property, mainly focused on preventing internal flooding of buildings.	6	(-) Residual flood risk remains as measures rely upon effective operation and maintenance to function.	Inspection and maintenance of measures carried out by property owner.	£36,270 (based on 2008 costs and accounting for inflation at 2.6%/ year)	Properties may not be appropriate for proposed measures.  Property owners may reject due to perceived devaluation of property.	Short (3+ months)
	All areas	Fluvial	1 in 1000	29	£603,000	Rainfall runoff discharges to Arkle Beck rapidly. Due to a lack of floodplain attenuation	13	Flow Attenuation	Implement floodplain embankments in two areas of existing floodplain upstream of Whaw. The embankments provide impediments to floodplain flow, increasing water levels	Reduced peak flows in Arkle Beck would reduce fluvial flood risk to properties.	17 (+ additional properties benefitting in Reeth & Fremington)	(+) Reduced flood risks to transport infrastructure & crossings.  (+) Increases flooding in area remote from properties to	Inspection of embankments to ensure no erosion, settlement or invasive vegetation has taken place.  Routine vegetation management, as well as minor reinstatement	£605,000	The existing flood storage volume afforded by the natural floodplain is unknown. The material benefit, in terms of storage gained	Long (12+ months)



Ref.	Location	Flooding Source	Estimated Flood Frequency (1 in x years)	Properties estimated by WSP to be at risk for the flood frequency (No.)	Estimated Property Damages (£)	Assumed flooding problem/s	Option No.	Intervention Type	Intervention Description	Anticipated hydraulic benefits	Estimated Properties Benefiting (No.)	Secondary Flood Risk Benefits (+) or Disbenefits (-)	Intervention Maintenance Requirements	Indicative Construction Cost (£)	Key Option Unknowns/Limitations	Mitigation Sequence
						peak flows in the watercourse are very high.			within the floodplain, thus increasing floodplain storage.  Increasing floodplain storage means water is released more gradually from the floodplain back to the downstream watercourse channel, reducing peak flows in the watercourse.			reduce flood risk in urban areas.  (-) Erosion of embankments could result in failure. If this occurs during a flood event where water levels are elevated, then the resulting breach would behave similarly to a small reservoir failure.	works as identified by inspections.		is also unknown.  No hydraulic analysis has been undertaken when sizing the embankments. The size presented in Appendix C is indicative for the purposes of costing. It is unknown whether implementing floodplain embankments would have a significant impact on flood risk in Arkengarthdale without use of hydraulic modelling.	
	All areas	Fluvial/ Surface Water	1 in 1000	29	£603,000	Members of the parish council have advised that government grants were previously awarded to implement drainage channels in the upper moors which have since eroded and become much larger in scale. It is believed that this is contributing to more rapid runoff during rainfall events, with Arkle Beck becoming	14	Natural Flood Management	Undertake a series of land use changes/interventions in order to reduce rate of hillslope runoff. Interventions may include tree planting, leaky dams, removal of formal land drainage, limiting sediment transport.  Aim to infill a number of drains or 'grips' in the upper catchment to slow runoff/discharges to Arkle Beck.  Undertake peatland restoration where erosion and degradation of natural peatland has occurred.	Reduced peak flows in Arkle Beck would reduce fluvial flood risk to properties.  Where more localised interventions are introduced the risk of surface water flooding would be reduced by slowing the rate of hillslope runoff.	29 (+ additional properties benefitting in Reeth & Fremington.	(+) Likely ecological benefit (this would be an additional aim)  (+) Provides passive flood risk management  (+) Given the unique circumstances of the Arkle Beck catchment, and how extensively the upper moor is actively managed, NFM could prove to provide benefits beyond the usual low RP events which is often a constrained in other catchments.	Will vary depending on intervention; however, maintenance activities are likely to fall on the landowner.	Costs could not be meaningfully estimated due to unknowns regarding type and extent of intervention necessary to have a meaningful impact.	Will require landowner buy-in, which has currently not been discussed.  The extent of possible interventions is not fully known. A high level NFM scoping study would be advised as the first step towards implementing catchment wide interventions.	Scoping study – Medium (6+ months)  Interventions – Long (12+ months)

Ref.	Location	Flooding Source	Estimated Flood Frequency (1 in x years)	Properties estimated by WSP to be at risk for the flood frequency (No.)	Estimated Property Damages (£)	Assumed flooding problem/s	Option No.	Intervention Type	Intervention Description	Anticipated hydraulic benefits	Estimated Properties Benefiting (No.)	Secondary Flood Risk Benefits (+) or Disbenefits (-)	Intervention Maintenance Requirements	Indicative Construction Cost (£)	Key Option Unknowns/ Limitations	Mitigation Sequence
						much flashier in the last few decades. Peat erosion has also been noted to be an issue as a result.										

## 4.4 PARISH COUNCIL CONSULTATION

On 1st March 2021 WSP and NYCC held a consultation meeting with members of Arkengarthdale Parish Council. This opportunity was used to share the findings of the study so far and to capture further information that could be incorporated into the optioneering process.

The primary purpose of the meeting was to summarise the understanding of flood risk in the settlement and confirm whether this fitted with the councillors' local knowledge and experience of flooding in the area. In addition to this, the options currently being considered were described and any feedback recorded for further assessment of the options.

Several important pieces of information were obtained during the meeting. Arkengarthdale Parish Council highlighted two areas of Langthwaite in which flooding had occurred and not been reported by residents. One property adjacent to Hill Crest, which was a former blacksmith shop and recently converted to a residential property, was affected during the 2019 event. An external wall was knocked down by flood waters, though it is unknown whether internal flooding occurred. The second location highlighted was the area adjacent to the Langthwaite sign, where residential properties were flooded when the unnamed watercourse overtopped the road. These two areas have been included in the study with potential options outlined to mitigate flood risk.

A total of 16 options were presented to the council for comment. Based on the feedback provided at the consultation amendments were made to four options and four other options were scoped out as they were either not feasible or aimed to mitigate a flood risk issue that had since been addressed. A further four options were added following the consultation to address newly highlighted issues, or to provide variations on some options. A total of 16 options were therefore carried forward for costing.

In addition to feedback on presented options the parish council provided WSP with information relating to some of the flood mitigation measures that have been implemented by residents in Arkengarthdale. It is important that the impacts of these interventions are considered before implementing any of the presented options in Table 4.2.

One resident informed WSP and NYCC of recent dredging works that residents completed in Arkle Beck over a large reach of the watercourse. The works saw the removal of bed material down to the bedrock, with 2m depths of excavation achieved in some locations. Upstream of Langthwaite a river island was removed from Arkle Beck as it was thought that the island was pushing water out on to the left bank, which then flowed towards the village overland.

As well as dredging, riparian management has been undertaken to remove dead trees from the channel banks in order to reduce the risk of blockage at bridges over Arkle Beck. The parish council expressed that more help with riparian management would be considered beneficial.

The parish council informed WSP and NYCC that the culvert under the main road, opposite Hill Crest and the former blacksmith shop, is as much as 50% blocked, approximately halfway along the barrel. Attempts have been made to clear the culvert with no success thus far. More comment is made regarding this in Table 4.2 (Option 6).

With regards to flooding on Booze Road, the parish council informed WSP that there are highway drainage gullies along the road. These gullies are prone to blockage, resulting in surface water being conveyed along the road towards the village.

Members of the parish council gave anecdotal accounts of the runoff response of Arkle Beck in previous decades, stating that following a rainfall event water levels in the beck rose more gradually and were more sustained than they are today. According to residents Arkle Beck has become flashier, with water levels rising and falling much faster, resulting in much higher flows than would have normally been observed in past decades. It is believed the reason for this is related to the way the upper catchment and moors have been managed. According to the parish council, grants were awarded some 30-40 years prior to implement extensive drainage in the upper catchment. These drains have since eroded to an increasingly significant size, as well as contributing to peatland erosion. Specific locations could not be provided as to where these drains are located; however, it is thought that they are extensive in the upper catchment.

## 5 CONCLUSIONS

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WSP have undertaken a review of flood risk data alongside the findings of the previous phase of flood investigation work to improve the understanding of flooding problems and property risk across Arkengarthdale.

As such, the following flood locations have been identified as being key problem areas due to the estimated numbers of properties affected and assumed frequency of flooding:

- A) Langthwaite – Arkle Beck Left Bank,
- B) Langthwaite – Booze Road,
- C) Langthwaite – High Green,
- D) Langthwaite South, and
- E) Whaw – Arkle Beck Left Bank

Total damages were calculated for each flood location, which indicated the current property damage that would occur if no intervention was put in place. The total property damages at the locations ranged from £54,000 to £279,000. These damages were estimated based on a single storm event and do not consider total economic damages over the lifetime of an intervention that would allow a more complete whole-life benefit-cost ratio to be developed.

The calculated damages provided an indication of the maximum value of benefits that could be achieved by any intervention at each location. The cost of an intervention would typically need to be lower than the value of benefits in order to be considered favourable for investment, excluding at this stage consideration of any other benefits such as mental health, access, amenity, environmental, etc. These benefit values therefore provided a guide to the scale of intervention that could be considered when developing options.

Potential solutions were identified for each flood location by considering a range of interventions that may be suitable to address the assumed mechanisms of the flooding issue. In total, 16 potential interventions were identified across Arkengarthdale, which included: drainage modifications, flow attenuation, planning for exceedance, natural flood management and property-level protection.

Each of the potential options were described according to a range of criteria that provided information to support the flood risk management decision-making process in future phases of work. A plan sketch was provided to show the arrangement of the interventions across the settlement.

A construction cost was estimated, where such could be meaningfully derived, along with likely associated maintenance requirements. These criteria provided an indication of the likely capital and revenue costs associated with the interventions. Construction costs ranged from £7,800 to £1,424,500 with the majority of interventions falling within a range of £15,000 to £99,000.

As the economic benefits of the options could not be directly calculated at this stage, full benefit-cost analysis could not be carried out. The economic information presented is considered indicative and intended to help inform next stage decision making.

## 6 RECOMMENDATIONS

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As the investigation into intervention options progressed, a number of significant assumptions were made in order to address key unknowns. In relation to the identification of the flood problem at each flood location, the assumptions related to:

- Condition and dimensions of existing drainage assets,
- Sizing of drainage assets such as watercourses and culverts,
- Distribution of flood risk, depths and frequency of flooding,
- Number of properties at risk for a given flood frequency, and
- Value of property damages and maximum benefit value at each location.

Further work should be considered to fully understand the flood problems at each location outlined in this report. Some opportunity areas were identified, such as Natural Flood Management (NFM), which could have wide ranging benefits for Langthwaite & Whaw, as well as the downstream towns of Reeth and Fremington. A specific NFM scoping study would be recommended to confirm whether there are significant flood risk benefits to implementing NFM strategies in Arkengarthdale.

As part of this investigation, consultation was undertaken between the client and other stakeholders, including residents and town councillors. It is recommended that this engagement continues and that the findings of this report are carefully considered and evaluated in light of any additional information.

A range of investigations and assessments are available to further define the solutions listed below, which should be considered on a case-by-case basis depending on the scale and complexity of the conceptual intervention:

- Survey of drainage assets where possible to understand the current condition, connections and size,
- Hydrological assessment to estimate flows for flood frequencies,
- Drainage calculations to determine if the drainage network is adequately sized and define requirements for upsizing,
- Localised hydraulic modelling to improve the definition of flood risk to properties and to test options – only where data allows, and
- Assess the location and condition of culverts that cross the highway, and consequences of flooding to the local road network.

In the cases where locations are at low risk of flooding, the cost of undertaking these activities may outweigh the value of any potential benefits that result from the intervention. It is recommended that the locations with highest flood risk are prioritised for further investment.

It should be acknowledged that the reported incidents of property flooding were made as a result of an exceptional storm and that the existing drainage infrastructure was not designed to convey this magnitude of flow. Our recommendations for investigation and improvement of drainage infrastructure should be considered, so that adequate capacity can be provided at problem locations to mitigate stressors, such as asset deterioration and long-term climate change.

# Appendix A

## OPTION COST ESTIMATES



# Appendix B

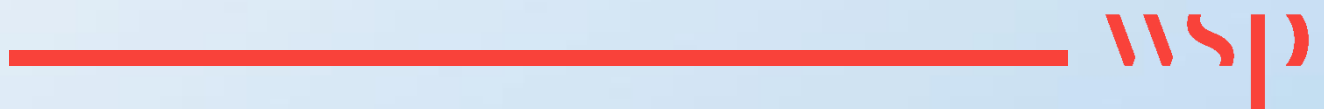
## OPTION ARRANGEMENT SKETCHES





# Appendix C

## OPTION DETAILS PROFORMAS







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