Cromford Canal Beggarlee Extension Flood Risk Assessment



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On behalf of Friends of Cromford Canal
2/4/2019

CROMFORD CANAL BEGGARLEE EXTENSION

FLOOD RISK ASSESSMENT

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Cromford Canal - Beggarlee Extension Flood Risk Assessment

1.0 Introduction

1.1 This Flood Risk Assessment (FRA) forms part of the Cromford Canal Beggarlee Extension Planning Application and considers the flood risk impact of restoring a 1.0km section of the Cromford Canal between the existing canal at Langley Mill Basin and Stoney Lane to the north on the Derbyshire/Nottinghamshire border. Figure 1 shows the location of the application site including the red line boundary.

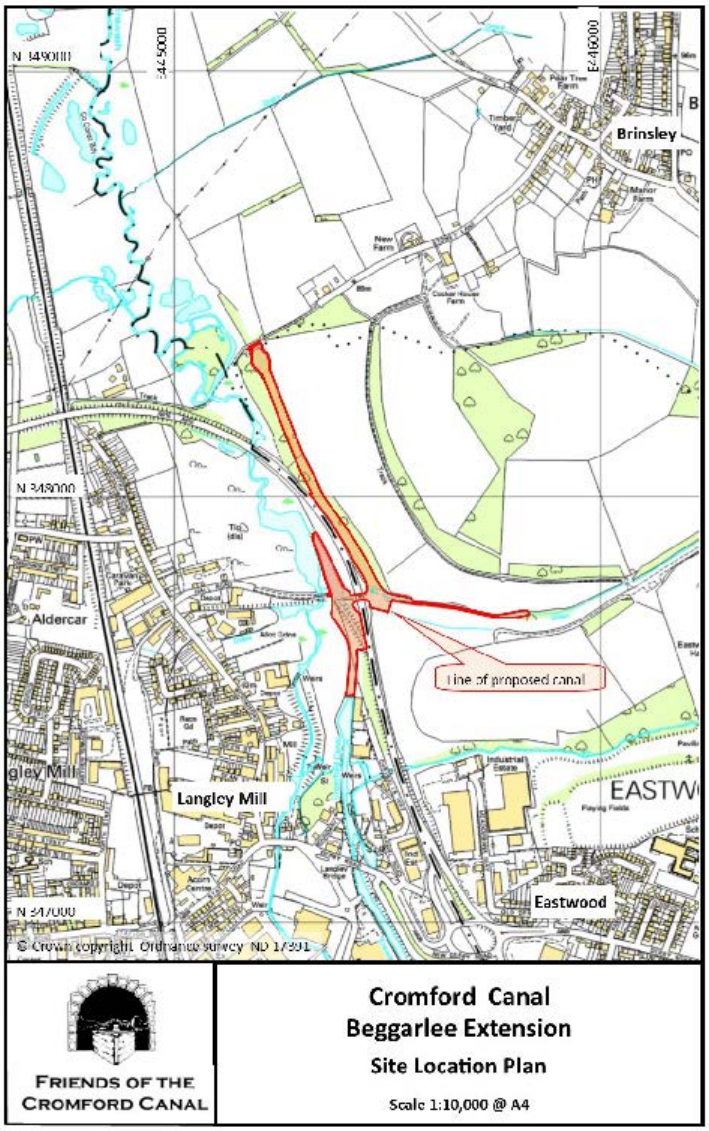


FIGURE 1 – SITE LOCATION PLAN

1.2 This will be the first section of the Cromford Canal at its southern end to be restored with further sections planned for the future extending the canal eventually to Ironville and Pinxton Wharf. An FRA is required under guidance of the National Policy Planning Framework (NPPF) to assess the impact of the canal proposals and under existing and future conditions on the River Erewash floodplain and to set out proposed mitigation measures to offset these impacts taking climate change into account.

1.3 This FRA focuses on the southern section of the canal where it impacts on the River Erewash floodplain. The proposed extension works do not cross the channel of this river, so no direct restrictions of this watercourse will arise from the completed development. A small local (un-named) watercourse crosses the line of the canal immediately east of the A610 bridge crossing. It is proposed to divert this into the canal to provide a water supply.

2.0 Development Proposals

2.1 General Arrangements drawings of the canal development and flood mitigation proposals (drg no.s FCC\BLE\DWG 000 – 014 and FFC\STH\DWG 301 - 304) are included in **Appendix A**. A longitudinal section along the centreline of the canal is also included in **Appendix C**. An aerial perspective view of the scheme is included over the page (**Figure 2**) to give an impression of what the scheme will look like.

2.2 The first 150m or so of the canal extension from the end of the existing canal at Langley Mill basin follows the original canal alignment north as far as Beggarlee Locks through open undeveloped land. This section lies within the Environment Agency's (EA) Flood Zones 2 & 3 and is potentially at risk of flooding from the River Erewash. Hall Road and the A610 highway on an earth embankment then cuts across the original line which means the canal has to follow a diversion route in order to cross over these roads. When the A610 was built, around 1980, an overbridge was constructed to accommodate what was then an existing mineral railway which serviced Moorgreen Colliery. The colliery has since closed and the railway abandoned. It is proposed to take the canal under the A610 using this overbridge. Before this bridge a new (double) lock, the Beggarlee Locks, will be constructed which will raise the canal 4.65m to a level of 64.70mAOD taking it well out of the flood plain i.e. within Flood Zone 1 and will also facilitate its construction through the overbridge.

2.3 Once clear of the A610 road embankment the canal will take a sharp left and head northwest as far as Stoney Lane following the line of the former Great Northern Railway which is currently open woodland. The alignment is a little way east of the original route and takes advantage of higher ground outside the floodplain of the River Erewash. This area along with the fields to the east were part of an opencast coal site in the 1990's which was reinstated back to agricultural use but unfortunately the plans to restore the canal as part of the site's restoration scheme were abandoned.

2.4 The canal and associated towpath will be designed to current best practice standards which will enable the CRT to adopt the canal at an agreed time in the future and ensure that the risk of a breach is minimal. A back-pumping system will be incorporated at the Beggarlee Locks to ensure there is sufficient water in the canal upstream to operate the locks. It is envisaged that once the canal has been extended to Ironville back-pumping will no longer be required as there should be an adequate water supply available from reservoirs upstream including Codnor Park and Butterley Reservoirs. A Water Resources Study is to be undertaken during 2019 to assess the water supply requirements for the canal once extended to Ironville and identify potential sources.

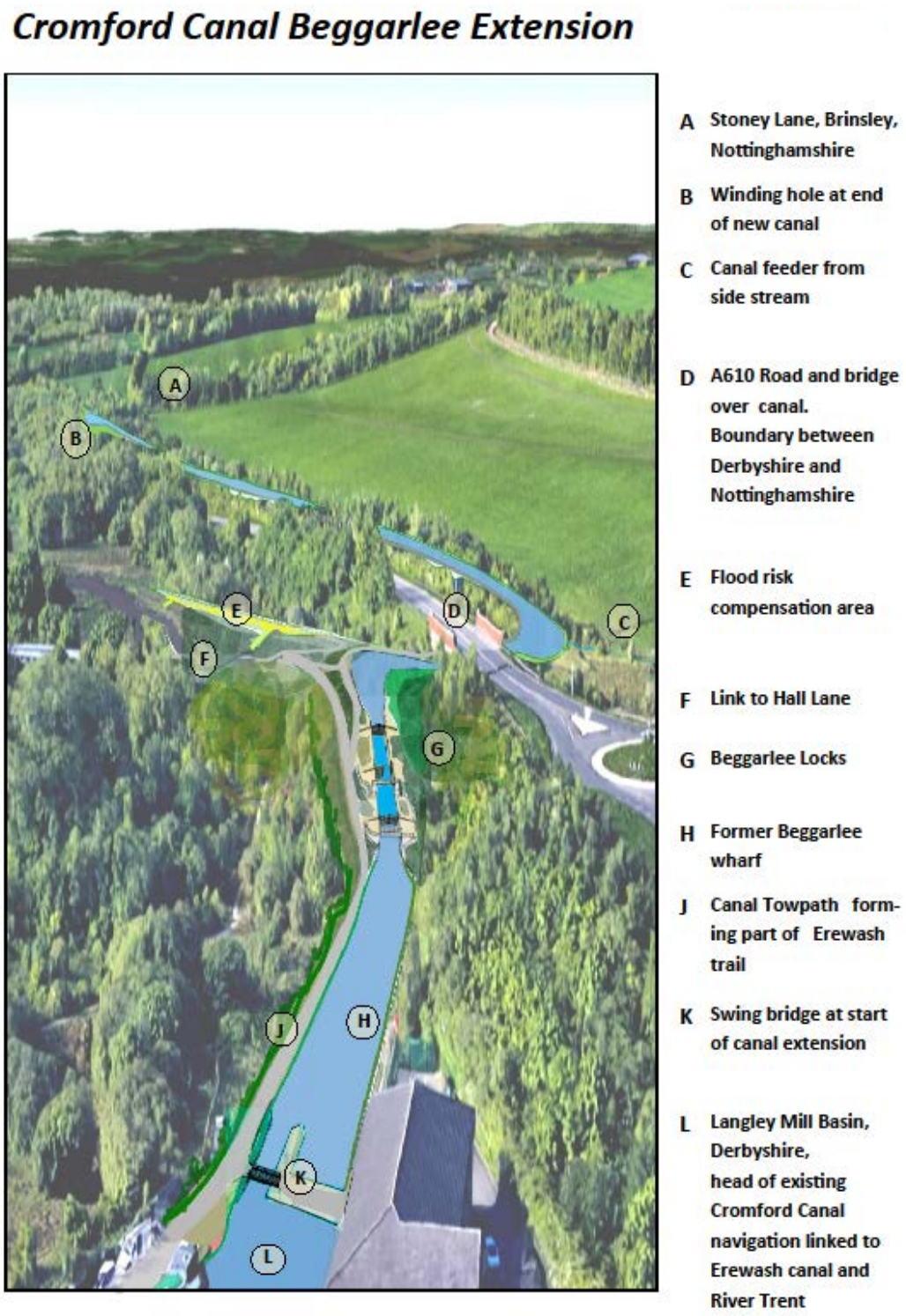


FIGURE 2 - SCHEME PERSEPECTIVE

2.5 At Beggarlee Locks the change in ground level will be achieved using a combination of earthwork embankments and walls to limit the land take and minimise the loss of floodplain. A by-wash will be constructed alongside the locks to discharge flows arriving at the top of the locks around the locks and into the continuation channel below. In addition, an overflow weir structure will be constructed on the canal on the east side of the A610 utilising the culvert that currently takes the flows in the minor (un-named) watercourse under the A610 to the River Erewash.

2.6 A meeting between representatives of The Friends of Cromford Canal (FCC) and the EA was held on 31st October 2017 at Trentside, Nottingham, where the canal proposals were discussed. The canal proposals vulnerability classification were considered as being water-compatible development and therefore could be permitted within the floodplain. However, the EA advised that, where the proposed route of the canal is located within Flood Zone 3, the canal would need to remain operational and safe for users in times of flood and flood storage compensation will be required on a level for level basis where FCC are raising ground levels. They also advised that consideration will need to be given to the flood risk impact of any narrowing of the floodplain resulting from the canal works as this can sometimes result in increases to flood levels upstream. It was agreed that 2D hydraulic computer modelling would be required to investigate the impact of the canal scheme on flood risk and to be able to test mitigation measures where these are required. Also, the canal should not be designed to convey flood flows as this was likely to exacerbate an existing flood risk in Long Eaton (via the Erewash Canal) downstream. Canal bank levels should therefore be set at appropriate levels based on modelled flood levels taking climate change into account.

3.0 Planning Policy Context

3.1 The revised National Planning Policy Framework was published in July 2018 and sets out the government's planning policies for England and how these are expected to be applied. Waterways are considered to be part of the historic environment. The National Planning Policy Framework sees the protection and enhancement of the historic environment as a strategic policy (paragraph 20(d)) within the drive to achieve sustainable development (as defined in paragraphs 7-14, and noting particularly 8(c). The appropriate conservation of heritage assets is covered principally in paragraphs 184-202. Canals are within the definition of "open space" (Glossary, p.69) so also have the protections outlined in paragraphs 96-101.

3.2 A detailed review of current planning legislation and its application to waterways was recently undertaken by the Town and Country Planning Association (TCPA) on behalf of the Canal & River Trust (CRT 2015). The review argues that waterways are a form of multifunction green infrastructure and can serve a variety of open space network functions including;

- strategic links between areas;
- important wildlife corridors;
- recreation and sport resources;
- accessible amenity in urban areas;
- access to the countryside;
- visual amenity;
- community resources for healthy activity and wellbeing;
- educational resources.

3.3 Historically, the boundary between Derbyshire and Nottinghamshire lay along the centre of the River Erewash. However, following the construction of the A610 Eastwood Bypass road in the 1980s the County boundary was moved to the centre of the new A610, bringing the length of canal to the west of the A610 into the Amber Valley Borough of Derbyshire, with the length to the east of the A610 remaining in the Broxtowe District of Nottinghamshire. Within Amber Valley the line has been protected in their Draft Local Plan by Policies IN2, which protects disused transport routes, and specifically by policy IN3, which supports the restoration of the Cromford Canal. Within Broxtowe the revised line has been supported by Eastwood Town Council in their Neighbourhood Plan submitted for inclusion in the Broxtowe Local Plan.

Amber Valley Draft Local Plan policies

12.3 Cromford Canal

12.3.1 The Borough Council is working with a number of other organisations, through the Cromford Canal Partnership, in relation to the future management and development of the Cromford Canal. The management and development options that have been explored include minimum intervention, the development of a linear water park and destination nature reserve with increased public access, partial restoration to navigation (restoring the section between Langley Mill and Butterley Tunnel, including the Pinxton Arm but not restoring the tunnel itself or the sections to the west of the tunnel), through to full restoration to navigation. The Local Plan can support these management and development options, including by safeguarding a route from any development proposals that might prejudice the delivery of any of the options.

Policy IN3

The Borough Council will support proposals for the sensitive restoration and maintenance, to navigable status, of the route of the Cromford Canal, as shown on the Proposals Map. The Borough Council will also seek to protect the route from any development that is likely to prejudice its future restoration and maintenance.

Development will be permitted for any proposals that would:-

- **positively contribute to the restoration of the canal and towpath**
- **improve access to and along the route of the canal to encourage its use for transport, leisure and recreational purposes**
- **respect, improve or enhances the landscape & townscape character, setting, biodiversity and historic value of the canal**

providing the proposals would not have any adverse impact on amenities by virtue of noise, odour or visual impact.

3.4 Much of the line within Broxtowe District lies within the green belt. Development within Green Belt land is covered in NPPF section 13 as updated in July 2018. It is considered that there are special circumstances for permitting the proposed canal development. Paragraph 141 places a duty on Local Planning Authorities to " plan positively to enhance the beneficial use of the Green Belt, such as looking for opportunities to provide access; to provide opportunities for outdoor sport and recreation; to retain and enhance landscapes, visual amenity and biodiversity; or to improve damaged and derelict land". Paragraph 145b considers new construction in the green belt is not inappropriate if it provides "appropriate facilities for outdoor sport, outdoor recreation and for cemeteries as long as it preserves the openness of the Green Belt and does not conflict with the purposes of including land within it". Paragraph 146c considers certain forms of development within a green belt are not inappropriate, including "local transport infrastructure which can demonstrate a requirement for a green belt location". The alignment and levels of the proposed canal have been selected as the only practical engineering solution to restoring the length of canal concerned.

4.0 Site Specific Flood Risk

4.1 The main source of flood risk to the lower section of the development is the River Erewash. The EA have provided to FCC the Products 4 mapping covering the River Erewash area between Langley Mill and Ironville. A copy of the mapping covering the extent of the current scheme proposals are included in Appendix B. The floodplain and floodwater levels provided in these maps were based on SFRM2 modelling undertaken by Hyder in 2013. As this was a strategic river model, the level of detail at any one location is usually insufficient for site specific flood risk assessments. The EA provided a copy of the Hyder hydraulic and hydrological models to FCC's modelling consultants, Riverscape Environmental Consultants (REC) to use as a basis for the Cromford Canal assessment. It was agreed with the EA that the detail of the model would be increased in the vicinity of the proposed canal extension to improve the accuracy of the modelling results. Topographical survey was undertaken for FCC by Terra Measurement Ltd to obtain existing ground levels and features such that cross sections through the floodplain could be interpolated and incorporated into the model. A copy of the topographical survey is included in Appendix C.

4.2 REC has undertaken a hydraulic modelling study which included constructing an 'existing model', a 'with scheme model' and a 'with scheme model including mitigation measures'. The models were run under a range of return period flood events from a 1 in 20 annual chance (5% AEP) to a 1 in 1000 annual chance (0.1% AEP). The changes in flood water levels were noted and shown on flood extent plans. The full modelling report is included as Appendix D. A comparison of the results from the 'existing' and 'with scheme' models has shown there to be no notable changes in water level i.e. the values fall within +-0.01m, except at the site itself where the raising of ground levels along the line of the canal extension has taken the land out of the floodplain. The 'with scheme' model included a minimum towpath level set to 60.5mAOD. The model demonstrated that this should be sufficient to prevent the ingress of floodwater into the canal system up to the 1 in 100 +50% event.

4.3 The 'existing' and 'with scheme' models were analysed to establish the loss in flood storage arising from the canal restoration scheme. The volumes were calculated in elevation bands of 200mm between 59.2mAOD and 60.4mAOD which typically represents the range of flood water levels between the 1 in 20 event and the 1 in 100 + 50% event at the site. FCC have designed a provisional flood storage compensation scheme to replace the storage lost. This takes the form of a linear channel, approximately 120m long located upstream of Hall Road on the east bank immediately alongside the A610 embankment on the edge of the floodplain. The excavated storage channel is to be connected to the river via two ditches. A copy of

the proposed storage compensation scheme drawings (FCC\STH\BLE\DWG 301 to 304) are included in Appendix A. The elevation bands in the linear channel were adjusted to take account of the equivalent average flood levels at the compensation storage site which resulted in equivalent elevation bands of varying depths of 290mm or 300mm and a range of water levels of between 59.25mAOD and 61.03mAOD. The storage volumes were calculated using scheme cross sections. A copy of the spreadsheet calculations is included in Appendix E. The net change in flood storage volumes for flood events up to the 1 in 100 annual chance + 50% event is shown in Table 3.2.

Table 3.2: Change in flood storage resulting from the proposed canal restoration*.

Depth of flooding	Approximate elevation band	Loss of flood storage due to canal restoration	Equivalent elevation band upstream of Hall Road bridge for compensatory storage	Gain in flood storage due from compensation scheme	Net change in flood storage
1.0m to 1.2m	59.2m to 59.4m	0	59.25m to 59.54m	161	+161
0.8m to 1.0m	59.4m to 59.6m	-21	59.54m to 50.84m	211	+190
0.6m to 0.8m	59.6m to 59.8m	-109	59.84 m to 60.14m	240	+131
0.4m to 0.6m	59.8m to 60.0m	-207	60.14m to 60.43m	249	+42
0.2m to 0.4m	60.0m to 60.2m	-294	60.43m to 60.73m	248	-46
0.0m to 0.2m	60.2m to 60.4m	-339	60.73m to 61.03m	347	+8

** Compensatory flood storage volumes provided by Friends of the Cromford Canal.*

4.4 It is evident that the proposed compensation scheme would provide approximately 486m^3 of additional storage over and above that required to just to compensate for the loss due to the canal scheme alone (970m^3). The additional storage mostly occurs at the lower flood levels equivalent to flood events that are more frequent than the 1 in 20 event. The final design of the flood storage compensation scheme undertaken at detailed design stage would look to increase the storage gain in the 60.43 to 60.73m band by up to 50m^3 possibly by increasing the length of the linear channel by a few metres. A suitable planting scheme will be discussed and agreed with the landowner, Derbyshire County Council (DCC). The linear compensation scheme would be managed by FCC on behalf of and guided by DCC.

4.5 The overall conclusion drawn in the hydraulic modelling report is that the analysis of the section of proposed canal restoration works located within the River Erewash floodplain and the provision of compensatory flood storage, using an

improved version of the EA hydraulic model of the Erewash, has not revealed any negative flood risk impacts. The slight narrowing of the floodplain at the canal site does not appear to have any measurable impediment on flood flows and flood levels within the floodplain and doesn't increase flood risk elsewhere. The flood storage compensation scheme proposed would result in no net loss of floodplain storage. Setting the minimum level of the towpath alongside the canal to 60.50mAOD would ensure that the canal would remain operational and safe for users i.e. walkers, cyclists and boaters in times of flood on the River Erewash. This towpath level would also ensure that the canal is protected from flood inundation from the Erewash for up to the 100year plus 50% climate change flood event which matches or exceeds the existing protection to the canal sections downstream.

4.6 The canal extension and associated towpath would be managed and maintained by FCC until such time in the future when the canal is offered to CRT for adoption. Appropriate maintenance schedules will be drawn up by FCC for CRT, DCC and NCC comment.

5.0 Surface Water Management

5.1 Water levels in the canal extension upstream of the Beggarlee Locks would be controlled by a by-wash around the Beggarlee Locks and an overflow weir located just upstream of the A610 overbridge. The required capacity of this weir will be based on the likely maximum flow entering the reach following a major storm event such that the towpath will not be overtopped. There will always be a minimum of 300mm freeboard to the towpath level and ground level on the opposite bank above the operational water level. The water level in the lower section of canal within the floodplain will be the same as in the existing Langley Mill Basin i.e. 60.05mAOD which is controlled by existing hydraulic structures downstream. The proposed minimum towpath level of 60.50mAOD along the lower section of canal gives a 450mm freeboard above the operational canal level. The by-wash flow around the Beggarlee Locks will easily pass through the Langley Mill Lock at the end of the Erewash Canal, where the lock gates are intentionally designed to be overtopped.

5.2 The risk of a breach occurring on the proposed canal is minimal as the design of the earthworks and structures will meet current standards required by CRT, as the canal, once extended up to Pinxton Wharf, will probably be offered to CRT for adoption. In the very unlikely event of a breach occurring on the Beggarlee Extension, the water that escaped from the canal reach would flow across undeveloped land to the River Erewash. No development or infrastructure would be affected.

5.3 A local land drainage ditch currently intercepts surface water runoff from the small hill above it located just to the north of boundary of the Nottingham 26 Business Park development site ecological mitigation area on the east side of the A610 and discharges under the A610 through a 1.0m diameter culvert. This ditch and associated on-line settlement ponds will be affected by the construction of the canal. The existing bed level of the ditch is such that it cannot be culverted under the canal as the level of the pipe would be too high such that it would protrude above the canal bed obstructing the channel. It is therefore proposed to regrade approximately 150m length of the ditch so that it becomes a canal feeder discharging into the canal on the bend immediately east of the overbridge at a water level of 64.65mAOD. A drawing showing the proposed arrangement is included in Appendix F. Such a scheme will need to be discussed and agreed with the Lead Local Flood Authority, Nottinghamshire County Council. The route to be taken by the canal feeder would be following the line of the existing ditch to the north of the Ecological Mitigation Zone - land owned by the developers of the Nottingham 26 site. The landowner has agreed in principle to FCC purchasing the western end of this mitigation zone to facilitate the construction of the canal.

5.4 Surface water runoff from the fields to the east of the proposed canal along the section north of the A610 crossing will discharge overland directly into the canal. The

resulting small flows would be discharged through the by-wash at the Beggarlee Locks and, in exceptionally wet weather, via an overflow weir to be constructed on the canal at the location of the start of the existing minor watercourse culvert where it passes under the A610. As the canal is extended further north in future phases, additional overflow weirs will be constructed at appropriate intervals along the canal to control water levels. The overflow weir will be designed to pass flood flows based on the expected inflows from the reach upstream as far as the future aqueduct structure which will take the canal over the River Erewash. Hydraulic design calculations and overflow design details will be submitted at the detailed design stage of the scheme.

5.5 The A610 carriageway has highway drainage which discharges through piped systems to outfall into the River Erewash. The canal works in the vicinity of the Beggarlee Locks in particular will impact on parts of this drainage system. Some modifications to the system will be required which might include diverting some of drainage discharges into the canal. Suitable arrangements will be drawn up by FCC and then discussed and agreed with Derbyshire County Council (DCC) at the detailed design stage.

6.0 Flood Risk Assessment Credentials

6.1 The FRA and this FRA report has been undertaken on behalf of The Friends of Cromford Canal by Chris Broome, B.Sc, C.Eng, MICE, C.WEM, MCIWEM, a retired Chartered Civil Engineer who, until taking early retirement in 2017, was a Principal Engineer with AECOM in Chesterfield specialising in the field of water engineering and flood risk undertaking many Flood Risk Assessments during his career.

6.2 This FRA was undertaken during 2018 and completed in February 2019.

APPENDICES

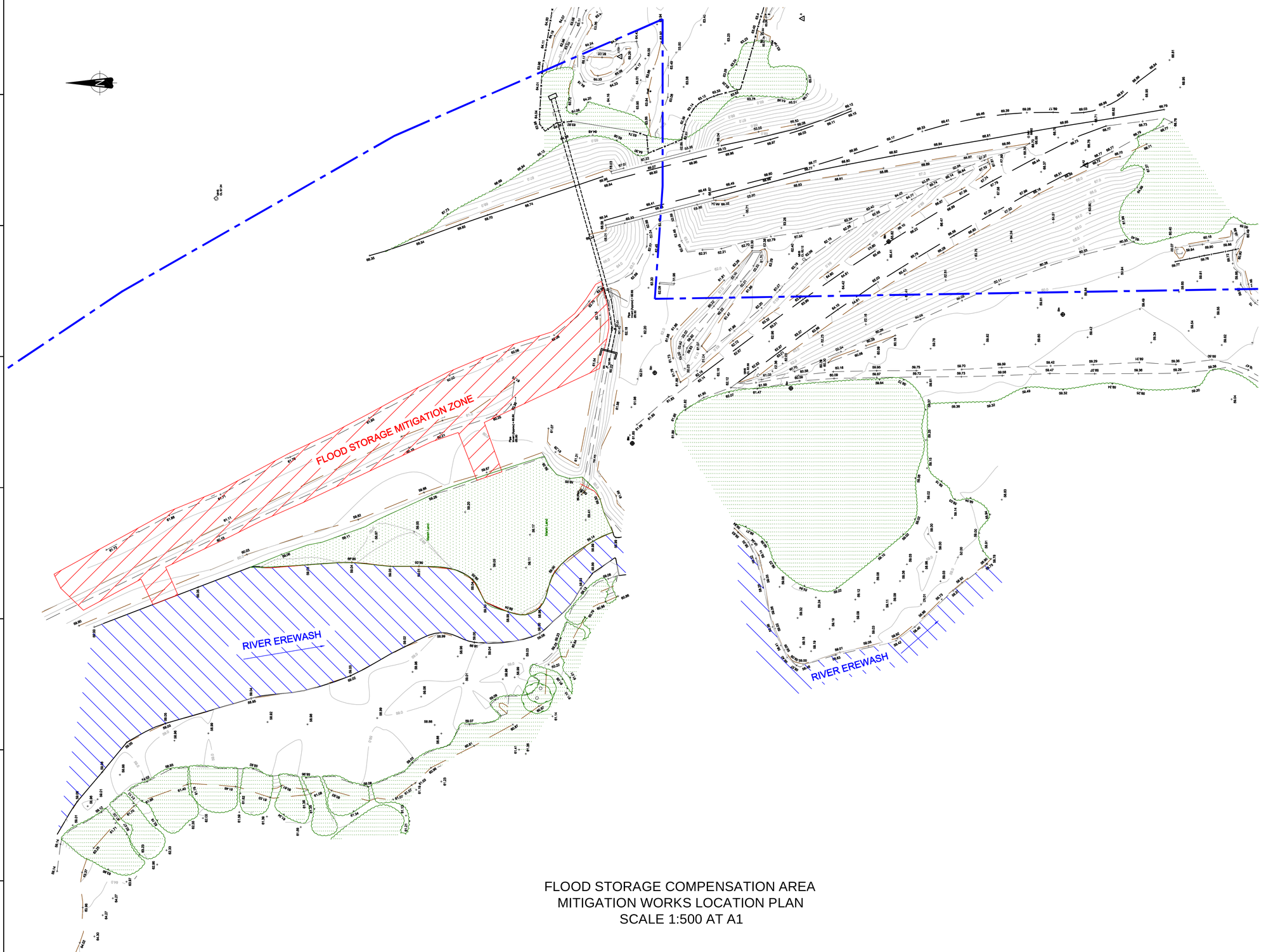
APPENDIX A

Proposed Development Drawings

Drawings FCC\STH\BLE\

DWG 301 Proposed Mitigation Location Plan
DWG 302 Proposed Mitigation Plan & Sections, Sheet 1 of 3
DWG 303 Proposed Mitigation Plan & Sections, Sheet 2 of 3
DWG 304 Proposed Mitigation Plan & Sections, Sheet 3 of 3

Please also refer to Drawings FCC\BLE\DWG 000 to DWG 014 showing the overall proposals which are included in the Planning Application



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FLOOD STORAGE COMPENSATION AREA
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KEY:

PROPOSED ALIGNMENT OF RESTORED CANAL

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0A	FIRST ISSUE	DR	APR 18	CB	FEB 19	GR	FEB 19

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Strategic Restoration Committee
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Cromford, DE4 3RQ

Section: SOUTH SECTION
Site: BEGGARLEE EXTENSION
Title: BEGGARLEE EXTENSION
FLOOD RISK ASSESSMENT
PROPOSED MITIGATION
LOCATION PLAN

Drawn	Date Drawn	Checked	Date Checked	Approved	Date Approved
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Status				Scale	Format
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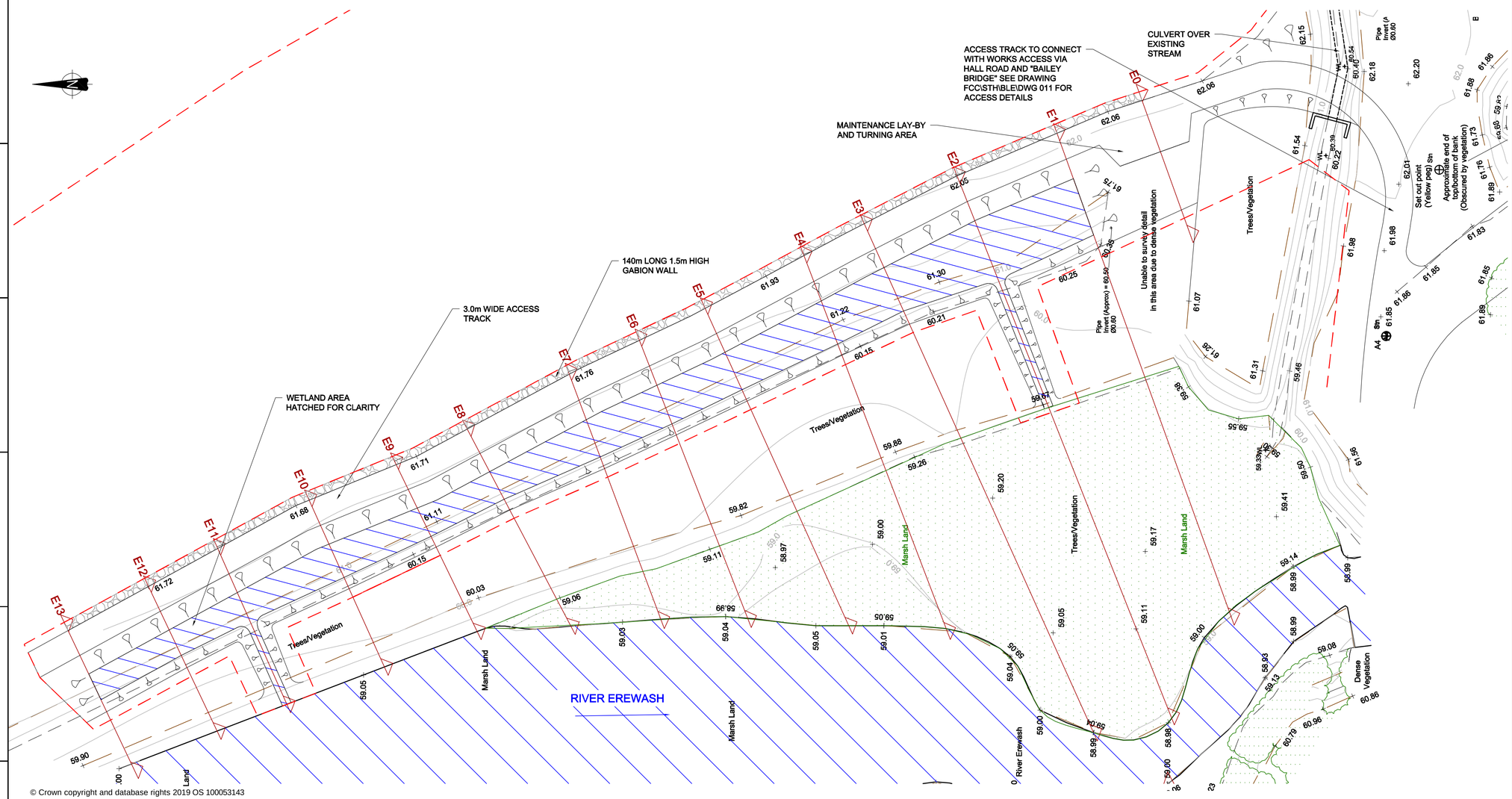

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MITIGATION WORKS PLAN
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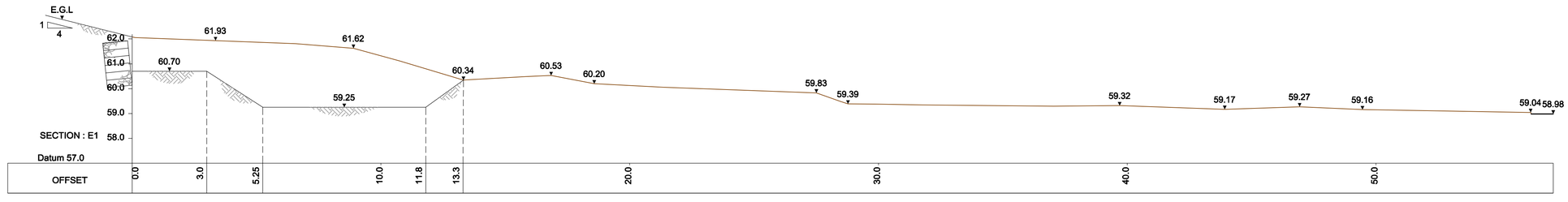

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FLOOD RISK ASSESSMENT
PROPOSED MITIGATION PLAN AND SECTIONS
SHEET 1 OF 3

Drawn	Date Drawn	Checked	Date Checked	Approved	Date Approved
D. READLE	APRIL 18	C. BROOME	FEB 19	G.ROGERS	FEB 19

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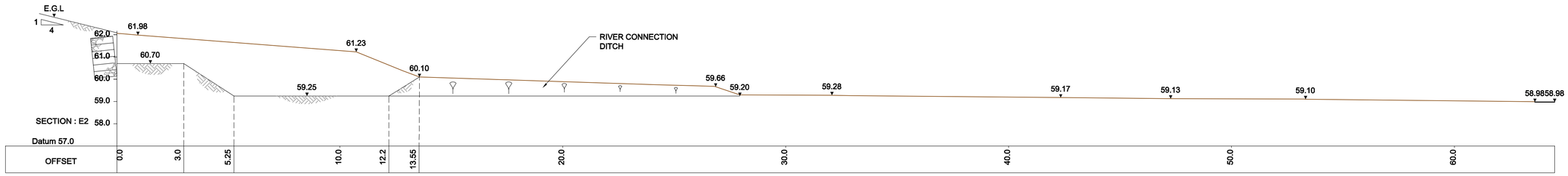

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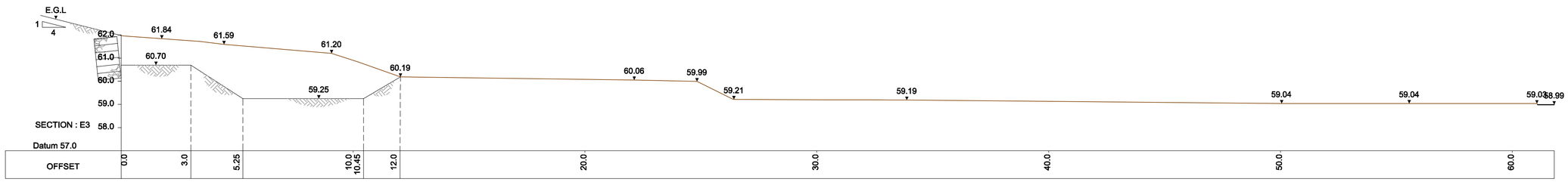

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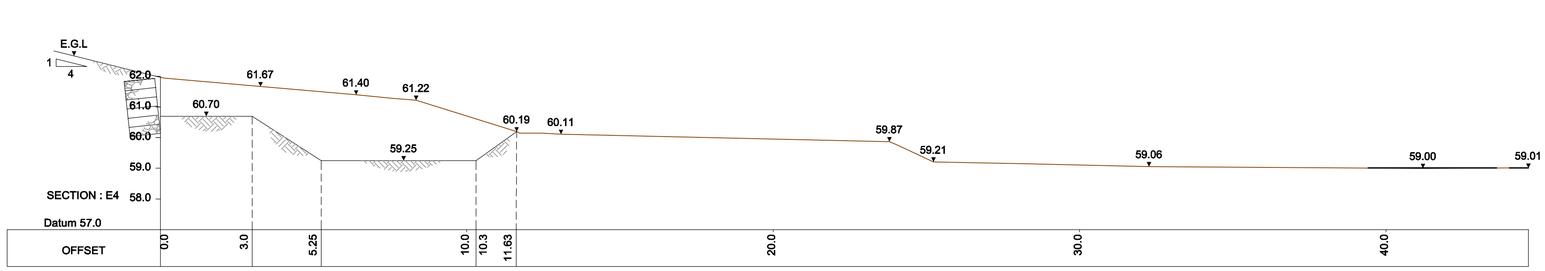

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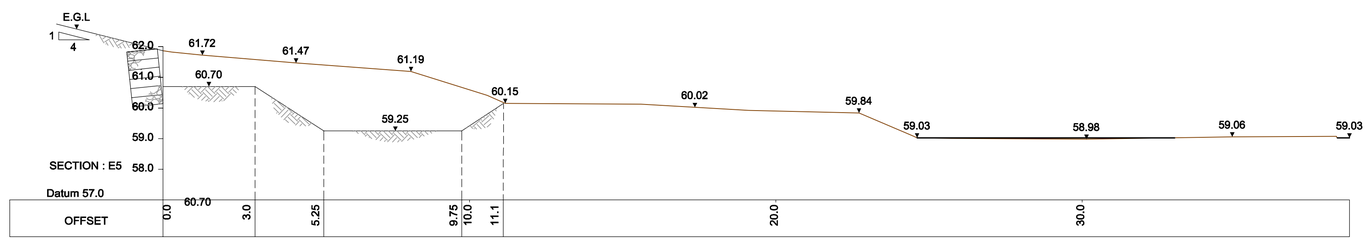

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FLOOD RISK ASSESSMENT
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Drawn	Date Drawn	Checked	Date Checked	Approved	Date Approved
D. READLE	APRIL 18	C.BROOME	FEB 19	G.ROGERS	FEB 19

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Rev: A0

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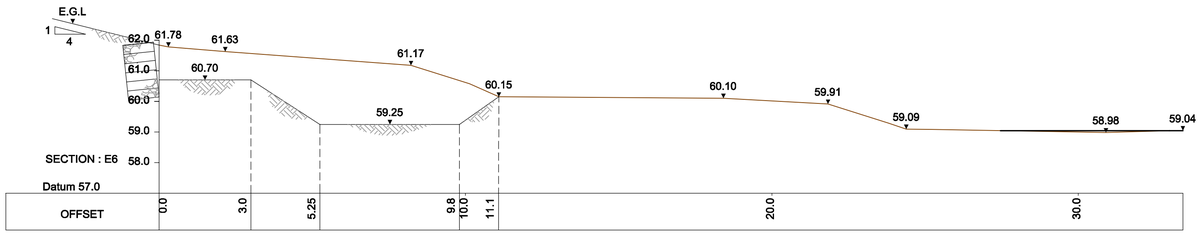

MITIGATION WORKS SECTION E6
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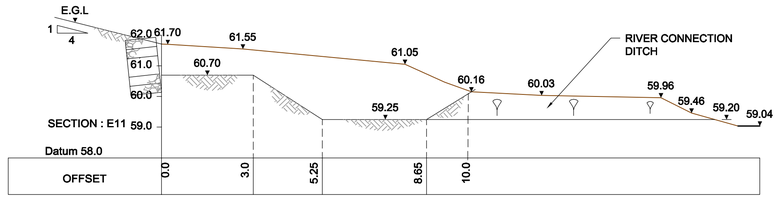

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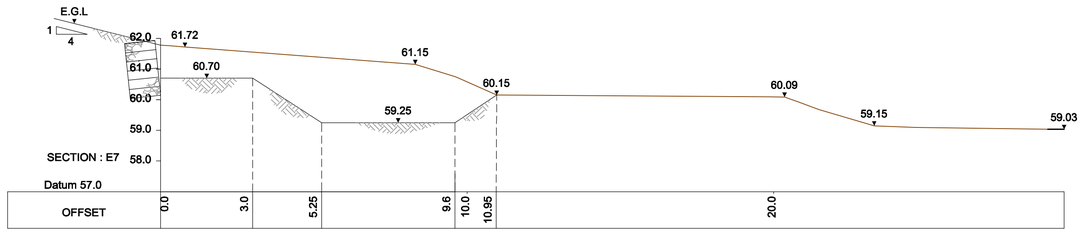

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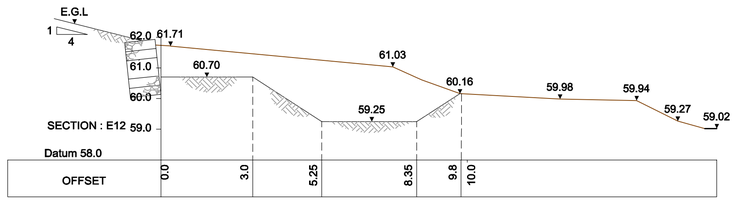

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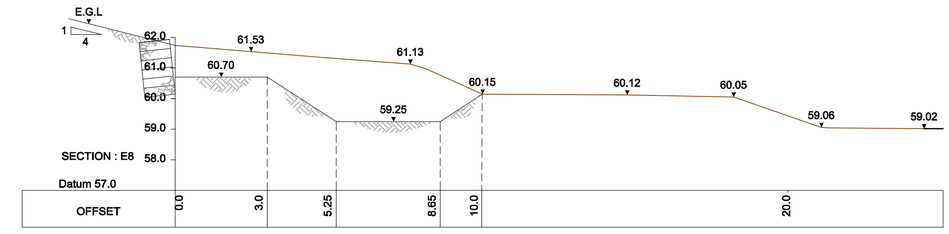

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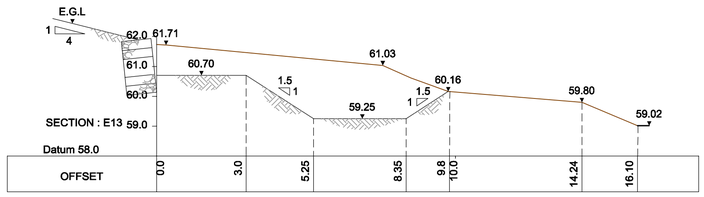

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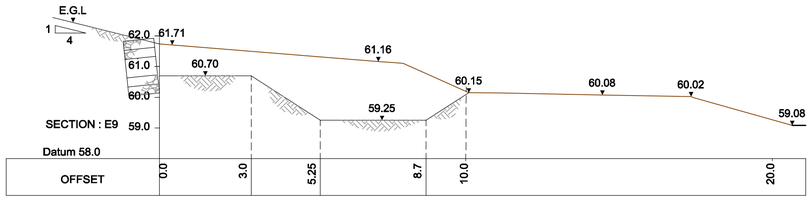

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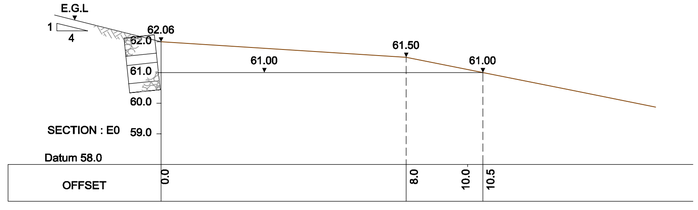

MITIGATION WORKS SECTION E0
SCALE 1:100 AT A1

E.G.L

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4. BASED ON SURVEY WORK UNDERTAKEN BY TERRA MEASUREMENT (PROJECT NUMBER: 1556) BETWEEN JANUARY AND FEBRUARY 2018.

Rev	Revision	Drawn	Date	Chkd	Date	App	Date
0A	FIRST ISSUE	DR	APR 18	CB	FEB 19	GR	FEB 19

THE FRIENDS OF THE CROMFORD CANAL

Registered Charity No. 1164608
www.cromfordcanal.org

Strategic Restoration Committee
Weighbridge Office
Gothic Warehouse, Mill Road
Cromford, DE4 3RQ

Section: SOUTH SECTION
Site: BEGGARLEE EXTENSION
Title: BEGGARLEE EXTENSION
FLOOD RISK ASSESSMENT
PROPOSED MITIGATION PLAN AND SECTIONS
SHEET 3 OF 3

Drawn	Date Drawn	Checked	Date Checked	Approved	Date Approved
D. READLE	APRIL 18	C.BROOME	FEB 19	G.ROGERS	FEB 19

Status				Scale	Format
PRELIMINARY		CONSTRUCTION		AS SHOWN	A1
APPROVAL	A	AS BUILT			

FCC Drawing No	Sheet	of	Rev
FCC\STH\BLE\DWG 304	3	3	A0

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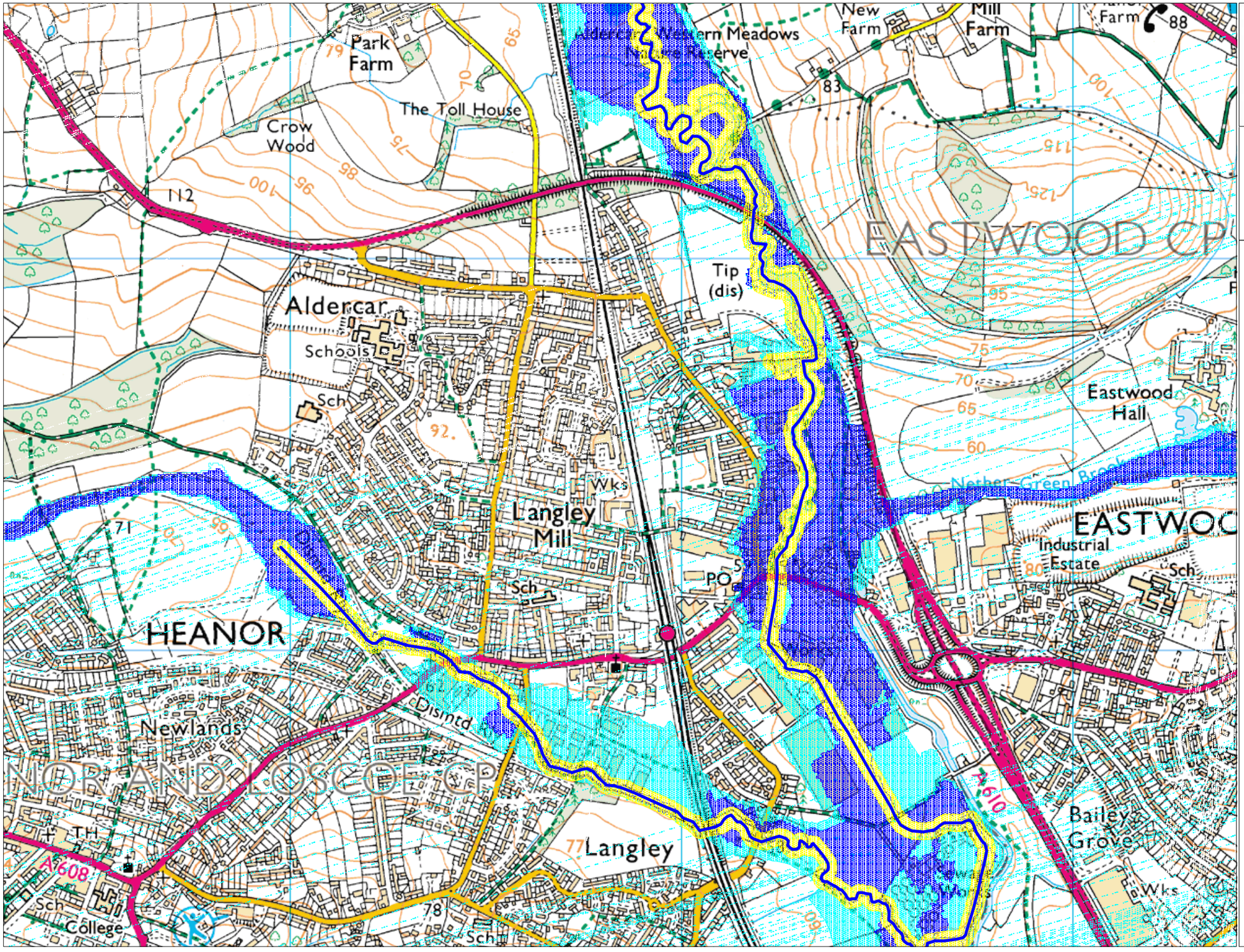
APPENDIX B

EA Product 4 Flood Mapping

Flood Maps for Scheme Area:

- Flood Map
- Floodplain Heights
- Flood Defences
- Modelled Extents

Detailed FRA/FCA Map No. 3 between Victoria Street, Ironville and Station Road, Langley Mill - created 10 November 2016



Environment Agency

Scale 1:10,000

N W E S

Legend

- 1% (1 in 100 year) floodplain
- 0.1% (1 in 1000 year) floodplain
- Main River
- Bank Top ePlanning Tool

A Strategic Flood Risk Assessment may be available, providing further information for this site. Please contact your Local Planning Authority to access this information as it will need to be considered within any Flood Risk Assessment submission.

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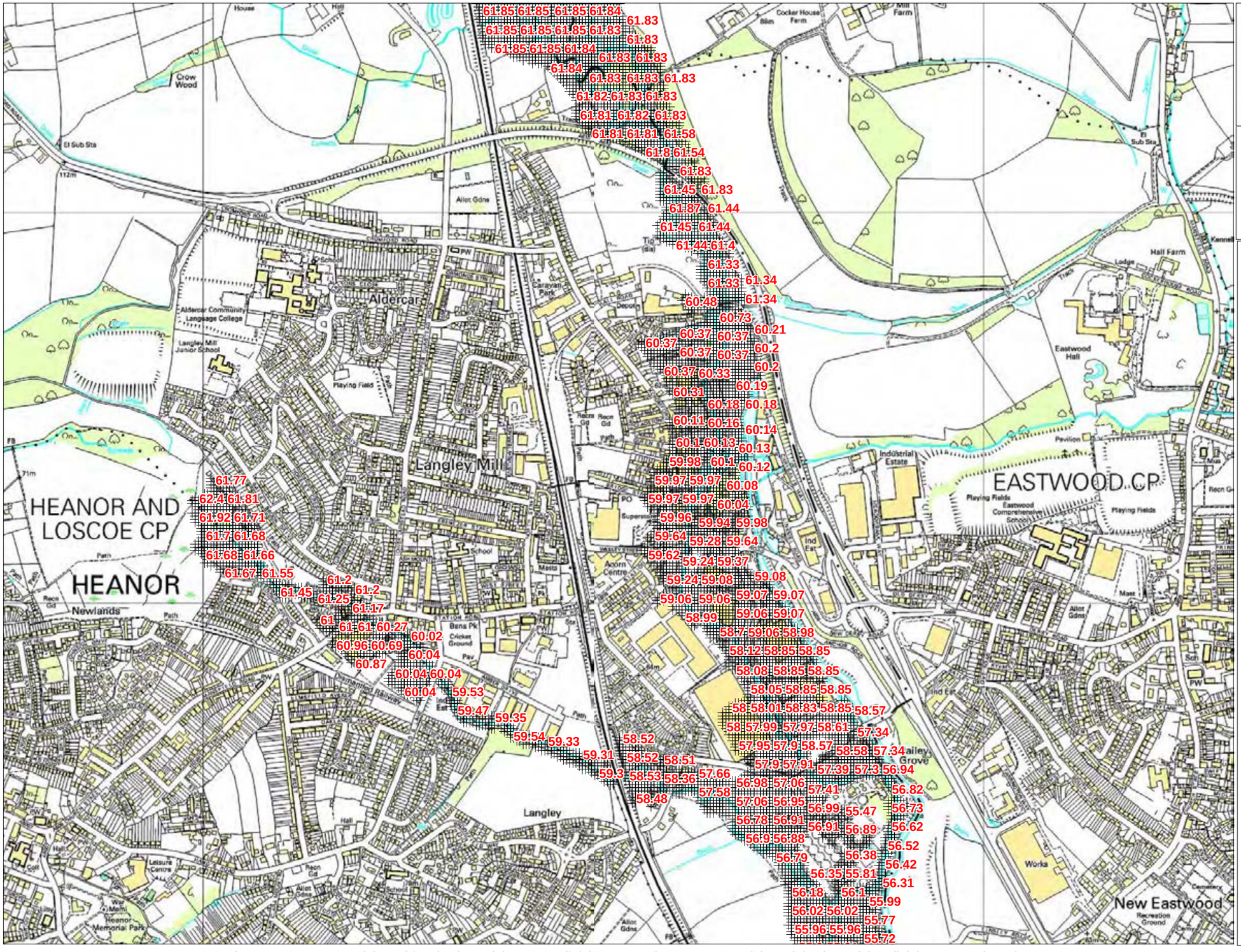
Floodplain Heights Map No. 3 between Victoria Street, Ironville and Station Road, Langley Mill - created 10 November 2016



Environment Agency

Scale 1:10,000

N
W E
S

Legend

x.xx — 1 in 100 year + Climate Change Floodplain Level (mAOD)

Source: River Erewash SFRM2 Study, Hyder, 2013

A Strategic Flood Risk Assessment may be available, providing further information for this site. Please contact your Local Planning Authority to access this information as it will need to be considered within any Flood Risk Assessment submission.

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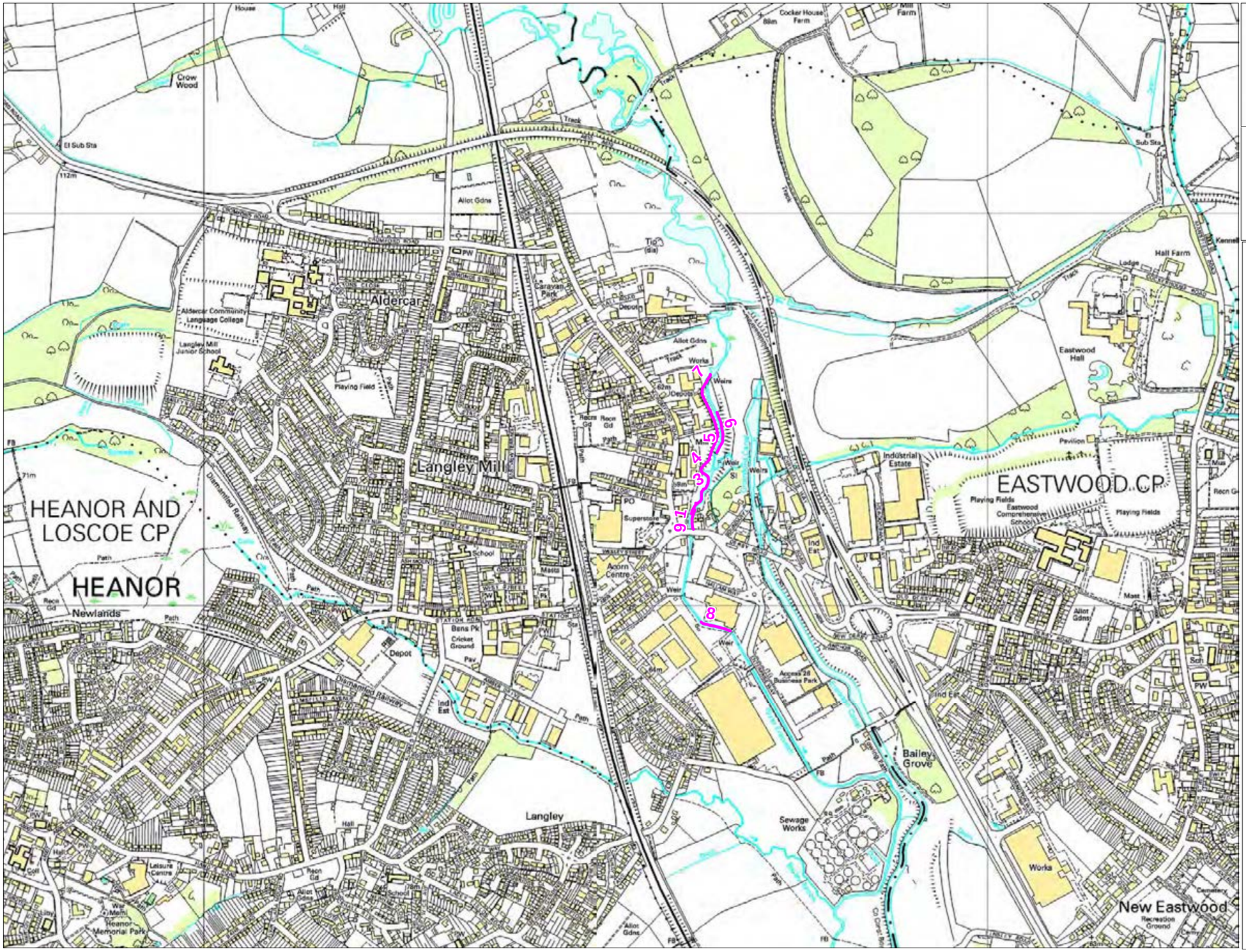
Defences Map No. 3 between Victoria Street, Ironville and Station Road, Langley Mill - created 10 November 2016



Environment Agency

Scale 1:10,000

N
W E
S

Legend

Flood Defence Locations

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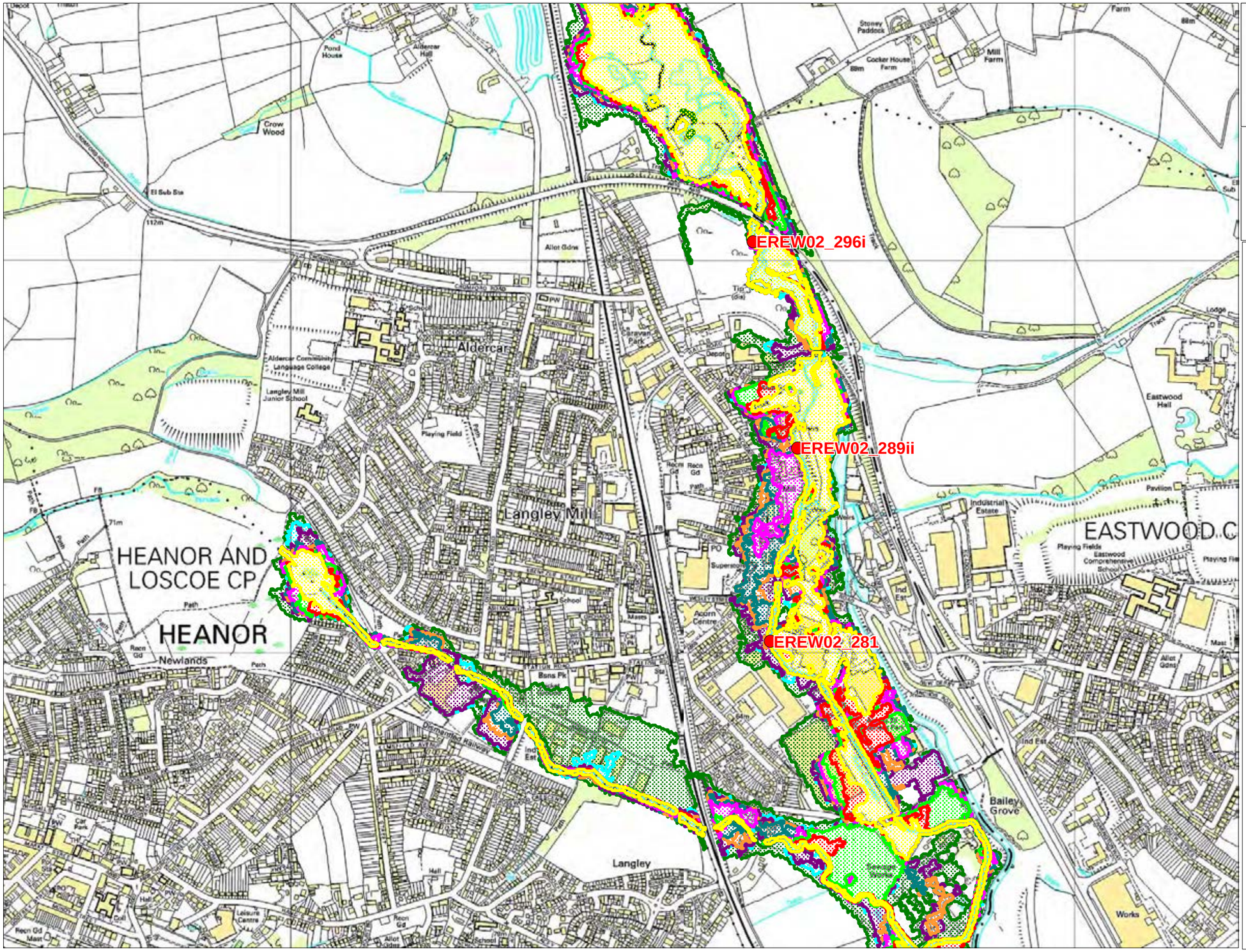
Modelled Extents Map No. 3 between Victoria Street, Ironville and Station Road, Langley Mill - created 10 November 2016



Environment Agency

Scale 1:10,000

N
W E
S

Legend

- 1 in 5 year Modelled Extent
- 1 in 10 year Modelled Extent
- 1 in 20 year Modelled Extent
- 1 in 50 year Modelled Extent
- 1 in 75 year Modelled Extent
- 1 in 100 year Modelled Extent
- 1 in 100 year Modelled Extent (including climate change forecast)
- 1 in 200 year Modelled Extent
- 1 in 1000 year Modelled Extent
- Modelled Node Location and Reference

Source: River Erewash SFRM2 Study, Hyder, 2013

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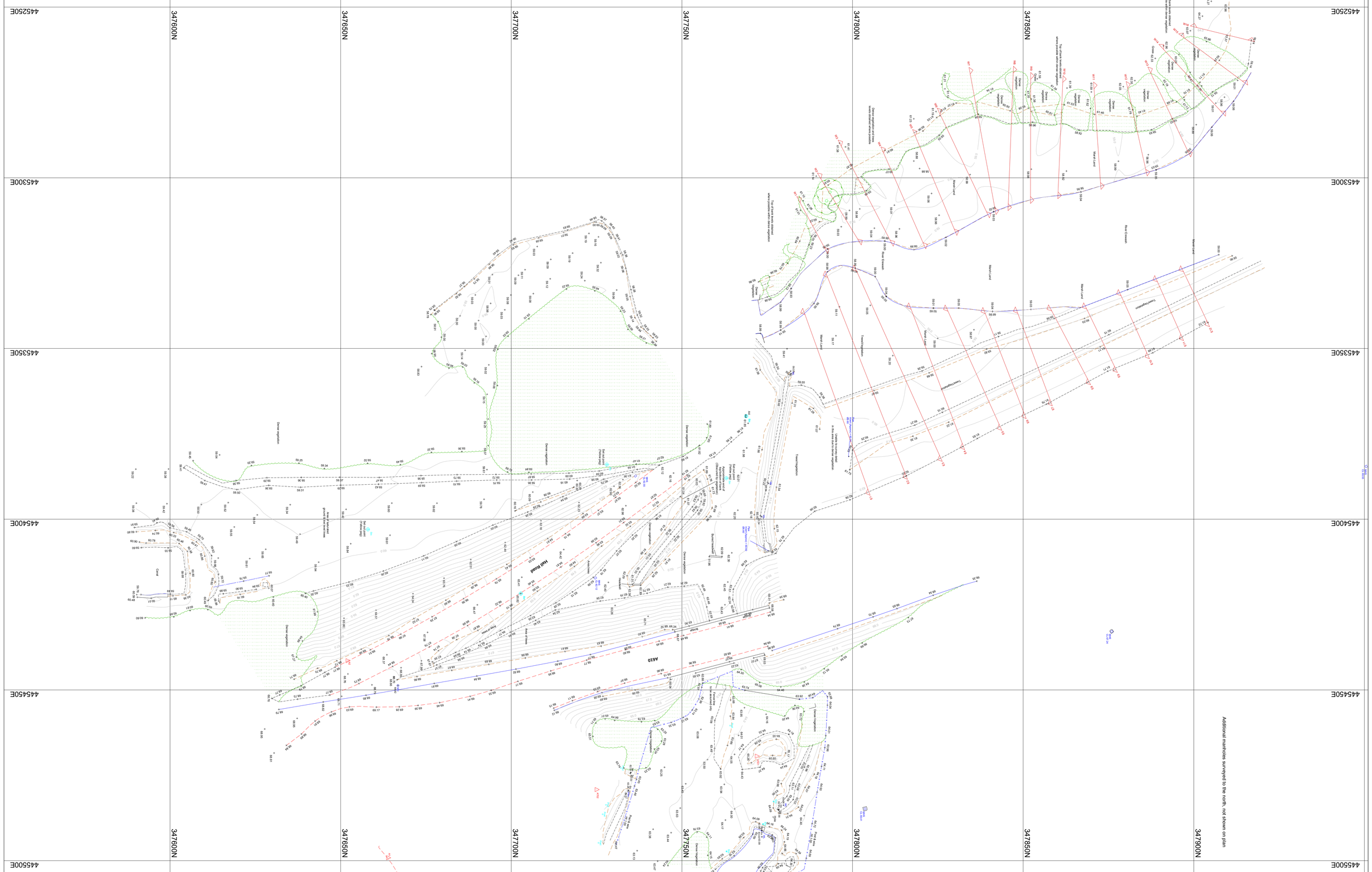
APPENDIX C

Topographical Survey

Topographical sections

Canal Centreline Longitudinal Section, Sheet 1



REV. NO.	DESCRIPTION TO REVISION	REV. BY	DATE
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	AND MANHOLES THROUGH JOHN SMITHS FIELDS		18-04-2017
B	ADDITIONAL SURVEY AND LEVELS TO THE WEST	JP	18-05-2017
C	ADDITIONAL SURVEY EITHER SIDE OF RIVER	AJB	11-01-2018
	FOR GROUND MODLE ONLY		
D	ADDITIONAL SURVEY TOP OF BANK LEVELS ADDED	JL	07-02-2018
	TO WESTERN SIDE OF SITE		
E	SECTION LOCATIONS ADDED TO SURVEY	AJB	23-02-2018

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CLIENT:
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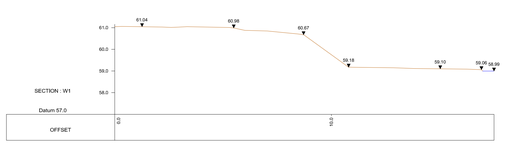
PROJECT:
CROMFORD CANAL
BEGGARLEE EXTENSION
LANGLEY MILL

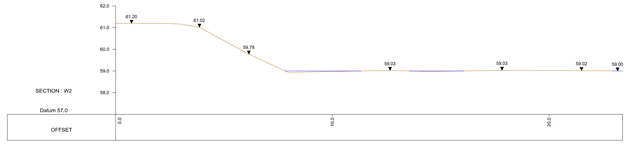
TITLE:
TOPOGRAPHICAL SURVEY

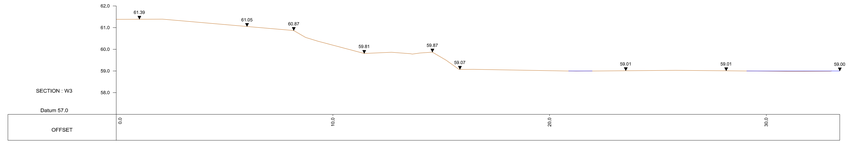
DATE:
18-05-2017

GRID:	LEVEL:	DATA TYPE:	OTHER DATA AVAILABLE:
ORDNANCE SURVEY	ORDNANCE SURVEY	2D	3D ACAD - YES 3D GROUND MODEL - YES 3D DGN - YES SECTIONS - YES CUT & FILL ANALYSIS - YES
DRAWN BY: JP	SCALE @ A1: 1:500	PROJECT NO.: 1556	DRAWING NAME: 1556 BEGGARLEE - LANGLEY MILL_REV E

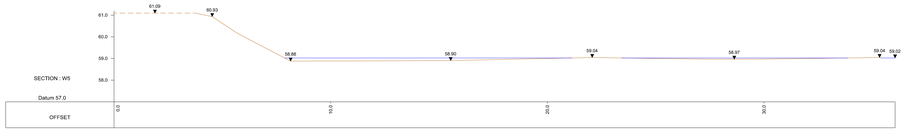
REV. E

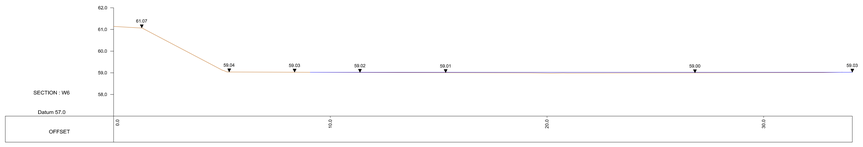


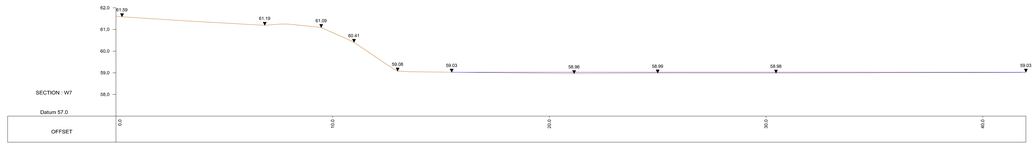


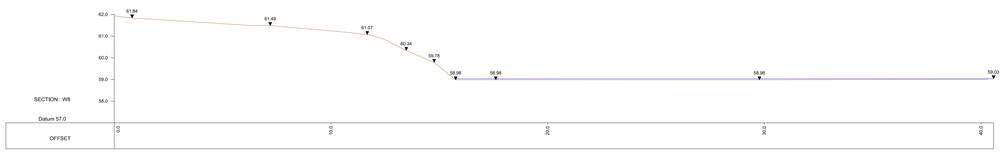


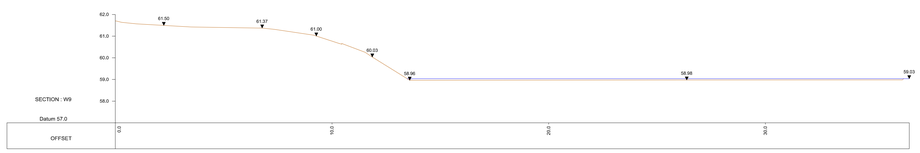


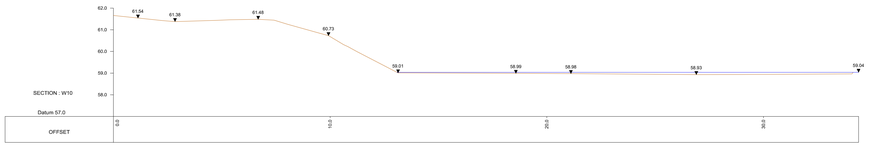


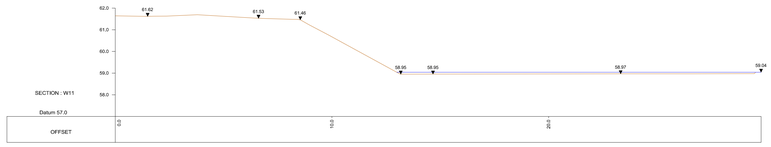


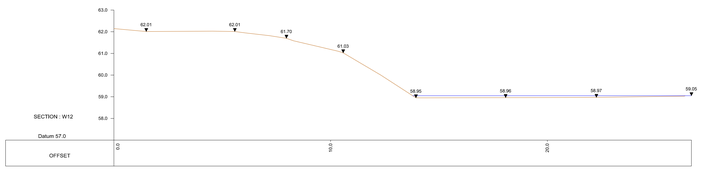


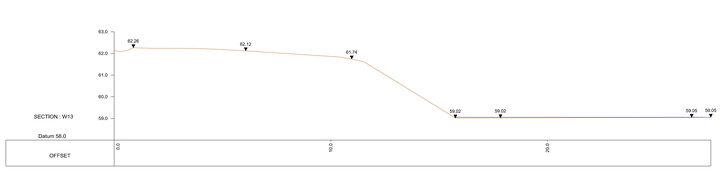


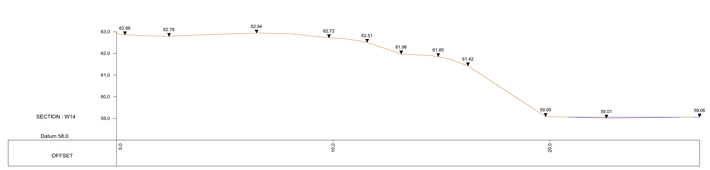


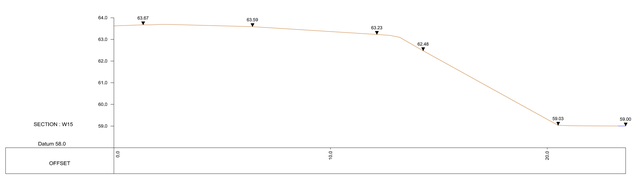


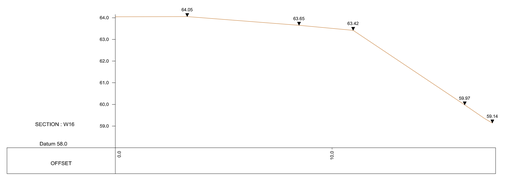












REV. NO.	DESCRIPTION TO REVISION	REV. BY	DATE
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	AND MANHOLES THROUGH JOHN SMITHS FIELDS		18-04-2017
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	TO WESTERN SIDE OF SITE		
E	SECTION LOCATIONS ADDED TO SURVEY	AJB	23-02-2018

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PROJECT:
CROMFORD CANAL
BEGGARLEE EXTENSION
LANGLEY MILL

TITLE:
SECTIONS
W1 - W16

DATE:
23/02/2018

GRID:	LEVEL:	DATA TYPE:	OTHER DATA AVAILABLE:
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DRAWN BY: AJB	SCALE @ A0: 1:100	PROJECT NO.: 1556	DRAWING NAME: 1556_BAGGARLEE-LANGLEY MILL_REV E_SECTIONS

REV. E

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W E
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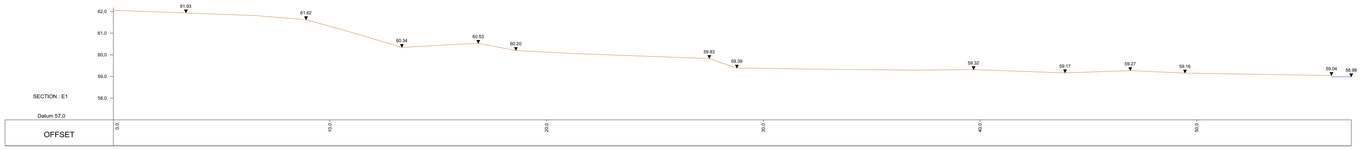

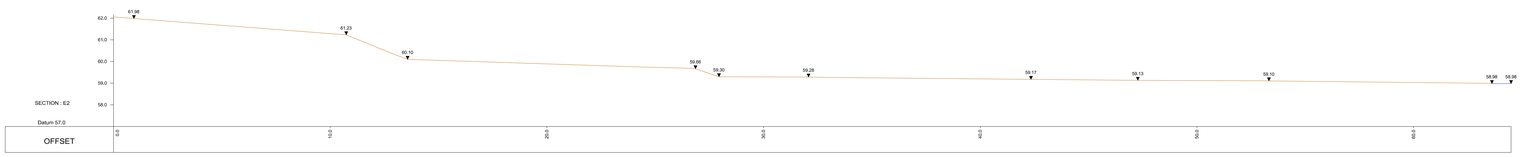

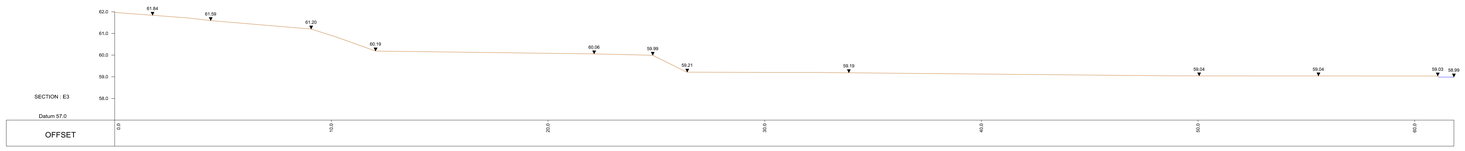

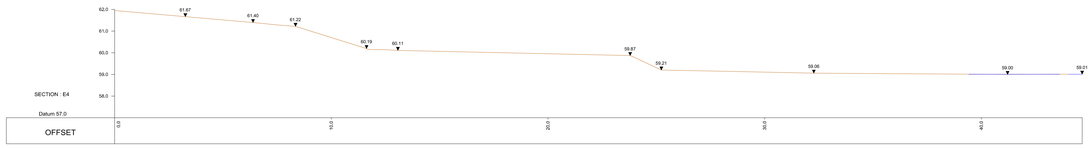

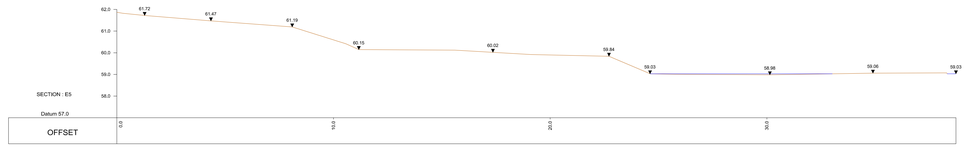

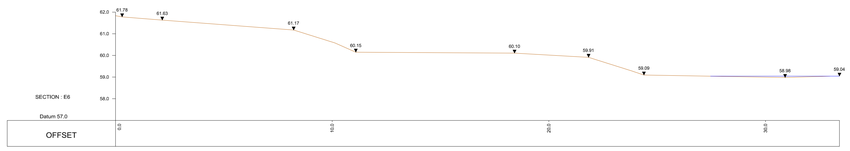

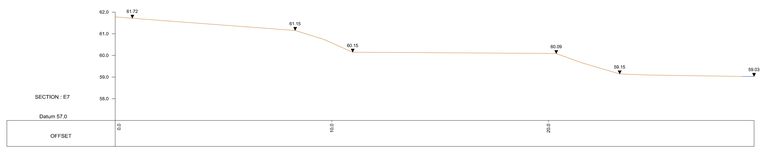

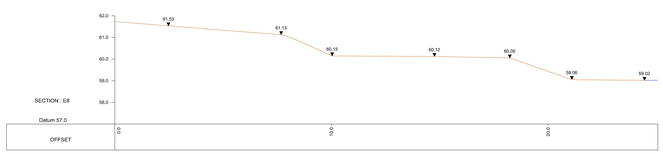

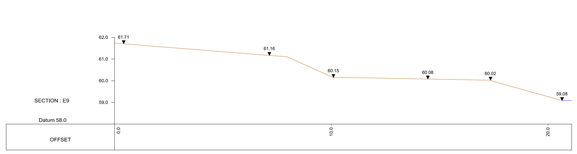

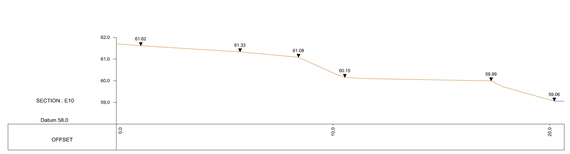

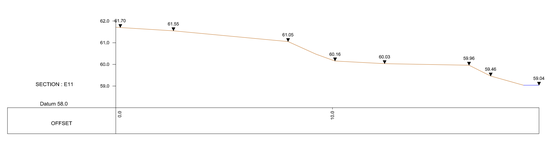

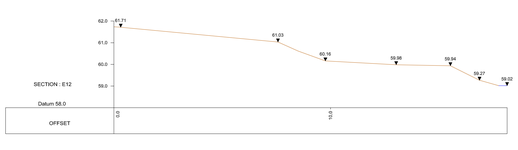

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CLIENT:
FRIENDS OF THE CROMFORD CANAL

PROJECT:
CROMFORD CANAL
BEGGARLEE EXTENSION
LANGLEY MILL

TITLE:
SECTIONS
E1 - E12

DATE:
23/02/2018

GRID:	LEVEL:	DATA TYPE:	OTHER DATA AVAILABLE:
ORDNANCE SURVEY	ORDNANCE SURVEY	2D	TIN MODEL - YES 3D MESH MODEL - YES POINT CLOUD - NO SECTIONS - YES CUT & FILL ANALYSIS - YES

DRAWN BY:	SCALE @ A0:	PROJECT NO.:	DRAWING NAME:	REV.
AJB	1:100	1556	1556_BAGGARLEE-LANGLEY MILL_REV E_SECTIONS	E

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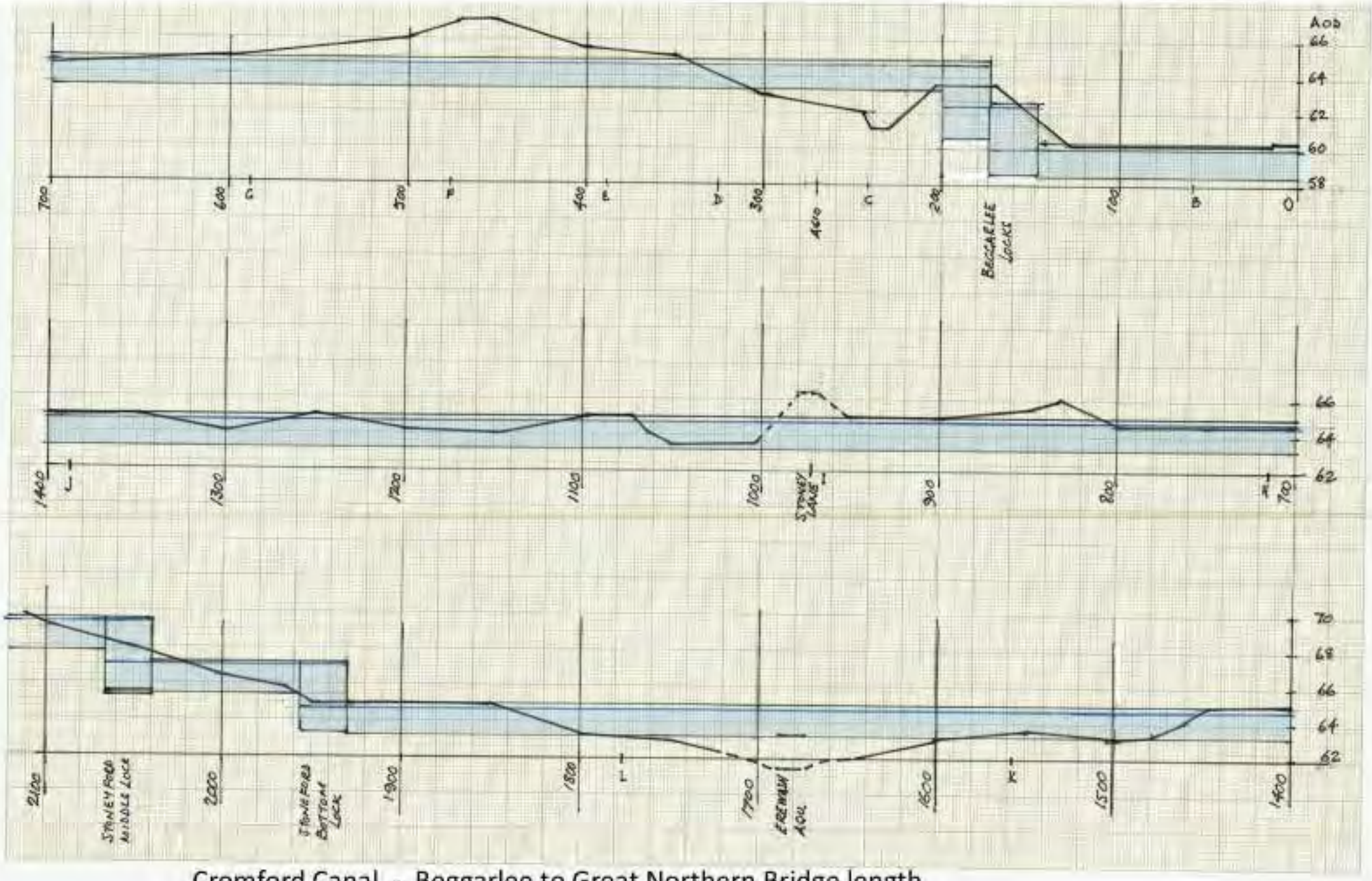

Cromford Canal - Beggarlee to Great Northern Bridge length

Provisional Alignment—Centreline long section - sheet 1

APPENDIX D

Riverscape Environmental Consultants

Modelling Report

Riverscape
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Consultants

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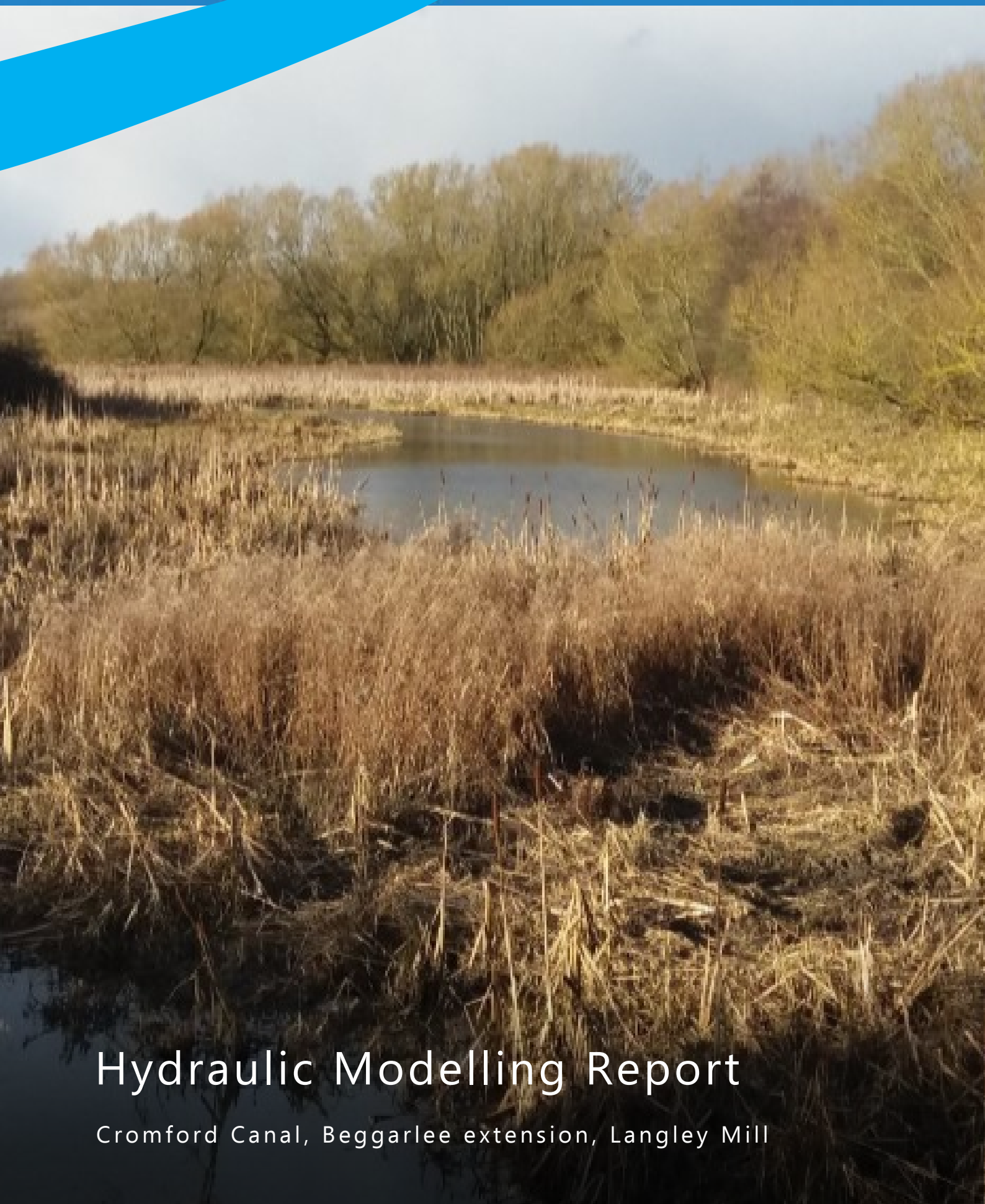
water environment



Hydraulic Modelling Report

Cromford Canal, Beggarlee extension, Langley Mill

Document History

Version	Date	Details
1.0	9th April 2018	1st issue
2.0	3rd September 2018	Revision following FCC comments
2.1	28th January 2019	Updated drawings

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Glossary

1d model	One-dimensional hydraulic model
2d model	Two-dimensional hydraulic model
AEP	Annual Exceedance Probability
AStGWF	Areas Susceptible to Groundwater Flooding
CFMP	Catchment Flood Management Plan
EA	Environment Agency
FDGIA	Flood Defence Grant-in-aid
FEH	Flood Estimation Handbook
Fluvial flooding	Flooding from rivers and streams
FRA	Flood Risk Assessment
FWMA	Flood and Water Management Act
IDB	Internal Drainage Board
IFRMS	Leicester Integrated Flood Risk Management Strategy
LFRMS	Local Food Risk Management Strategy
LIDAR	Light Detection and Ranging
LLFA	Lead Local Flood Authority
mAOD (N)	metres Above Ordnance Datum (Newlyn)
Main River	A watercourse included on the Main River Map, for which the Environment Agency has primary responsibility
NFM	Natural Flood Management
NPPF	National Planning Policy Framework
Ordinary Watercourse	All watercourses other than Main Rivers
Pluvial flooding	Overland flooding from surface water runoff due to lack of drainage capacity
Risk Management Authority	Bodies with a responsibility for flood risk management set out in the Flood and Water Management Act
RoFfSW	Risk of Flooding from Surface Water
SFRA	Strategic Flood Risk Assessment
SFRM study	Strategic Flood Risk Mapping study
SoP	Standard of flood protection from flood defences

1. Background

1.1. Introduction

Riverscape Environmental Consultants Ltd have been appointed by the Friends of the Cromford Canal to assess the impact of a proposed canal restoration scheme on flood risk from the River Erewash in Langley Mill, Derbyshire.

1.2. Location of the project

The proposed scheme is located to the immediate east of Langley Mill, to the north of the A608 and the west of the A610.

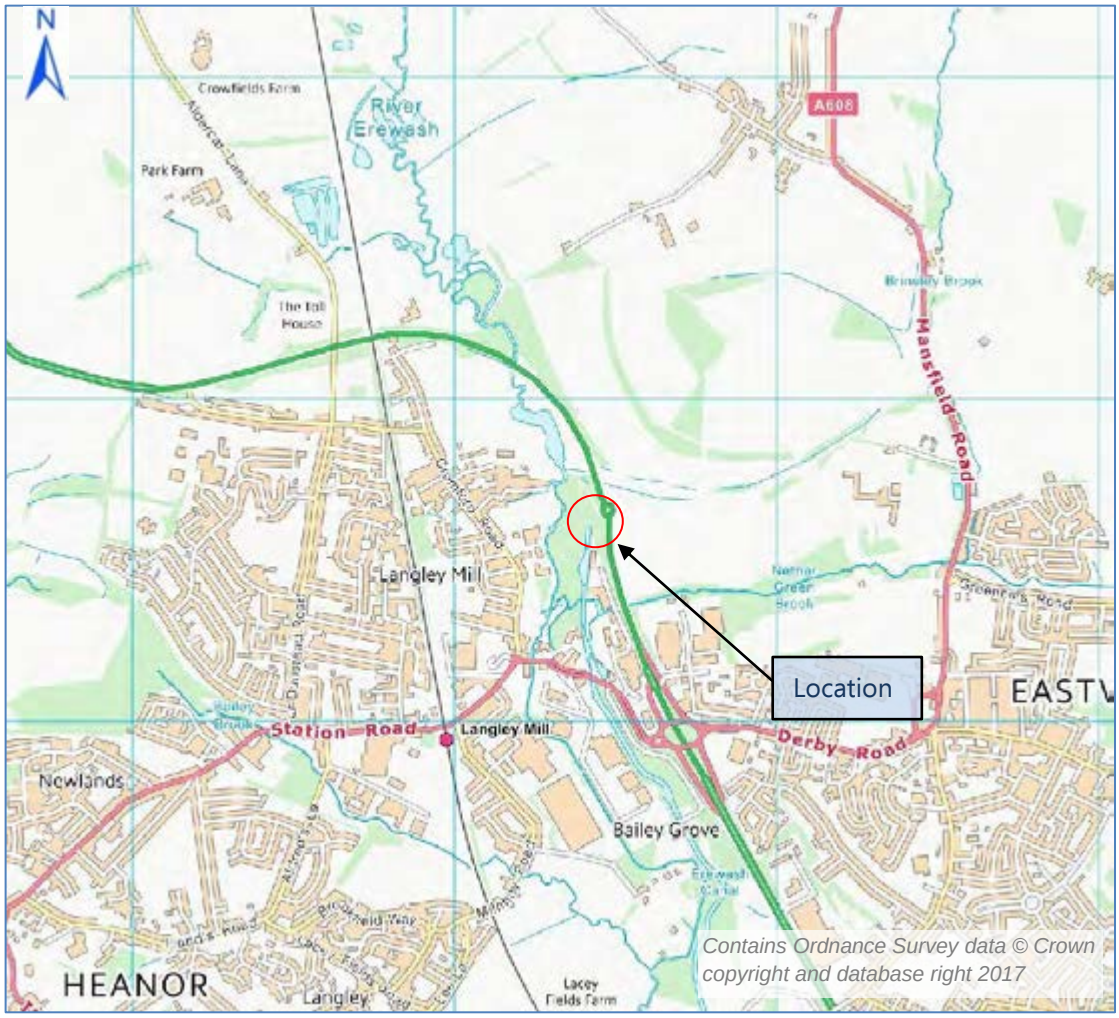


Figure 1.1: Location of the site.

1.3. Proposed scheme

The scheme involves extending the canal in a northerly direction from the existing basin which currently forms the northern limit of the Erewash canal (figure 1.2). Pre-application discussions between the Friends of the Cromford Canal and the Environment Agency highlighted the need to ensure that the western bank of the proposed canal extension is constructed at an elevation which prevents the ingress of floodwater from the River Erewash into the canal system, in a similar manner to the bank which runs along the existing canal to the south.

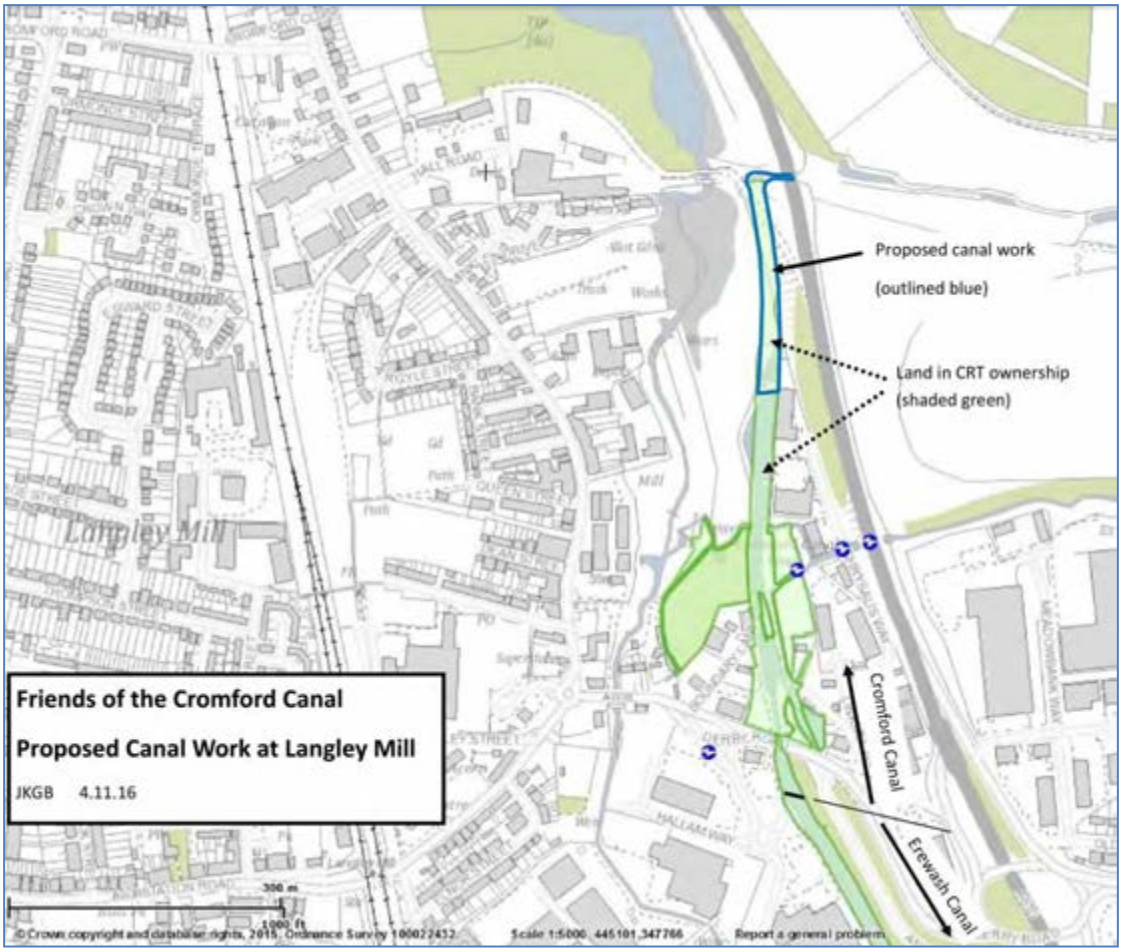


Figure 1.2: Proposed scheme. Image supplied by Friends of the Cromford Canal.

In addition, an area to the north of the proposed canal extension adjacent to the River Erewash has been identified for environmental enhancement and flood mitigation, described further in chapter 4.

1.4. Flood risk from the River Erewash

The proposed canal extension lies towards the eastern edge of the floodplain of the River Erewash. The Environment Agency Flood Zones (as at November 2017) are illustrated in figure 1.3.



Figure 1.3: Environment Agency Flood Zones.

1.5. Flood risk considerations

There is a small encroachment of the proposed works into the floodplain of the River Erewash, where ground raising will take place to form the new canal. As such, there are a number of potential impacts which must be assessed. A hydraulic model of the River Erewash has been used to assess the following:

1) Floodplain conveyance

The raising of ground levels to construct the canal extension will reduce the width of the floodplain locally. As such, it is necessary to establish whether the proposed works have a detrimental impact on flood levels along the river corridor by altering floodplain hydraulics.

2) Flood protection

It is understood from previous discussions with the Environment Agency have highlighted a need to raise the level of the canal towpath above the 1 in 100 annual chance +50% flood level to prevent floodwater entering the canal system. The Environment Agency hydraulic model of the River Erewash has been updated to provide new water levels which include allowances for climate change.

3) Flood compensation

The Environment Agency requires the provision of compensatory floodplain storage for any loss which occurs due to the scheme. As such, a mitigation scheme is required. The volumes of floodplain loss and gain are not part of this technical appendix to the FRA, but the hydraulic model has been used to assess any resulting changes in water level from the mitigation scheme.

2. Updates to the River Erewash model

2.1. Existing River Erewash Hydraulic Model

The most recent modelling of the River Erewash commissioned by the Environment Agency was the 2013 Strategic Flood Risk Mapping Study undertaken by Hyder Consulting (now Arcadis). The model of the River Erewash covers the full length of the main river designation and includes a number of smaller tributaries.

The model is a hydrodynamically linked 1d-2d model, where the river channel is represented using 1d cross sections in Flood Modeller Pro (previously ISIS) software and the floodplain is represented in 2d using TUFLOW software. This is a common approach to floodplain mapping which combines the benefits of both methods: 1d cross sections enable better geometric representation of channel and structure geometry than a relatively coarse 2d grid, and the 2d floodplain domain enables complex flowpaths to be captured better than a 1d floodplain approach, which has to be schematised *a priori*.

The Environment Agency model is a large, strategic scale model which has to balance spatial coverage against the level of detail, in order to manage computation times. The model is constructed with an 8m by 8m floodplain grid.

2.2. Truncation of the model and increased grid resolution

For the present study, it was considered preferable to focus the modelling on the area of interest and reduce the grid size to 4m by 4m, enabling a more detailed representation of the proposed scheme. In order to retain a sensible balance of detail and model run time, it was necessary to reduce the extent of the model and focus on the study area. The extent of the original Environment Agency model is illustrated on figure 2.1, alongside the truncated model domain used for this study. The truncated model is still relatively large in size, covering approximately 14km of the River

Erewash, and requires a 10 hour run time using an Intel i5-7600k processor running at 4.6Ghz. Halving the grid cell dimensions in this type of model typically increases runtimes by a factor of 8. As such, retaining the full model extent would have been impractical and was not necessary for the analysis of the proposed canal extension scheme.

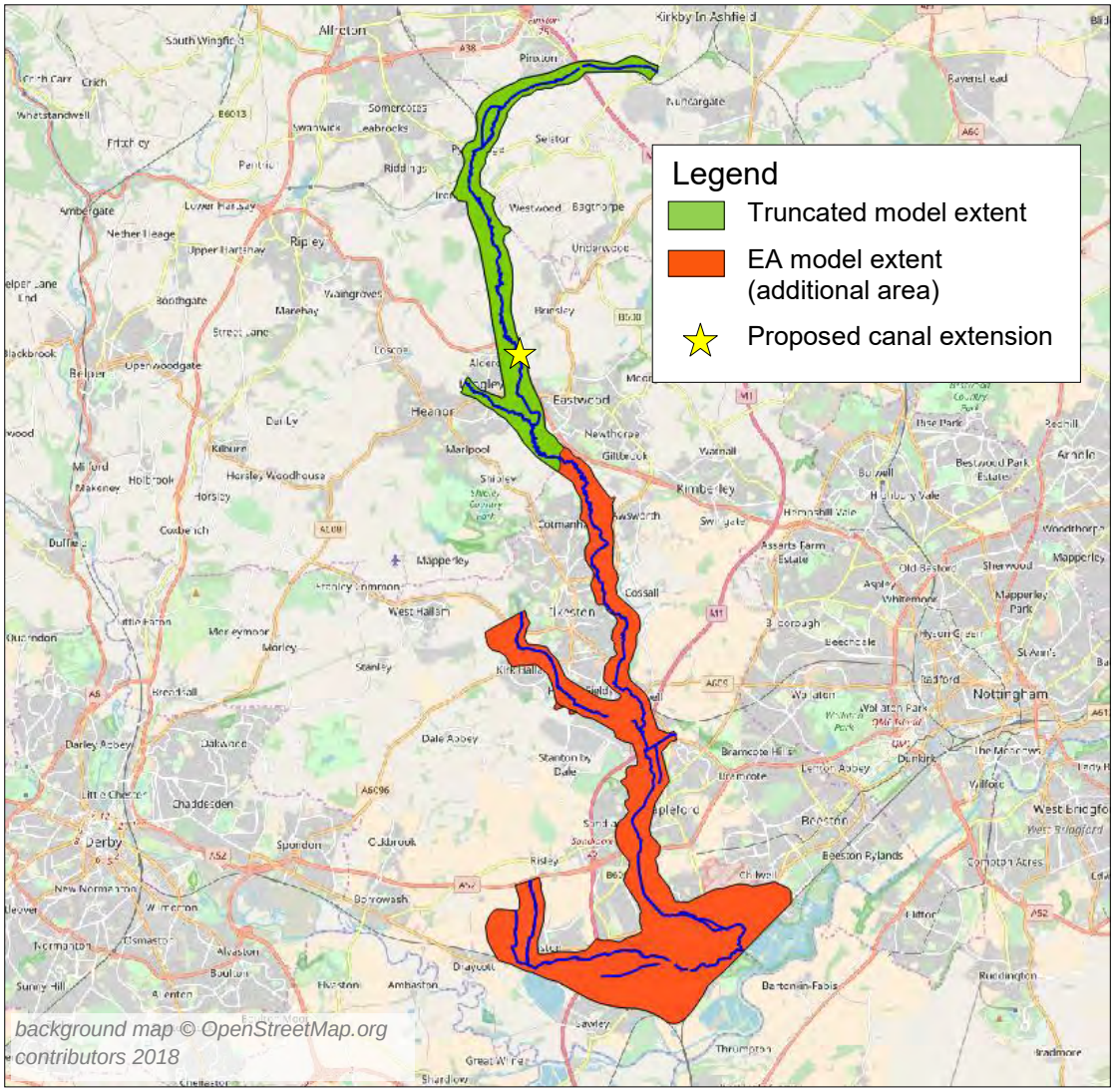


Figure 2.1: Truncation of the model to enable increased grid resolution.

The downstream limit of the truncated River Erewash model used in this study is still approximately 2.5km south of the site and there is an approximate drop in river bed level of 8m from the site to the downstream boundary of the model. As a result, the downstream boundary condition does not influence water levels at the study site. This has been confirmed through sensitivity testing (appendix b).

2.3. 1d-2d links

During the course of the modelling it was noted that the River Erewash model is relatively unstable and relies upon the use of SX connections between the 1d and 2d domains along river banks (figure 2.2). This is a less common approach to 1d-2d linking using Flood Modeller Pro and TUFLOW software, where ordinarily rivers are linked along river banks to the 2d domain using HX connections. The use of SX connections caused difficulties when assessing the proposed canal scheme, because the SX connections modify the level of the river banks in the 2d grid to ensure that they are compatible with the spill levels set in Flood Modeller Pro. It was also found that the model would not run using this schematisation when the grid cell size was reduced to 4m by 4m.

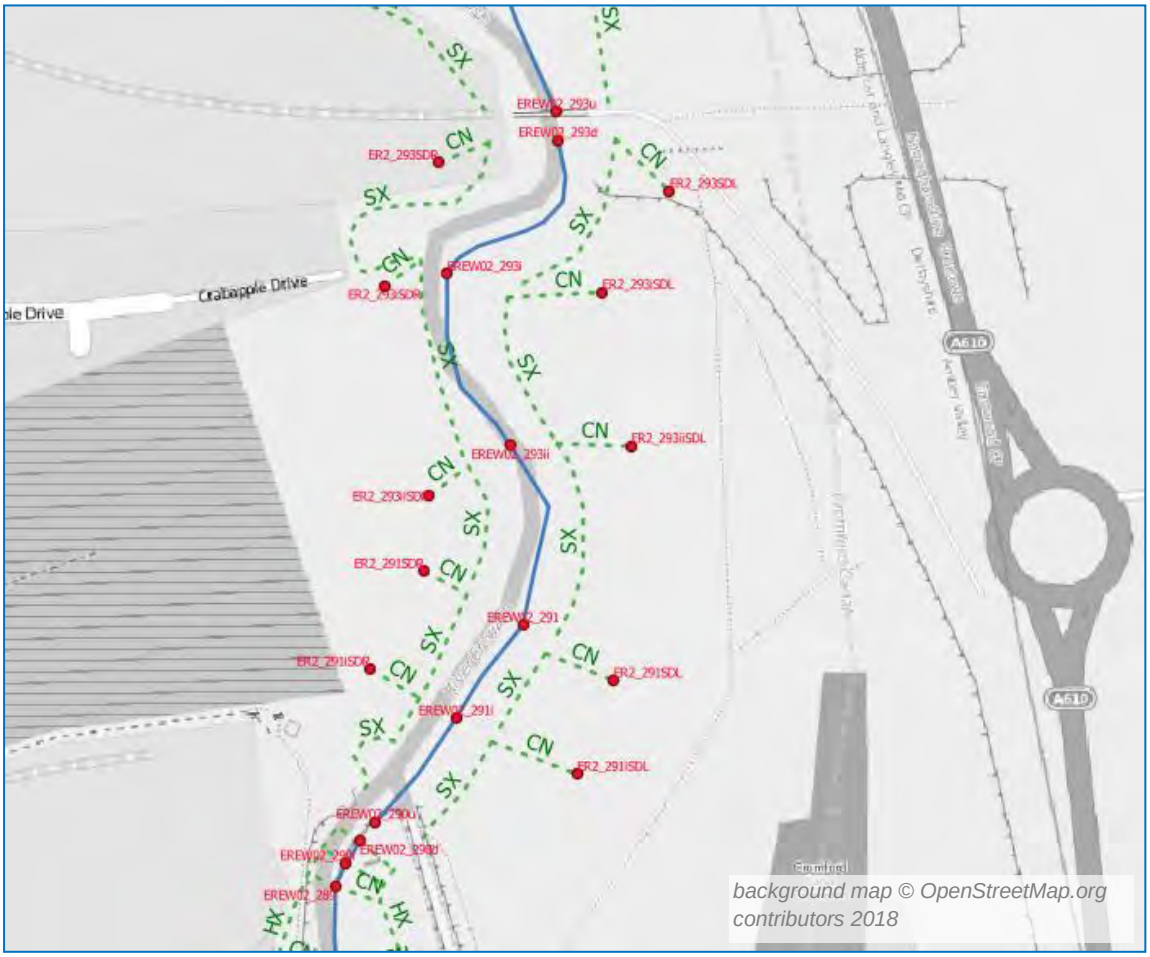


Figure 2.2: SX connections between the 1d and 2d domains in the Environment Agency River Erewash model.

In order to improve the definition of bank heights locally and to enable the model to run at a reduced grid size, the SX connections between the 1d and 2d domains of the hydraulic model were replaced along the River Erewash with HX lines and additional levels were added from LIDAR to prevent interpolation of high ground between bridges. This was found to be a source of stability problems.



Figure 2.3: Revised schematisation using HX connections between the 1d and 2d domains in truncated River Erewash model.

2.4. Topographic survey

Topographic survey of the site was added to the model by constructing a 3d TIN from survey points and adding this data to the hydraulic model geometry as a floating point grid (figure 2.4). The floating point grid overwrites the underlying digital elevation model, which is based on Environment Agency LIDAR data. The survey data was found to be adequately consistent with the underlying LIDAR (figure 2.5).



Figure 2.4: Topographic survey added to the model at the location of the proposed canal extension

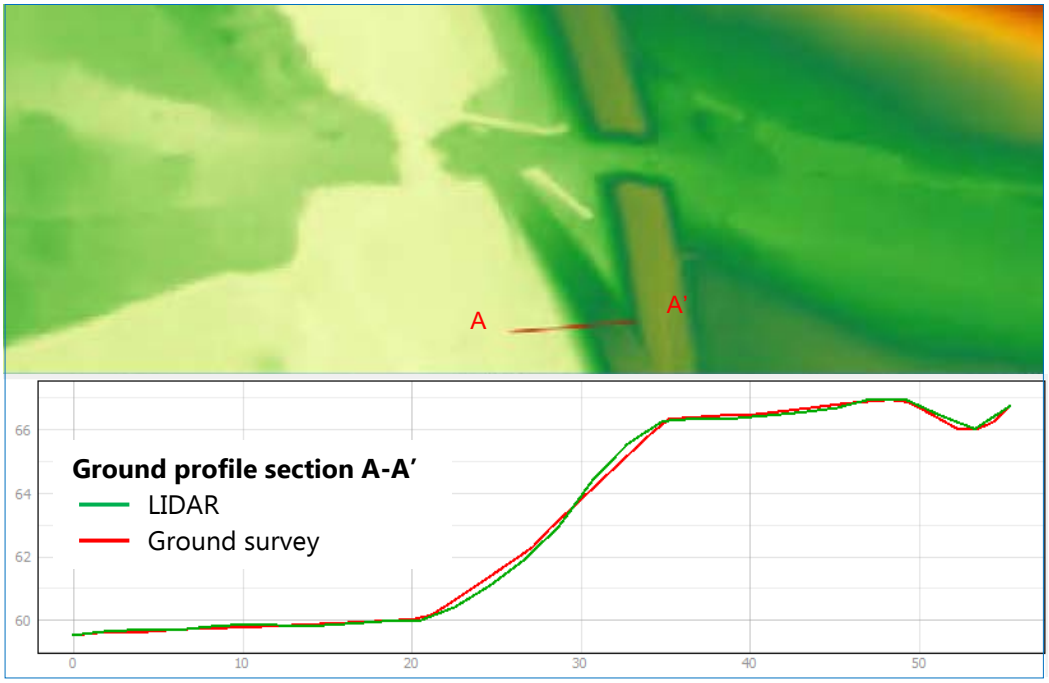


Figure 2.5: Example cross section comparing LIDAR with ground survey.

2.5. Water level lines

Water level lines are used within TUFLOW software to enable mapping of the flooding in the external (Flood Modeller Pro) 1d domain. Unfortunately the water level lines within the model were not producing high quality output, so improvements were made in the study area to improve the standard of flood risk mapping (figure 2.6).

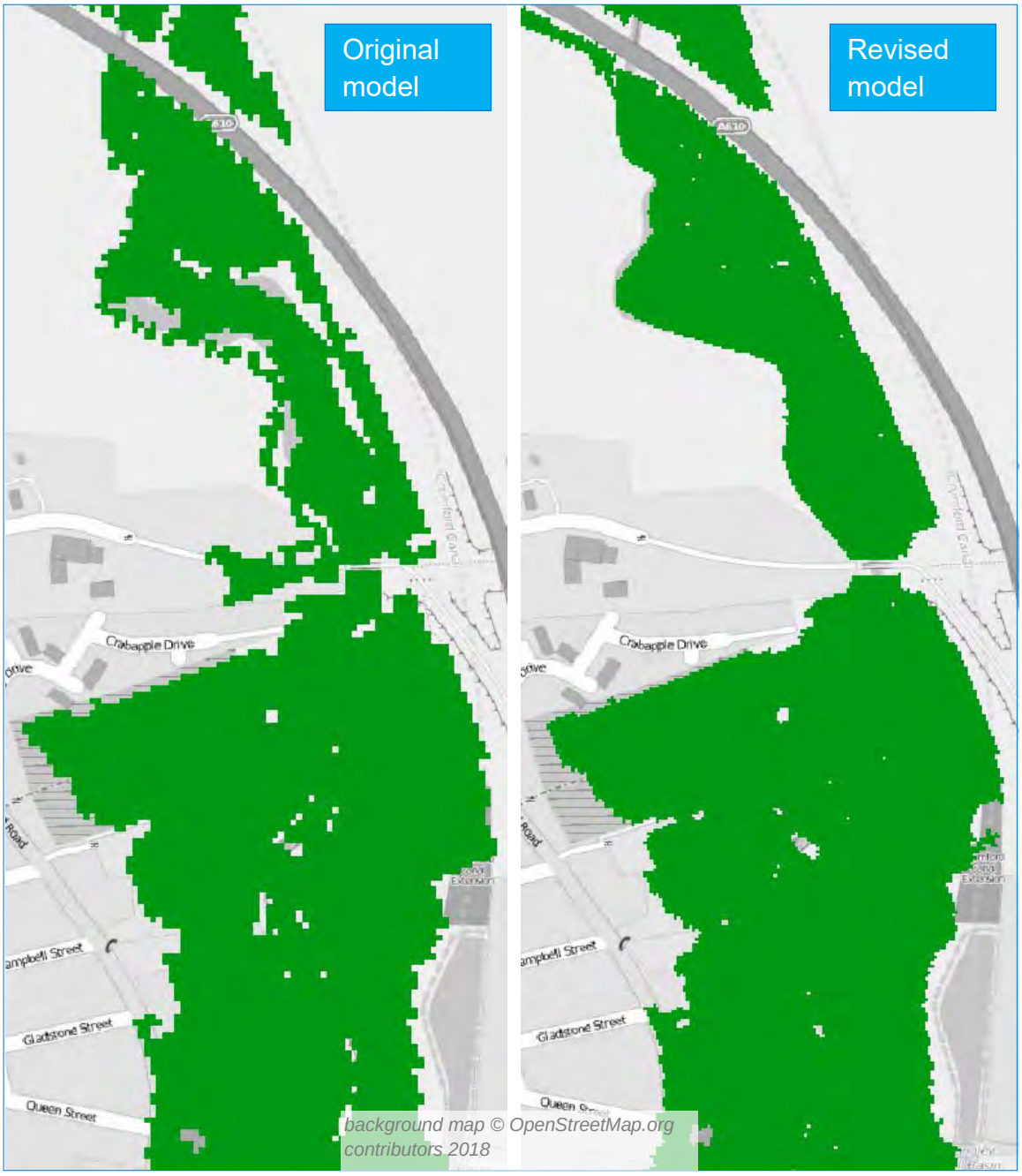


Figure 2.6: Improved floodplain mapping due to digitisation of new water level lines and reduced grid size.

2.6. Climate change model inflows

The 2013 Environment Agency model of the River Erewash accounted for future climate change impacts on flood risk through an additional model scenario, whereby the 1 in 100 annual chance flow was increased by 20%. This was standard practice at the time.

In February 2016 DEFRA/ EA published guidance entitled "Flood risk assessments: climate change allowances" [1]. This guidance forms part of the Technical Guidance to the National Planning Policy Framework. The climate change guidance is based on the output of the 2009 UK Climate Projections (UKCP09). The climate projections were then analysed in the context of UK river catchments in DEFRA research reports FD2020 and FD2048. This research has led to a range of flood flow allowances for different climate change emissions scenarios, and is further broken down into river basins within the UK. The flood flow allowances for each river basin are based on weighted average increases in flood flows predicted for individual catchments within the river basin.

The River Erewash is a tributary of the River Trent, which in turn falls within the Humber river basin (figure 2.7). The appropriate climate change allowances for the Humber river basin are set out in table 2.1.

Table 2.1: Climate change allowances for the Humber river basin.

Allowance category	Total potential change anticipated for the '2020s' (2015 to 2039)	Total potential change anticipated for the '2050s' (2040 to 2069)	Total potential change anticipated for the '2080s' (2070 to 2115)
Upper end	20%	30%	50%
Higher central	15%	20%	30%
Central	10%	15%	20%

[1] DEFRA (2018) *"Flood Risk Assessments: climate change allowances"* available at: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

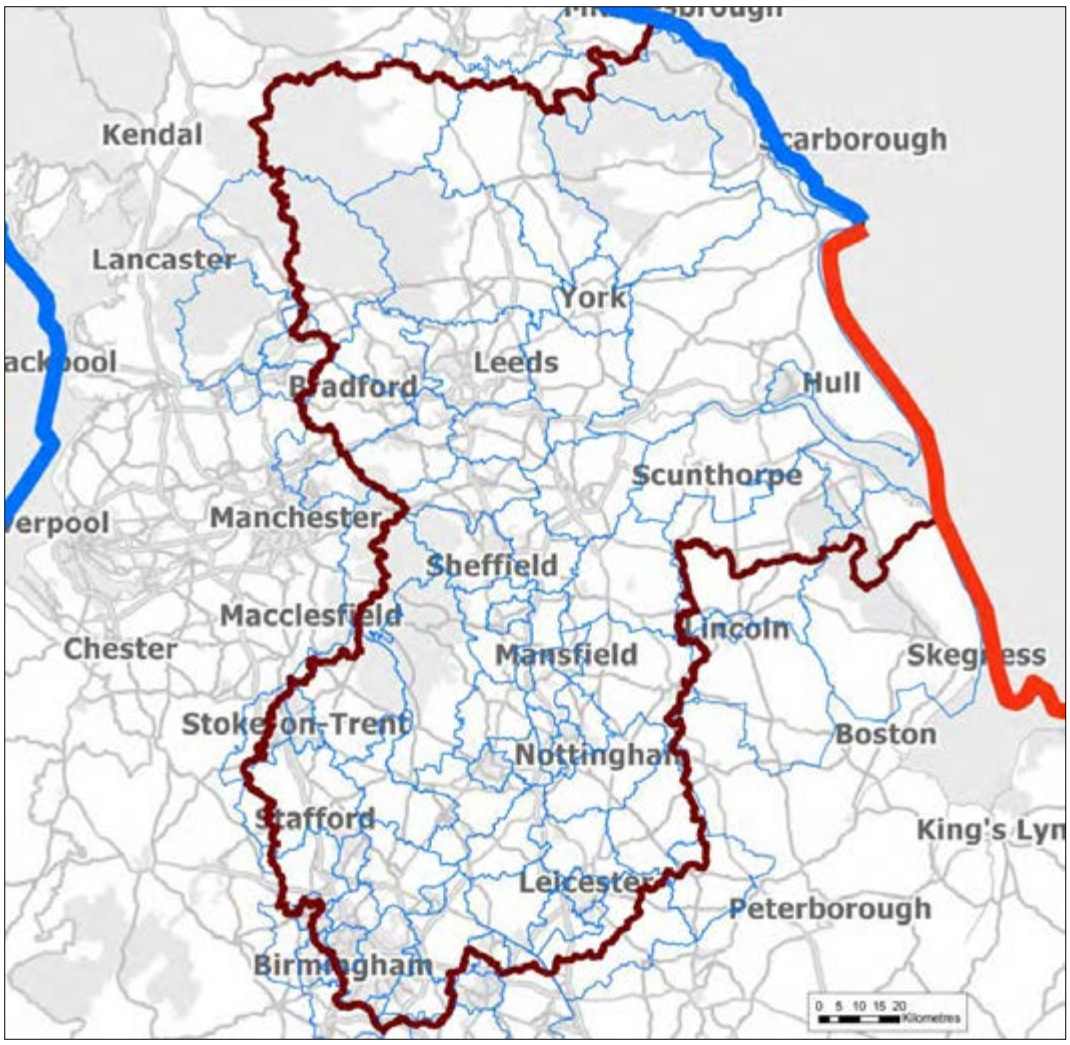


Figure 2.7: Humber river basin. *© Environment Agency copyright and/or database right 2015.*

In order to comply with the new climate change guidance the inflows to the model were increased by **20%**, **30%** and **50%** to represent the '**central**', '**higher central**' and '**upper end**' climate change scenarios respectively.

2.7. Model runs

The Environment Agency model includes two design storm scenarios: a long duration event representing the critical storm on the River Erewash and a short duration event representing the critical storm on the smaller tributaries of the river. For the purposes of this study, only the longer duration event was re-run, because the works are taking place adjacent to the River Erewash and lie some distance from any of the smaller modelled tributaries.

The hydraulic model was run at the following events, including the geometry of the proposed canal extension, for comparison against the baseline water levels:

- 1 in 20 annual chance (5% AEP);
- 1 in 100 annual chance (1% AEP);
- 1 in 100 annual chance +20% flow (1% AEP, central climate change scenario);
- 1 in 100 annual chance +30% flow (1% AEP, higher central climate change scenario);
- 1 in 100 annual chance +50% flow (1% AEP, upper end climate change scenario);
- 1 in 1000 annual chance (0.1% AEP).

2.8. Updated flood extents

The truncation of the model and improved grid resolution did not result in substantial changes in flood extent through Langley Mill, though it was noted that the smaller floodplain grid revealed much more detail on flood flow routes upstream of the site in areas such as Jacksdale. Whilst the modelled flood levels are relatively consistent between the original EA model and revised model used for this study, there are some notable differences of up to 300mm. These differences arise from the addition of extra height data along bank lines, taken from adjacent LIDAR floodplain levels, because the original model was interpolating high bank levels between bridges, and the replacement of the SX connections with HX connections which may have altered the flow transfer between the channel and the floodplain. Overall, the revised water levels are considered to be an improvement, but with a comparatively wide margin of error when taking into account to underlying survey, model and hydrological analysis. The modelled flood extents in Langley Mill are illustrated in figure 2.6. Note that the mapping in figure 2.8 is the raw ascii output from the FMP-TUFLOW model.

Modelled flood extents are illustrated in **Appendix A**.

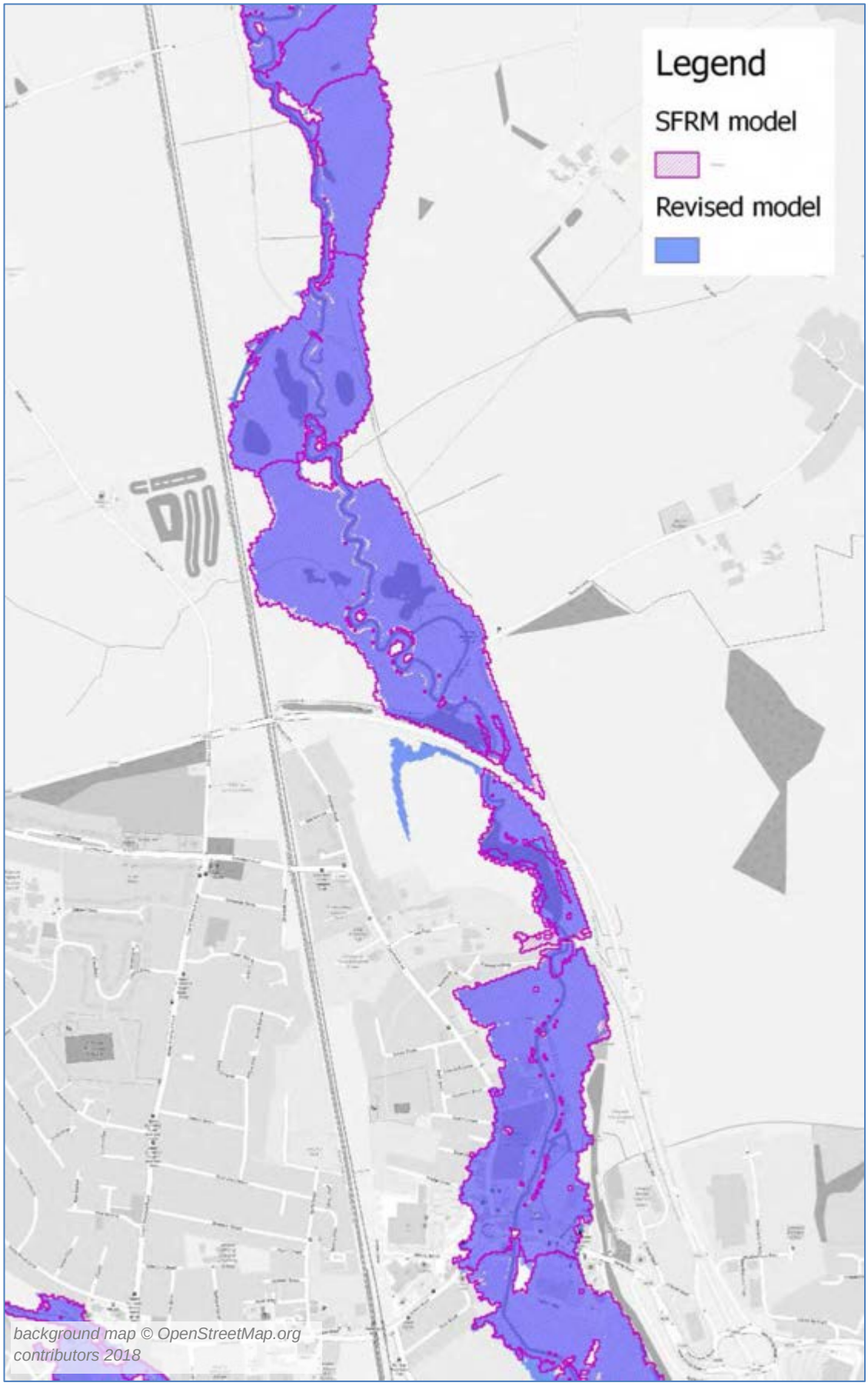


Figure 2.8: Comparison of flood extents 1 in 100+20% event.

3. Hydraulic analysis of the Proposed Canal Extension

3.1. Representation of the proposed canal extension

The proposed canal extension is occurring some distance from the river channel, within the 2d domain of the hydraulic model. As such, the only changes made to the model to represent the proposed canal were GIS elevation data added to the TUFLOW model. No changes were made to the 1d Flood Modeller Pro .DAT file.

The Friends of the Cromford Canal provided section drawings of the proposed canal extension, which was converted into a 3d ground model. The ground model was then added to the TUFLOW GIS dataset as a floating point grid. This data overwrites the existing topographic survey data, described in section 2.4, at the location of the proposed works. In addition, a 'z-line' was added to continue the proposed level of the towpath (60.5m AOD) in a southerly direction towards the existing canal basin.

Figure 3.1 provides a comparison of the 2d model grid from the baseline and with scheme scenarios. The grids shown in figure 3.1 are extracts from the ascii check files produced by TUFLOW, confirming that the data has been read by the model correctly.

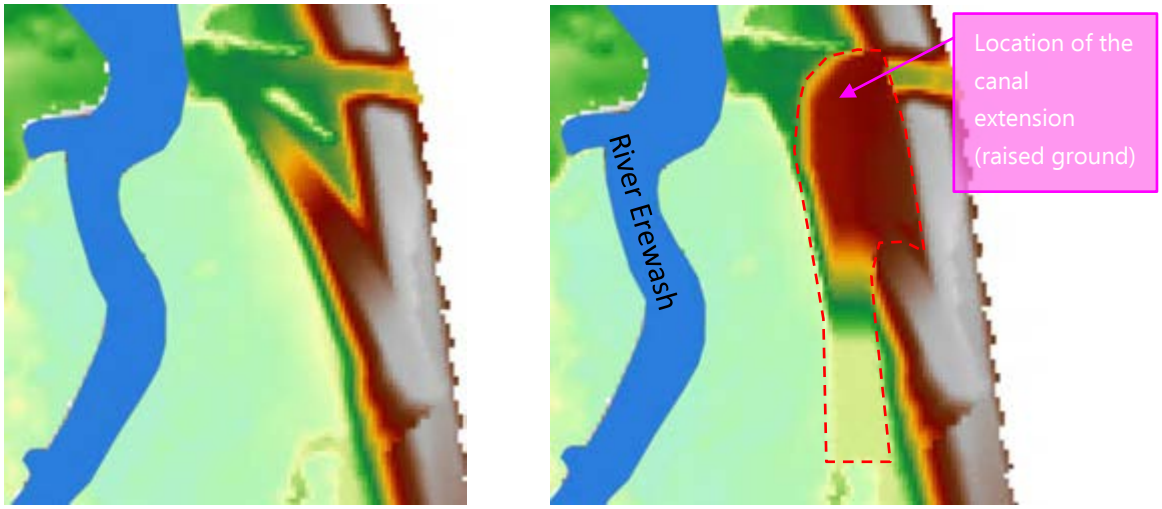


Figure 3.1: Comparison of baseline *(left)* and 'with scheme' *(right)* model grids.

3.2. Model results

1) Floodplain conveyance

Figure 3.2 provides a comparison of the 1 in 100 annual chance +50% flood extents in the existing and 'with scheme' scenarios. The mapping indicates that the only change is a reduction in flood extent at the location of the proposed canal, which is to be expected because ground levels are being raised. No negative impacts on third parties are evident from the mapping.

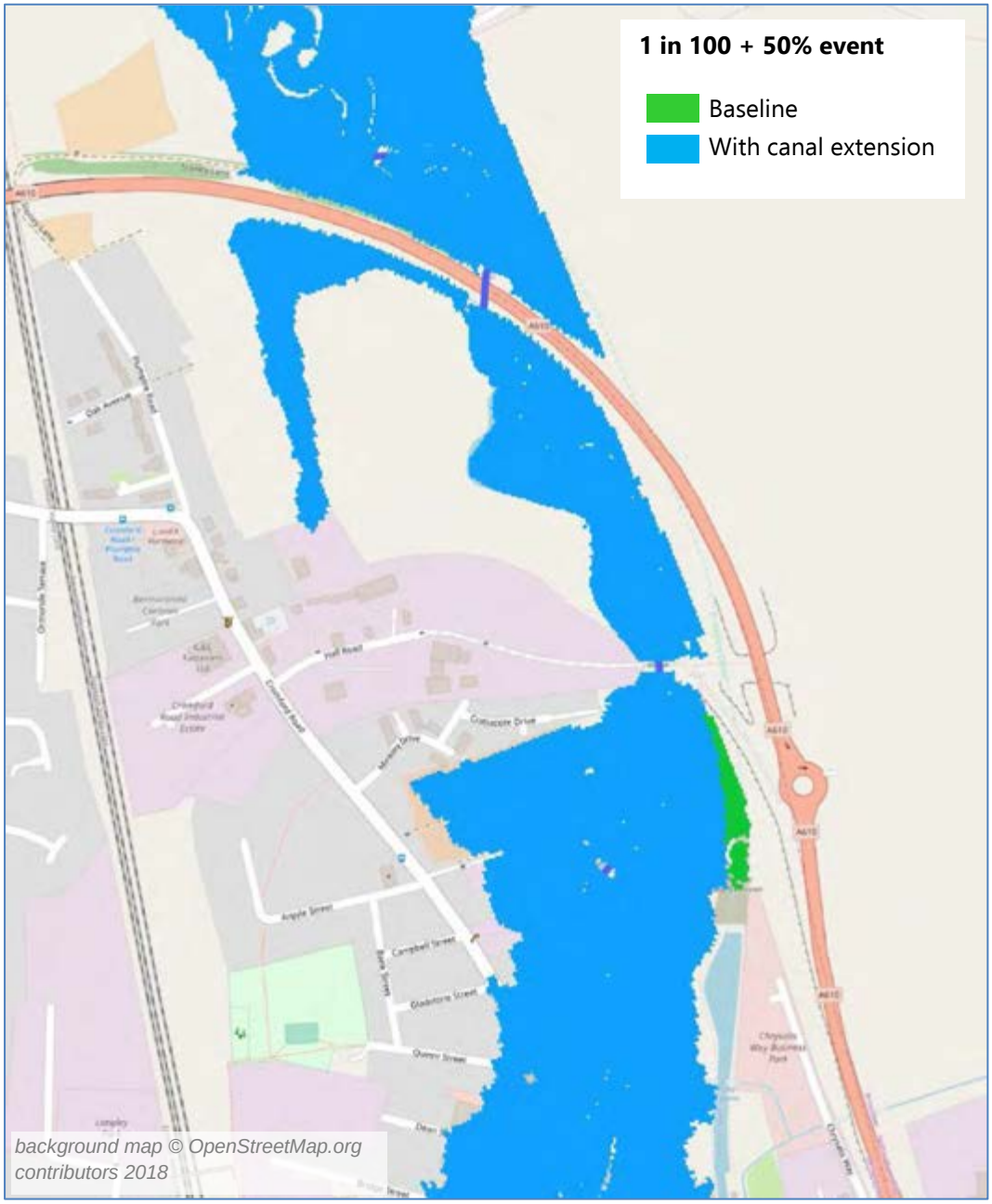


Figure 3.2: Pre- and post scheme flood extents, 1 in 100 annual chance+50% event.

The peak water level output grids from the 'with scheme' model were compared to those from the baseline model using the TUFLOW utility *asc_to_asc_w64.exe*, to investigate whether the scheme results in any changes in water level. No notable changes were found, except at the site itself where the raising of ground levels has taken the land out of the floodplain. Figure 3.3 illustrates the change in water level at the 1 in 100 + 50% event, but since all values fall within +-0.01m of the baseline model, the whole entire floodplain is shown in green. Minor fluctuations in water level remote from the site were noted in some of the runs, but these are due to minor instabilities in the underlying model rather than as a result of the proposed works. For example, minor instabilities at remaining SX connections on the Bailey Brook, some considerable distance from the site on a different watercourse, cause localised fluctuations in water level, but these are unrelated to the canal scheme. No notable detrimental impacts were noted resulting from the works.

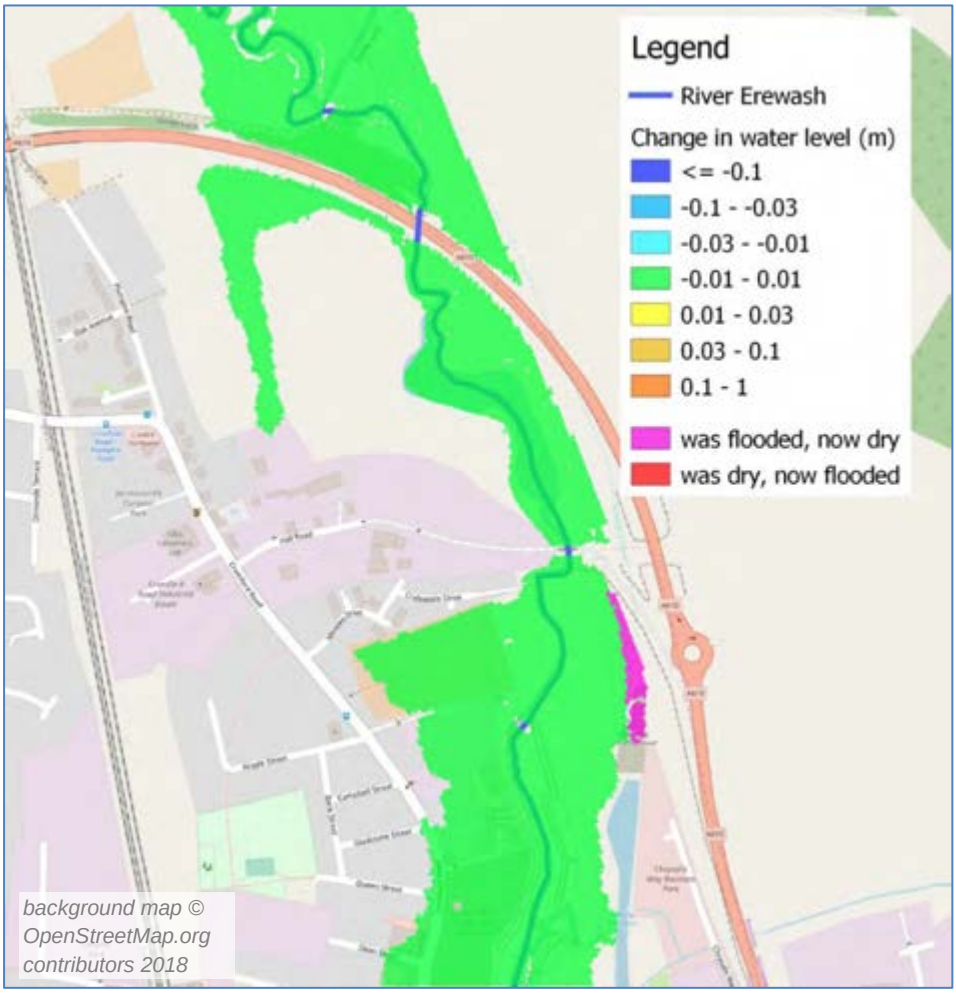


Figure 3.3: Change in water level, 1 in 100 + 50% event.

2) Flood protection

The analysis undertaken using the modified Environment Agency hydraulic model indicates that if the bank/ towpath level of the canal extension is set to 60.5m AOD(N)), this should be sufficient to prevent the ingress of floodwater into the canal system up to the 1 in 100 +50% event. Table 3.1 provides water level output at the upstream (northern) and downstream (southern) extents of the scheme, along with approximate bank levels for the proposed canal extension. The location of the measurement points is illustrated in figure 3.4.

Table 3.1: Water level output.

Flood event	Upstream proposed bank level	Upstream flood level	Downstream proposed bank level	Downstream flood level
1 in 20 annual chance	65.0m	59.93	60.5m	59.82
1 in 100 annual chance	65.0m	60.22	60.5m	60.15
1 in 100 annual chance +20%	65.0m	60.32	60.5m	60.25
1 in 100 annual chance +30%	65.0m	60.38	60.5m	60.31
1 in 100 annual chance +50%	65.0m	60.48	60.5m	60.42
1 in 1000 annual chance	65.0m	60.71	60.5m	60.66

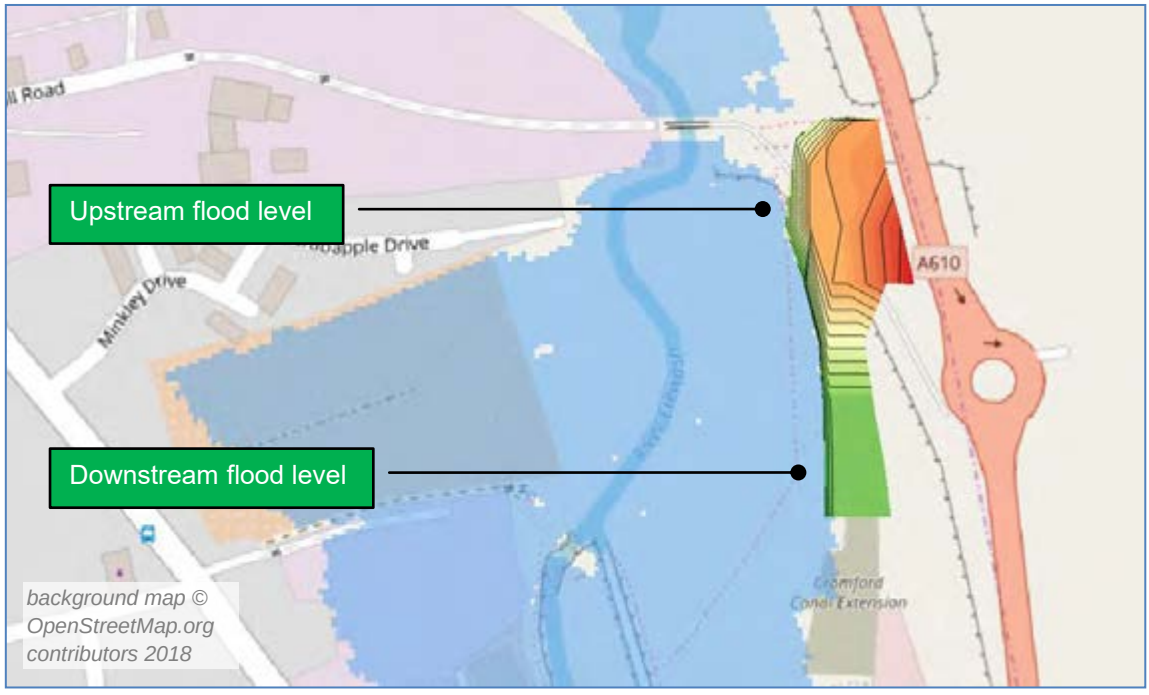


Figure 3.4: Water level measurement points.

Survey undertaken by the Friends of the Cromford Canal has indicated that there may be some low spots on the existing section of canal to the south of the proposed canal extension which are currently below 60.5m AOD(N). Detailed survey was not possible due to the presence of dense vegetation, but in order to achieve a consistent standard of protection along the canal system as a whole, it will be necessary to raise any low spots during detailed design of the scheme, as far as the existing canal basin to the south. The presence of any canal overflows will also need to be considered within the design. It is also recommended that during detailed design, the towpath should be raised higher if practical, and no lower than the minimum standard agreed with the Environment Agency. This would provide additional freeboard against the uncertainty inherent to flood estimation. In particular, the flux between the 1d and 2d domains and flow across vegetated floodplains are difficult to represent.

3) Flood storage

The 'existing' and 'with scheme' ground models were analysed to establish the loss in flood storage arising from the canal scheme. The calculations are presented in table 3.2, on page 20, and taken to approximately the 1 in 100 year +50% flood level. The Friends of the Cromford Canal are designing a compensatory storage scheme just upstream of the proposed canal restoration works to offset this loss of flood storage. The compensatory storage scheme itself is described in more detail within their Flood Risk Assessment.

In view of the location of the compensatory storage being slightly upstream of the canal restoration works, to the north of Hall Lane bridge, it is necessary to adjust the elevation band of the compensatory storage to account for the generally higher flood water levels upstream of the bridge. The range of water levels is also greater upstream of the bridge, because of the increasing headloss associated with the bridge as water levels rise. Translation of the flood storage bands into equivalent upstream elevations ensures that the compensatory storage becomes effective at roughly the same point in the flood hydrograph as the storage which is being lost.

Table 3.2: Change in flood storage resulting from the proposed canal restoration*.

Depth of flooding	Approximate elevation band	Loss of flood storage due to canal restoration	Equivalent elevation band upstream of Hall Road bridge for compensatory storage	Gain in flood storage due from compensation scheme	Net change in flood storage
1.0m to 1.2m	59.2m to 59.4m	0	59.25m to 59.54m	161	+161
0.8m to 1.0m	59.4m to 59.6m	-21	59.54m to 50.84m	211	+190
0.6m to 0.8m	59.6m to 59.8m	-109	59.84 m to 60.14m	240	+131
0.4m to 0.6m	59.8m to 60.0m	-207	60.14m to 60.43m	249	+42
0.2m to 0.4m	60.0m to 60.2m	-294	60.43m to 60.73m	248	-46
0.0m to 0.2m	60.2m to 60.4m	-339	60.73m to 61.03m	347	+8

** Compensatory flood storage volumes provided by Friends of the Cromford Canal.*

4. Impact of the Compensatory works

4.1. Compensatory works

In order to offset the loss of floodplain arising from construction of the new section of canal, a flood compensation scheme is proposed to the north of Hall Road bridge on the left (eastern) floodplain of the River Erewash. The outline geometry of the proposed scheme was provided by the Friends of the Cromford Canal as a series of proposed cross sections. A plan view of the proposed compensatory storage area is illustrated in figure 4.1 and a full set of cross sections is included in Appendix C.

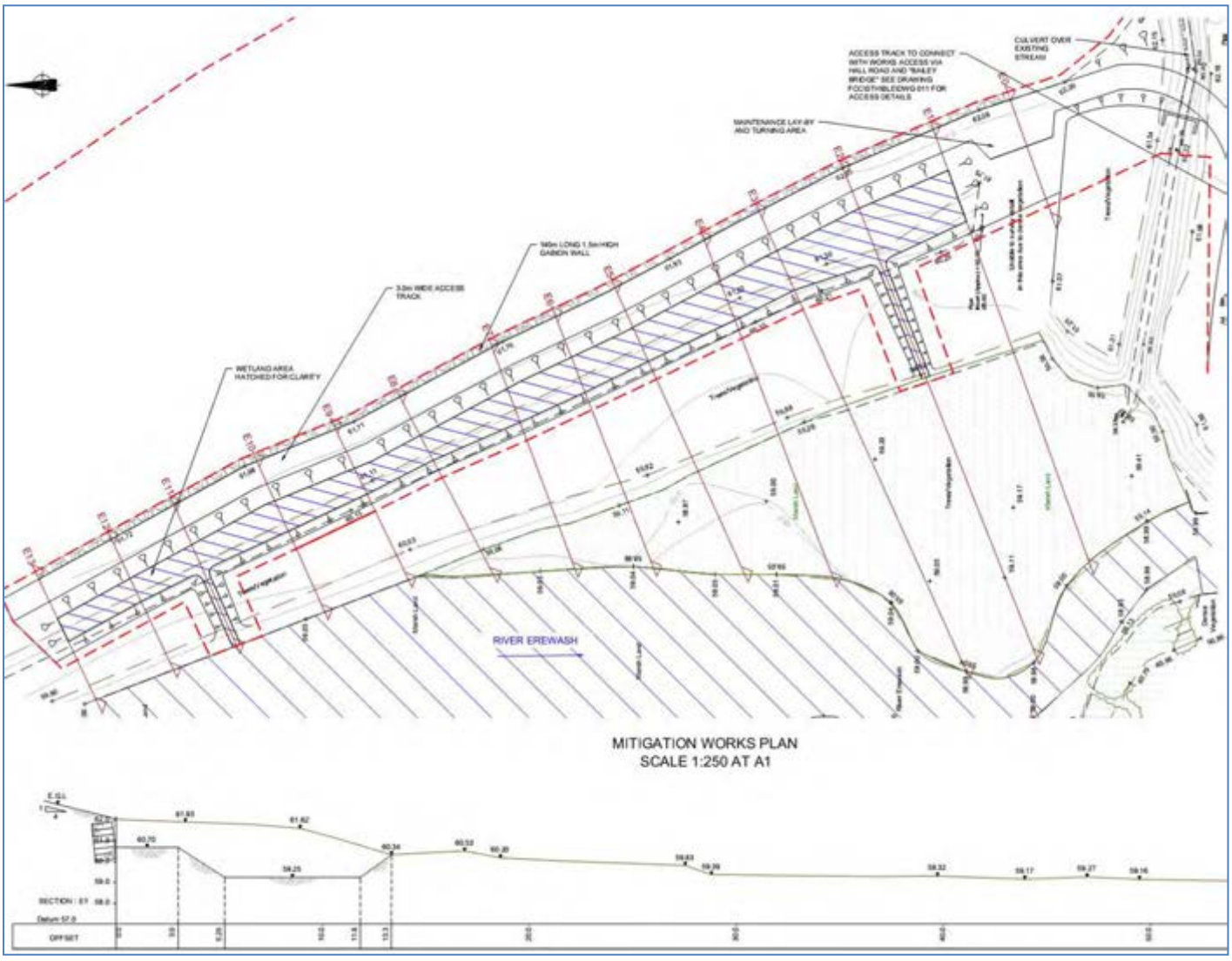


Figure 4.1: Plan view of the proposed compensatory floodplain storage.

These cross sections were used to build up a 3d ground model, which was superimposed onto the model geometry using a floating point grid (figure 4.2). A second series of hydraulic tests was undertaken across the full range of flood events. These tests included topographic patches to represent both the proposed canal (as described in the previous chapter) and the proposed flood compensation scheme.

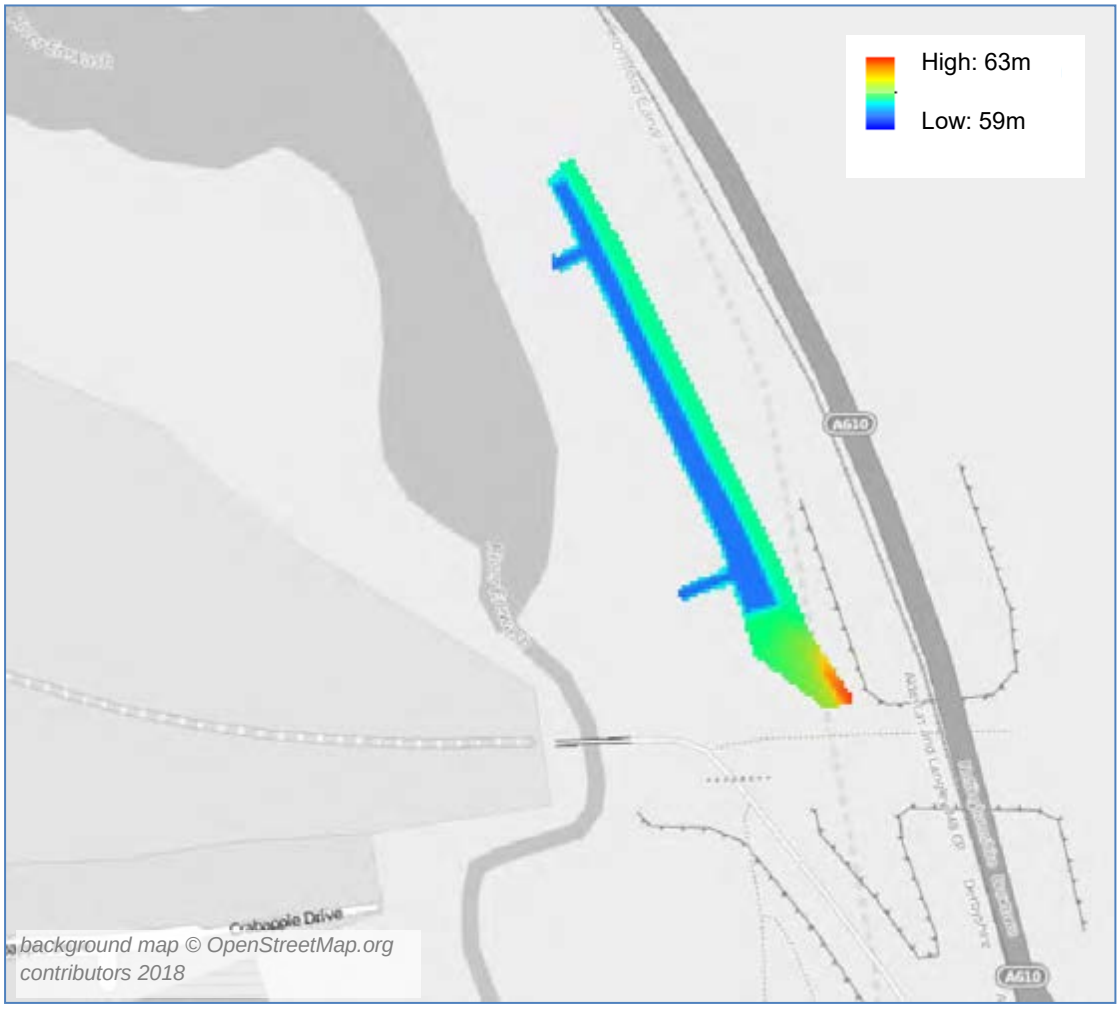


Figure 4.2: Geometry of the proposed compensatory floodplain storage.

4.2. Results

Modelling of the proposed flood compensation scheme reveals only negligible changes in water level as a result of the proposal. These water level changes are local to the area of the works. A small (10-30mm) rise in water level is calculated at the location of the compensatory works, because water is more effectively conveyed into this area, and a small (<10mm) reduction in water level is noted upstream of the

proposed scheme. The volumes of storage involved are comparatively small on a river the size of the Erewash, and as such there are no notable changes in water level downstream of the site. Although this analysis suggests that the compensatory works have little downstream benefit, it is still important to preserve the capacity of the floodplain because there is uncertainty associated with hydraulic modelling and very small features cannot always be fully represented in hydraulic models. Figure 4.3 illustrates the change in water level near to the site at the 1 in 100 annual chance +50% event.

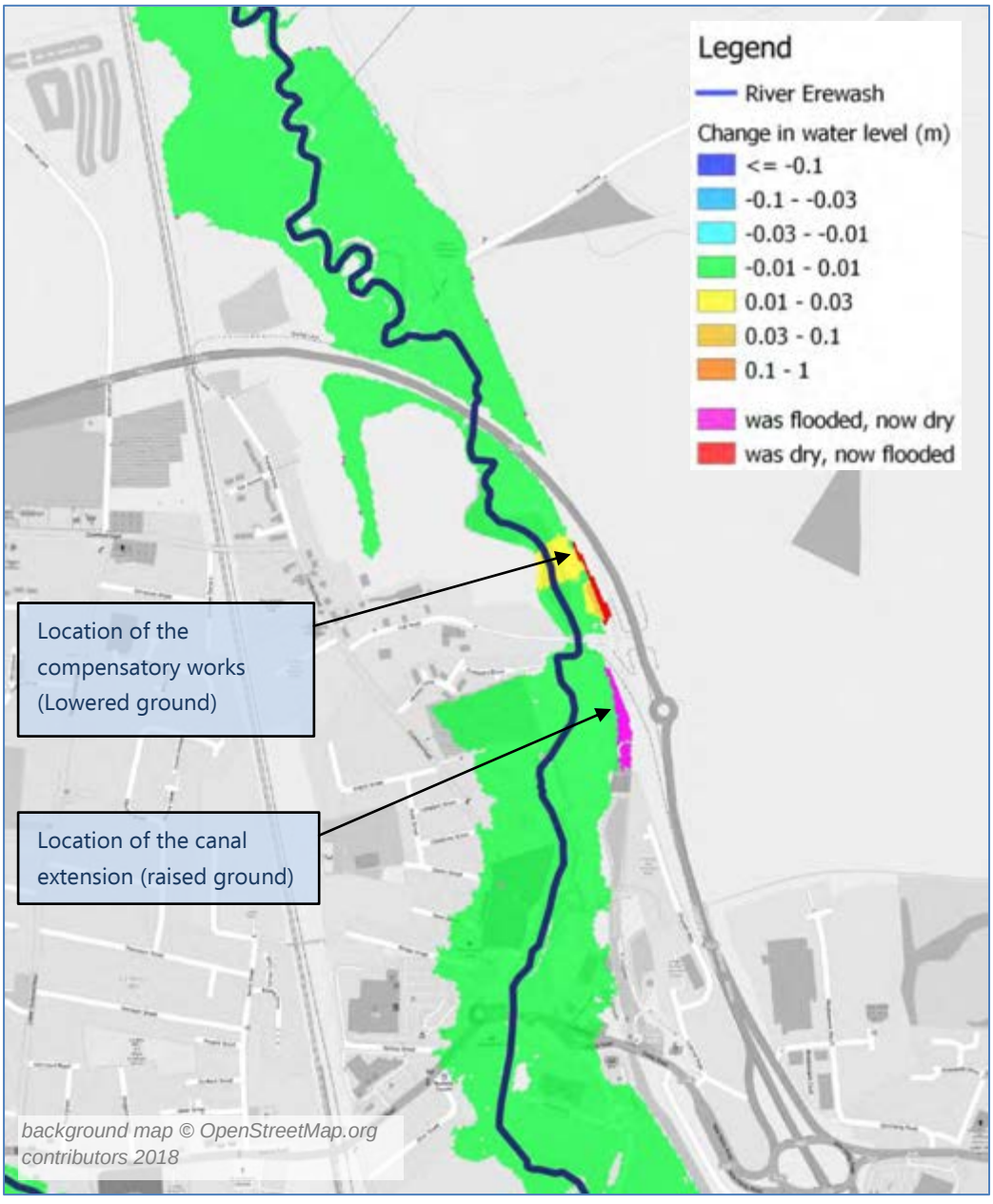


Figure 4.3: Change in water level due to flood storage creation, 1 in 100 +50% event.

5. Conclusions

The proposed reinstatement of the section of the Cromford Canal in Langley Mill involves the raising of ground levels to form the western bank of the canal, and the provision of compensatory flood storage. Analysis of the scheme using an improved version of the Environment Agency hydraulic model of the River Erewash does not reveal any negative flood risk impacts.

6. Limitations

This report is produced for the sole use of the Friends of the Cromford Canal and should not be relied upon in any way by any other party.

The work described in this report is undertaken using data supplied by third parties and is limited to the methods and information available at the time of writing. Although every effort has been made to check the validity of the supplied data, it is not possible to investigate every aspect of the supplied data. This is particularly the case with hydraulic models, which are reliant upon accurate topographic survey of river channels that can change in geometry over time, and LiDAR which is only considered accurate to within +- 250mm and can be out of date when new developments have taken place. In addition, hydraulic modelling is not a precise science- by definition a model is a simplification of highly complex natural systems which can only be approximated by even the most detailed studies.

High flow flood hydrology is always an uncertain science, because the climate is not stationary and often there is a need to extrapolate data beyond the timeframes in which it has been collected. For these and other reasons we cannot offer any guarantee that a particular location will not flood. Even areas with the best defences retain a residual risk of flooding.

This report must be read with recognition of these limitations.

Appendix A: Modelled Flood Extents

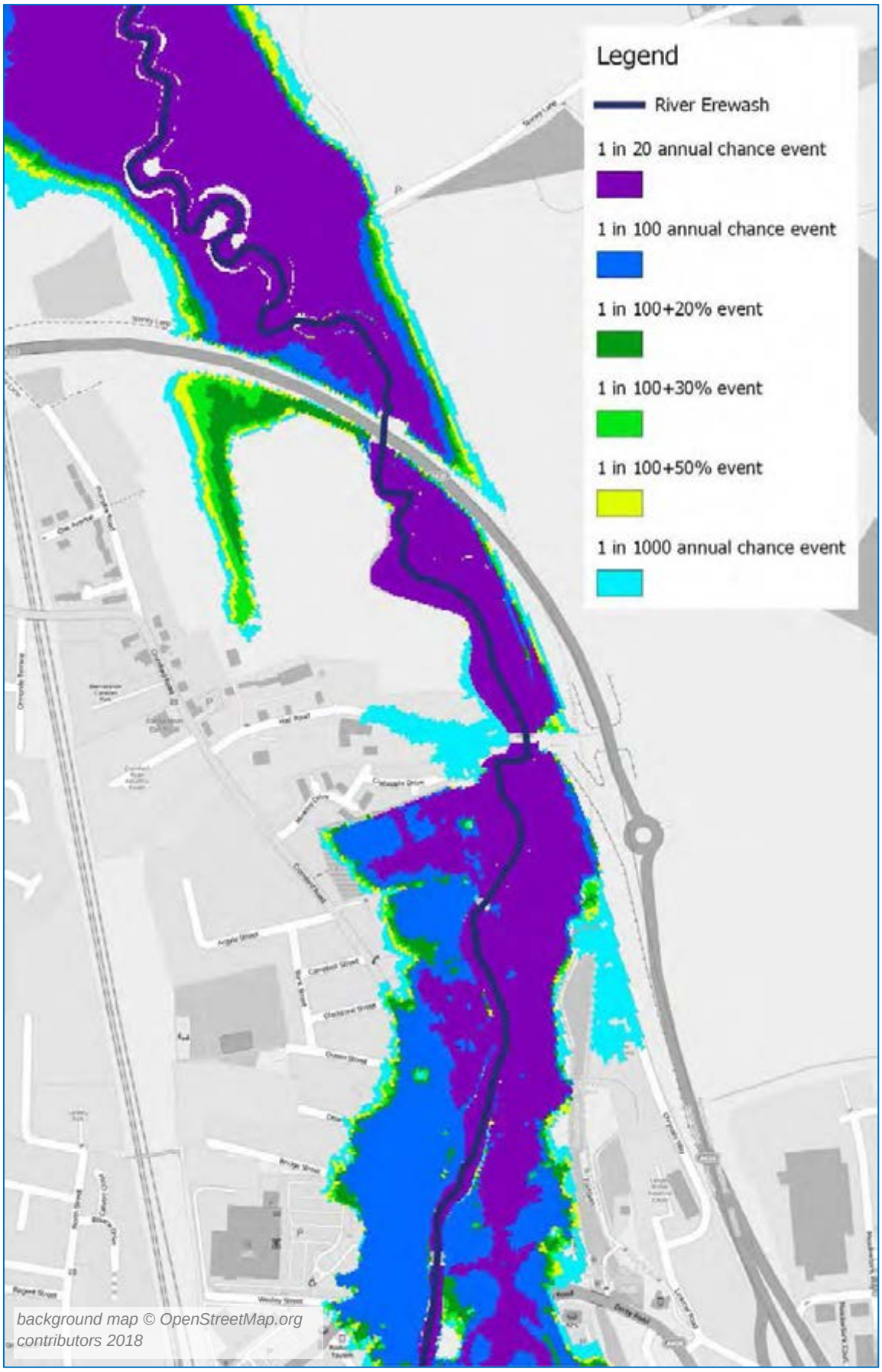


Figure A1: Existing flood extents.

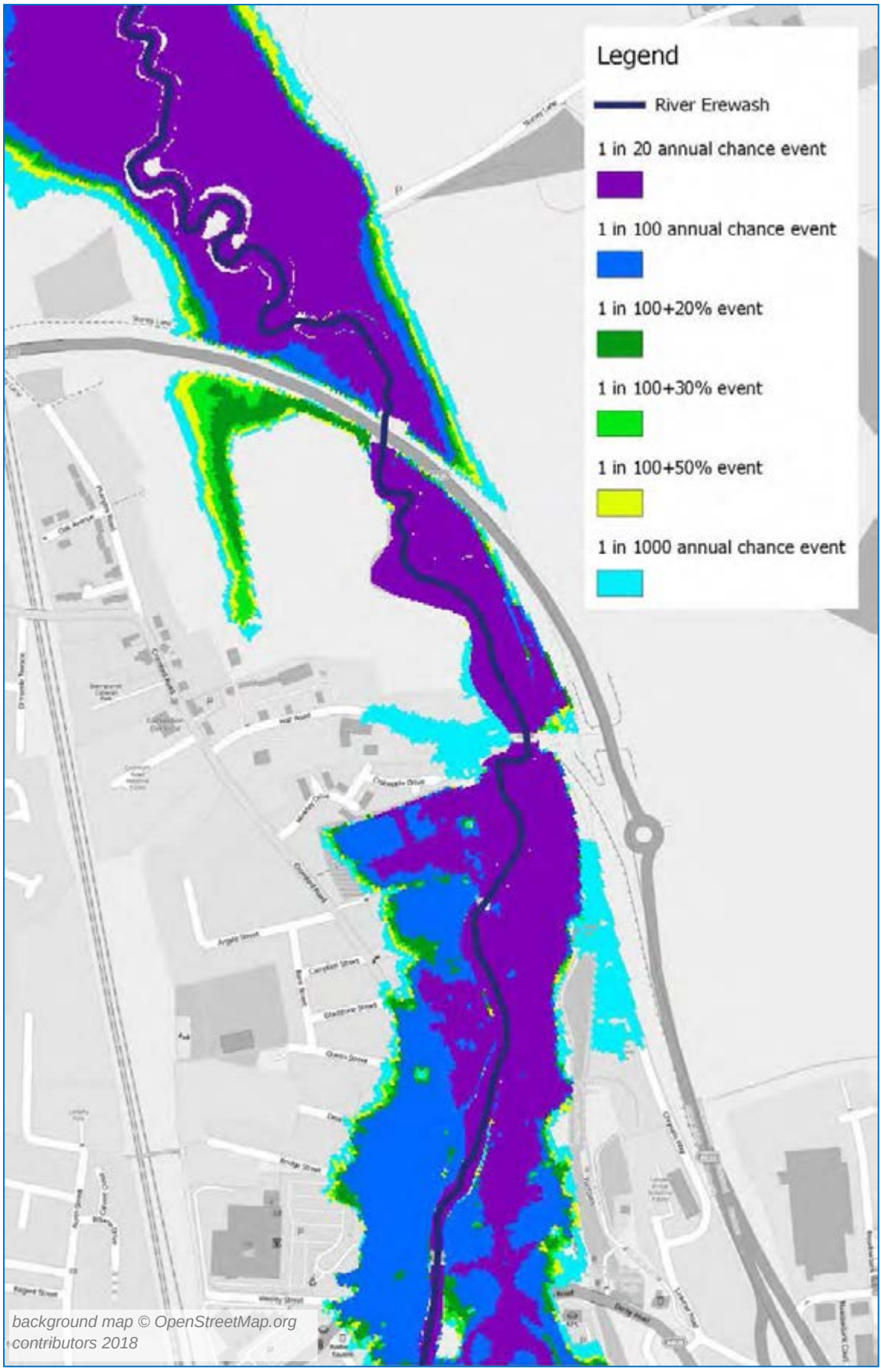


Figure A2: With scheme flood extents

Appendix B: Sensitivity Test: Downstream Boundary

Sensitivity Test: Downstream Boundary

The downstream boundary for the model was extracted as a stage hydrograph from the original Environment Agency model. The 1 in 100 +20% stage hydrograph was used as the downstream boundary for all climate change scenarios. This is a limitation when considering the higher central and upper end scenarios and as such water levels at the lowest end of the model should be treated with caution. Sensitivity testing was undertaken at the 1 in 100 + 50% event (upper end scenario), by raising the downstream boundary stage hydrograph to the 1 in 1000 year event, which exceeds the 1in 100+50% event in terms of flow. The backwater effect of this change to the downstream boundary diminished to zero well downstream of the site.

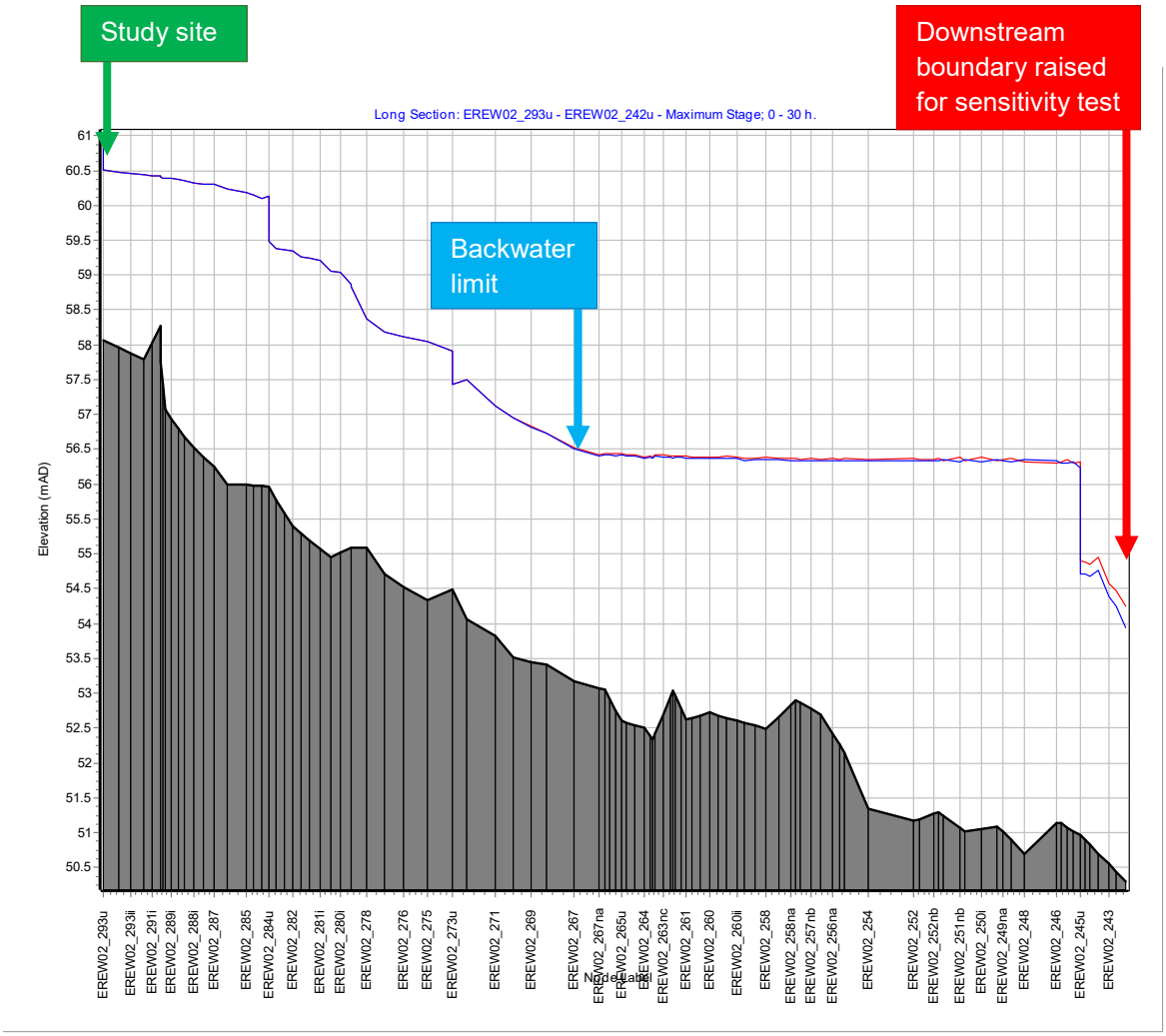
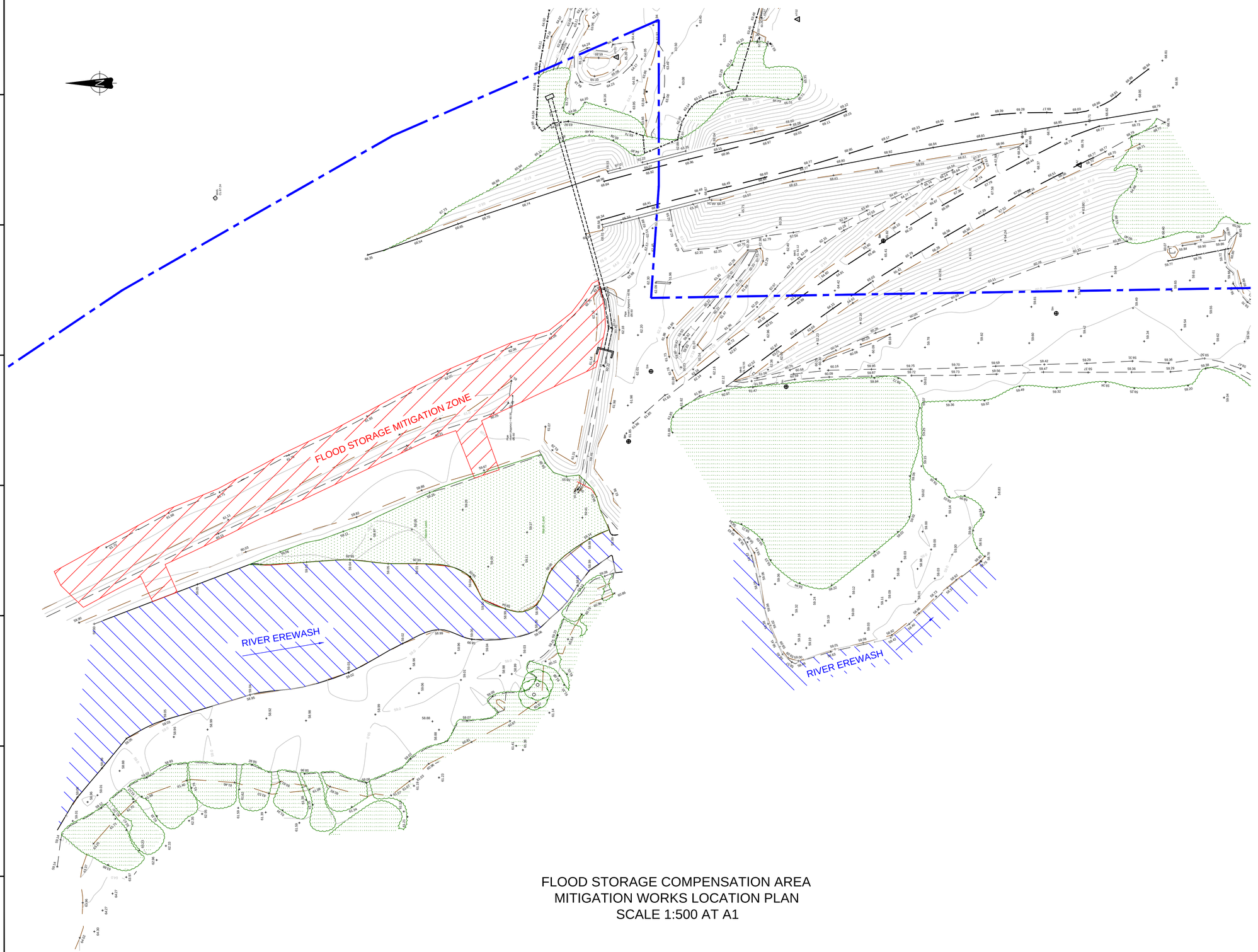


Figure B1: Long section: downstream boundary test. *Water surface from raised boundary condition shown as a red line, original water surface in blue.*

The peak water level at the downstream boundary is also raised approximately 300mm above the corresponding water level in the original Environment Agency model. This is because no location could be found where the flow remains purely within the 1d domain during high magnitude events, so floodplain conveyance has been limited by truncation of the active 2d model grid. This could be remedied by the addition of 2d outflow boundaries or through relocation of the boundary further downstream, but this would not have any bearing on the analysis of flood risk at the site of the canal extension because it is already well beyond the backwater limit of any reasonable downstream boundary. Water levels at the lower limit of the model should, however, be treated with caution as they are likely to be overestimated and there is some model instability at the lower limit of the model (which does not influence water level at the study site)

Appendix C: Compensatory Flood Storage



FLOOD STORAGE COMPENSATION AREA
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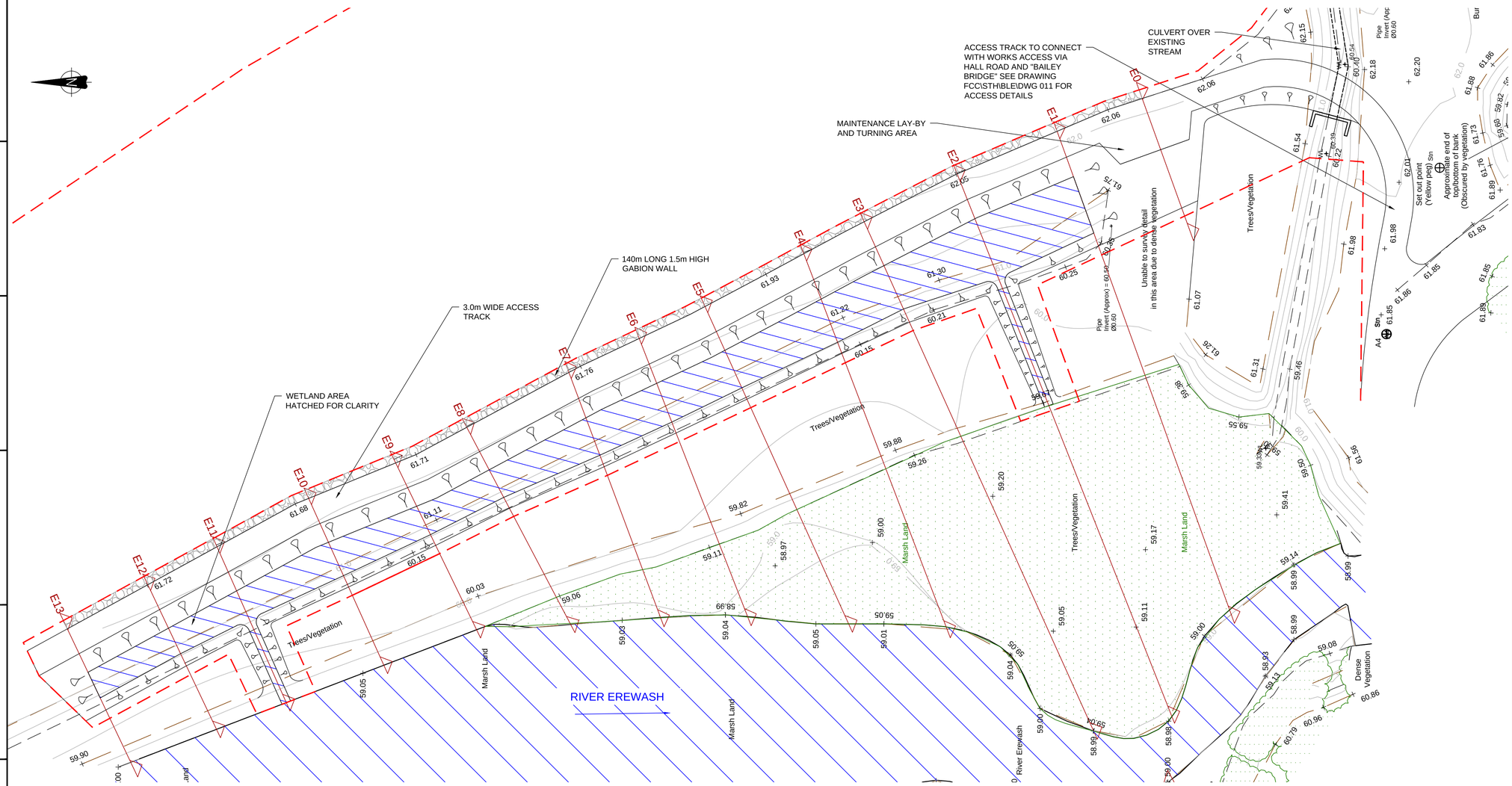

MITIGATION WORKS PLAN
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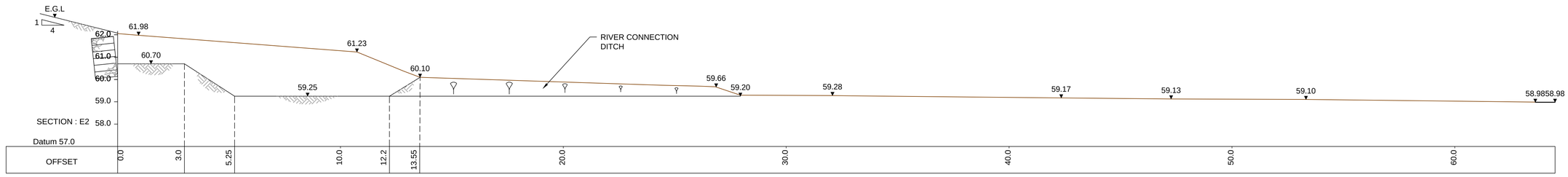

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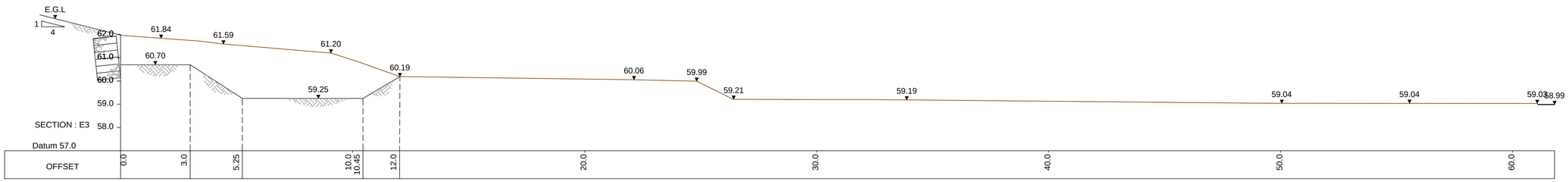

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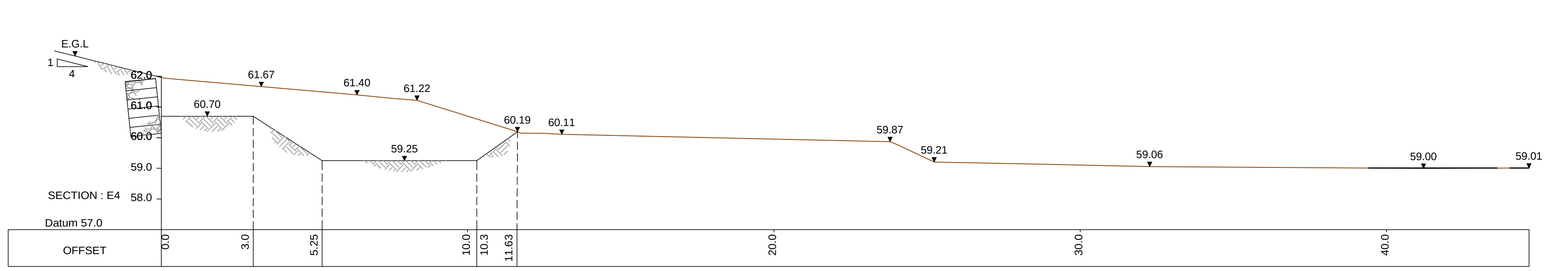

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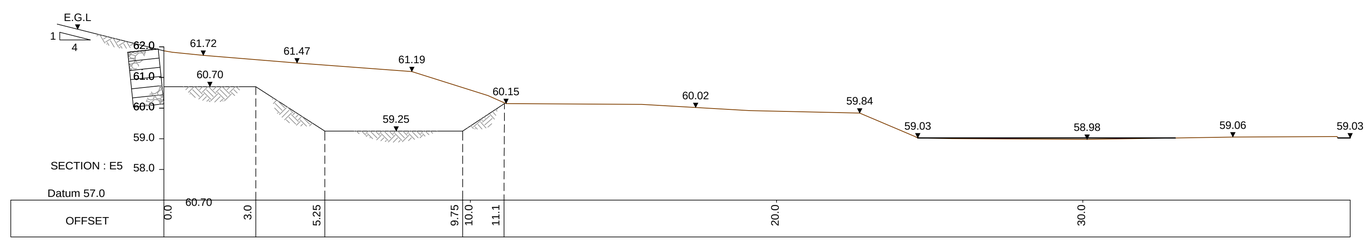

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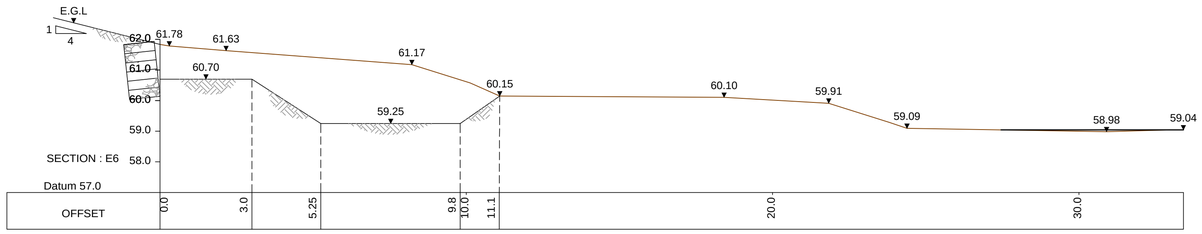

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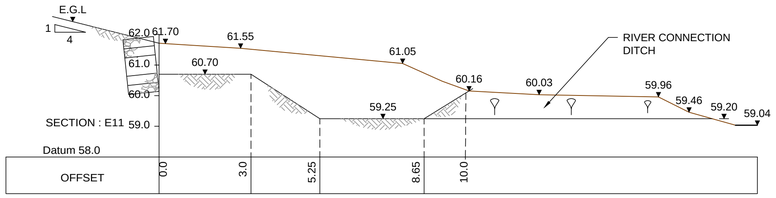

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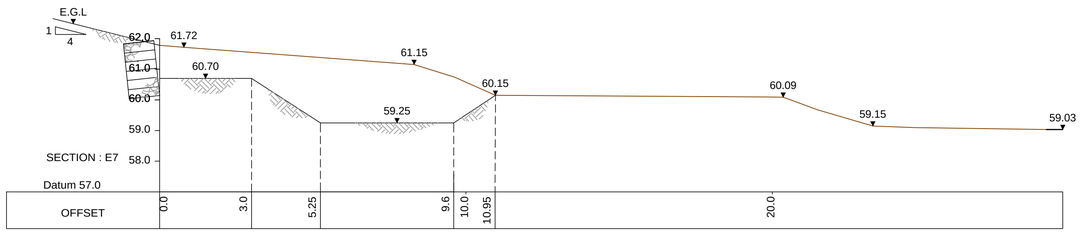

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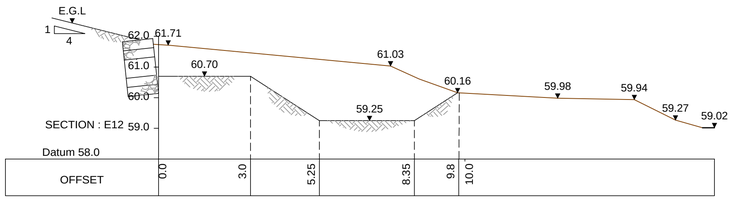

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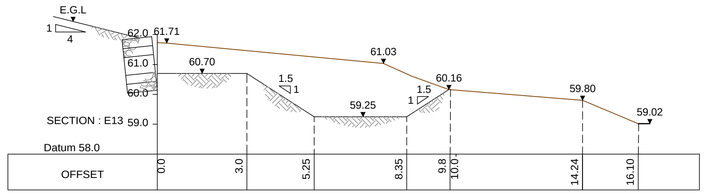

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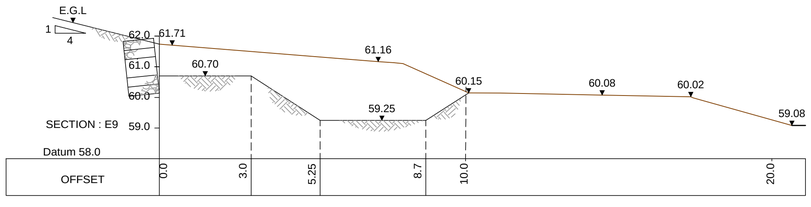

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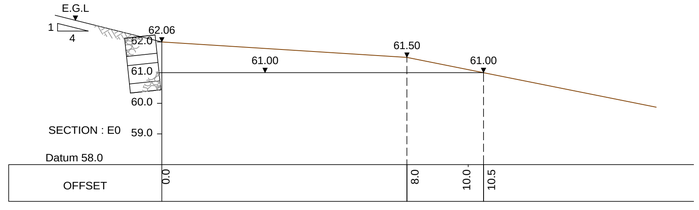

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APPENDIX E

Storage Compensation Volume Calculations

Cromford Canal Flood Risk Assessment Flood Compensation Scheme

Storage Volume Assessment

							Elevs. above the 1 in 100 yr + 50% events			Cumulative. Vol. (m3)	Notes
Band Elev (mAOD)	59.25 - 59.54	59.54 - 59.84	59.84 - 60.14	60.14 - 60.43	60.43 - 60.73	60.73 - 61.03	61.03 - 61.32	61.32 - 61.62	61.62 - 61.92		
Band Depth (m)	0.29	0.3	0.3	0.29	0.3	0.3	0.29	0.3	0.3		
Cross Section*:-											
E0 av. band width (m)	0	0	0	0	0	10	9.5	8.3	4.5		
E0 area (m2)	0	0	0	0	0	0.3	2.76	2.49	1.35		
E1 av. band width (m)	6.77	8	8.77	9.65	9.35	11.45	10.45	9.4	7.2		
E1 area (m2)	1.96	2.4	2.63	2.8	2.8	3.44	3.03	2.82	3.84		
E0-E1 vol. (m3)	**0**	**0**	**0**	**0**	**0**	**3**	**28.95**	**26.55**	**25.95**	**84.45**	
E2 av. band width (m)	7.17	8.6	9.17	9.4	9.2	11.5	10.9	7.8	3.7		
E2 area (m2)	2.08	2.58	2.75	2.73	2.76	3.45	3.27	2.34	1.11		
E1-E2 vol. (m3)	**20.2**	**24.9**	**26.9**	**27.65**	**27.8**	**34.45**	**31.5**	**25.8**	**24.75**	**243.95**	
E3 av. band width (m)	5.42	6.5	7.42	8.2	7.8	10	9.15	5.9	2.5		
E3 area (m2)	1.57	1.95	2.23	2.38	2.34	3	2.65	1.77	0.75		
E2-E3 vol. (m3)	**18.25**	**22.65**	**24.9**	**25.55**	**25.5**	**32.25**	**29.6**	**20.55**	**9.3**	**208.55**	
E4 av. band width (m)	5.27	6.5	7.27	7.65	7.25	9.4	8.45	5.7	2		
E4 area (m2)	1.53	1.95	2.18	2.22	2.18	2.82	2.45	1.71	0.6		
E3-E4 vol. (m3)	**15.5**	**19.5**	**22.05**	**23**	**22.6**	**29.1**	**25.5**	**17.4**	**6.75**	**181.40**	
E5 av. band width (m)	4.72	6	6.72	7.3	6.9	9.1	8.2	4.4	1.1		
E5 area (m2)	1.36	1.8	2.02	2.11	2.07	2.73	2.38	1.32	0.33		
E4-E5 vol. (m3)	**14.45**	**18.75**	**21**	**21.65**	**21.25**	**27.75**	**24.15**	**15.15**	**4.65**	**168.80**	
E6 av. band width (m)	4.77	6.1	6.77	7.2	6.95	9.15	8.2	4.4	0.4		
E6 area (m2)	1.38	1.83	2.03	2.09	2.09	2.75	2.38	1.32	0.12		
E5-E6 vol. (m3)	**13.7**	**18.15**	**20.25**	**21**	**20.8**	**27.4**	**23.8**	**13.2**	**2.25**	**160.55**	
E7 av. band width (m)	4.57	5.9	6.57	7	6.85	9.15	8.1	4.2	0.1		
E7 area (m2)	1.32	1.77	1.97	2.03	2.06	2.75	2.35	1.26	0.03		
E6-E7 vol. (m3)	**13.5**	**18**	**20**	**20.6**	**20.75**	**27.5**	**23.65**	**12.9**	**0.75**	**157.65**	
E8 av. band width (m)	3.66	4.75	5.62	6.2	5.9	8.35	7.1	3.3	0		
E8 area (m2)	1.06	1.43	1.69	1.8	1.77	2.51	2.06	0.99	0		
E7-E8 vol. (m3)	**11.9**	**16**	**18.3**	**19.15**	**19.15**	**26.3**	**22.05**	**11.25**	**0.15**	**144.25**	
E9 av. band width (m)	3.67	4.77	5.77	6.2	5.95	8.4	6.9	3.4	0		
E9 area (m2)	1.06	1.43	1.73	1.8	1.79	2.52	2	1.02	0		
E8-E9 vol. (m3)	**10.6**	**14.3**	**17.1**	**18**	**17.8**	**25.15**	**20.3**	**10.05**	**0**	**133.30**	
E10 av. band width (m)	4.22	5.32	6.22	6.5	6.35	8.8	7.4	3.5	0		
E10 area (m2)	1.22	1.6	1.87	1.89	1.91	2.64	2.15	1.05	0		
E9-E10 vol. (m3)	**11.4**	**15.15**	**18.00**	**18.45**	**18.5**	**25.8**	**20.75**	**10.35**	**0**	**138.40**	
E11 av. band width (m)	3.62	4.72	5.62	6.1	5.8	8.25	6.65	3.6	0		
E11 area (m2)	1.05	1.42	1.69	1.77	1.74	2.48	1.92	1.08	0		
E10-E11 vol. (m3)	**11.35**	**15.1**	**17.8**	**18.30**	**18.25**	**25.60**	**20.35**	**10.65**	**0**	**137.40**	
E12 av. band width (m)	3.32	4.42	5.32	5.9	5.4	7.85	5.8	2.95	0		
E12 area (m2)	0.96	1.33	1.6	1.71	1.62	2.36	1.68	0.89	0		
E11-E12 vol. (m3)	**10.05**	**13.75**	**16.45**	**17.4**	**16.8**	**24.2**	**18**	**9.85**	**0**	**126.50**	
E13 av. band width (m)	3	3.8	4.7	4.8	4.4	6.8	5.8	1.7	0		
E13 area (m2)	0.87	1.14	1.41	1.39	1.32	2.04	1.68	0.51	0		
E12-E13 vol. (m3)	**9.15**	**12.35**	**15.05**	**15.5**	**14.7**	**22**	**16.8**	**7**	**0**	**112.55**	
Band vol. (m3)	**160.05**	**208.60**	**237.80**	**246.25**	**243.90**	**330.50**	**305.40**	**190.70**	**74.55**	**1997.75**	
Plus:-											
north end vol. (m3)	**1**	**2**	**2**	**3**	**3**	**4**	**5**	**4**	**0**	**24**	
south end vol.(m3)	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**3**	**17**	**23**	
Gabion void vol. (m3)	**0**	**0**	**0**	**0**	**1**	**12**	**12**	**12**	**13**	**50**	Based on 30% voids
Total band vol. (m3)	**161**	**211**	**240**	**249**	**248**	**347**	**325**	**210**	**105**	**2096**	
Flood Storage Lost (m3)	**0**	**21**	**109**	**207**	**294**	**339**	**323**	**158**	**148**	**1599**	Determined from modelling
Storage +gain/-loss (m3)	**161**	**190**	**131**	**42**	**-46**	**8**	**2**	**52**	**-43**	**497**	Overall gain in storage volume**

* Compensation Scheme Cross Sections E0 to E13 are shown on Scheme drgs no.s DWG 302 - 304 in Appendix A

** Overall gain in storage volume up to the 1 in 100yr + 50% flood level (61.03mAOD) is 486m3