Barnhill Strategic Flood Risk Assessment

February 2019

Appendix 3

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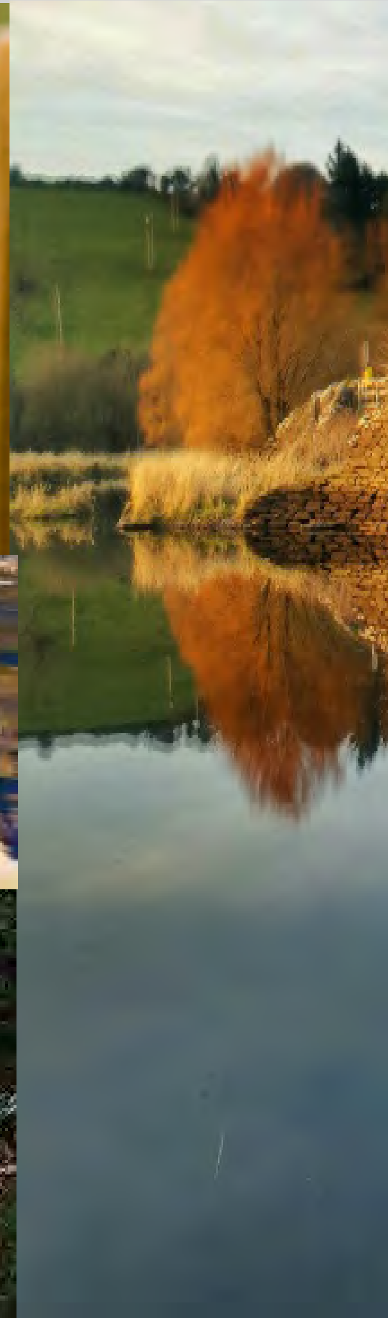
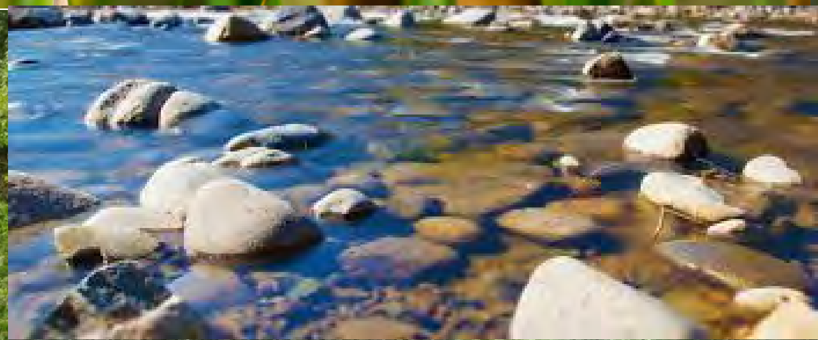





CONTENT

Barnhill Strategic Flood Risk Assessment

EXECUTIVE SUMMARY

Background

- The flood modelling shows that there are large areas of low-lying lands located to the north and south of the existing stream that are liable to flooding.
- The flooding is largely caused by the limited capacity of the culvert under the canal and railway.
- The highest predicted flood depths in the 100 year RP event are bewteen 0.9 and 1m, including an allowance for climate change.
- The highest predicted flood depths in the 1000 year RP event are between 1.1 and 1.3m, including an allowance for climate change.

Flood Zoning

The Flood Risk Mapping in Appendix A should be used to determine the appropriate zoning for the site in accordance with the Flood Risk Management Guidelines:

- Areas within the 1000 year RP flood plain can be considered in Flood Zone B.
- Areas within the 100 year RP flood plain can be considered in Flood Zone A.

Proposed Road Scheme

Analysis was undertaken of the proposed road scheme to determine the effect on the flood plain. The analysis indicates that the road embankment will displace some flood water during events in eccess of the 1 in 25 year return period. It is suggested that compensatory storage be provided for and possible areas where such storage could be provided have been indicated in the report

Key Recommendations

- Planning zoning within the LAP should reflect the flood mapping presented in this report and the flood zoning recommendations set out in the Flood Risk Management Guidelines.
- Ongoing maintenance of the stream and culverts is required to mimimise flood risk.
- Any planning applications in the study area should include a detailed justification test in accordance with the Flood Risk Management Guidelines.

SECTION 1

Introduction

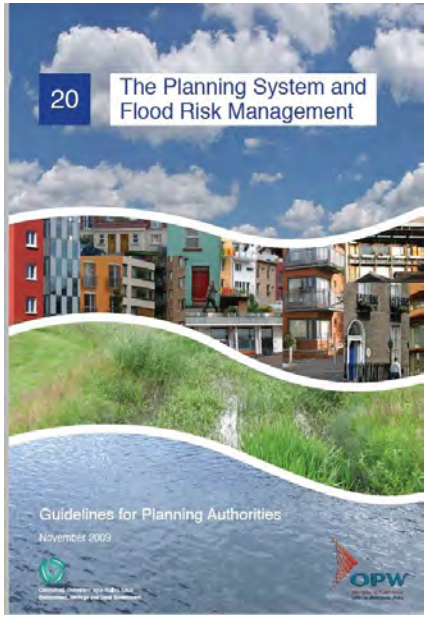
1. INTRODUCTION

1.1 Background

Fingal County Council has prepared a Local Area Plan (LAP) for Barnhill (lands south of the Dublin-Dunboyne Rail Line) in order to provide a statutory framework for the proper planning and sustainable development of a tract of 45.64 hectares of undeveloped land zoned Objective 'RA' Residential Area with the objective to– 'Provide for new residential communities in accordance with approved local area plans and subject to the provision of the necessary social and physical infrastructure.'

The Fingal Development Plan 2017-2023 includes important quality of life initiatives such as the Green Infrastructure Strategy and an emphasis on high quality design. The Barnhill LAP will enable these principles to be included with a strong emphasis on quality of life aspects such as neighbourhoods that support thriving communities, recreational spaces, new linkages and biodiversity. The LAP development is guided by a wide range of considerations, such as public and stakeholders consultation, key issues and needs identified by local communities and business, employment activities and opportunities, services and infrastructure, heritage and environmental issues, statutory requirements, flood risk assessment, sustainable urban development etc.

This Strategic Flood Risk Assessment (SFRA) of the Barnhill Area has therefore been undertaken by Fingal County Council to ensure that flood risk identification, assessment and management are incorporated into the Barnhill LAP. This SFRA has been undertaken in accordance with the national policy document on flood risk entitled "The Planning System and Flood Risk Management –Guidelines for Planning Authorities (OPW/DoEHLG, 2009)" and Circular PL02/2014 (August 2014) which sets out how to implement good planning practice in the management of flood risk.



1.2 Objectives of the SFRA

"The Planning System and Flood Risk Management Guidelines" published in 2009 (hereafter referred to as FRM Guidelines), sets out the core principles of adopting a risk based sequential approach to managing flood risk. Planning authorities are directed to have regard to the Guidelines in the preparation of Development Plans and Local Area Plans. The objective is to integrate flood risk management into the planning process, thereby assisting in the delivery of sustainable development. Paragraph 1.6 of the Guidelines states that the core objectives are to:

- avoid inappropriate development in areas at risk of flooding;
- avoid new developments increasing flood risk elsewhere, including that which may arise from surface run-off;
- ensure effective management of residual risks for development permitted in floodplains;
- avoid unnecessary restriction of national, regional or local economic and social growth;
- improve the understanding of flood risk among relevant stakeholders; and
- ensure that the requirements of EU and national law in relation to the natural environment and national law in relation to the natural environment and nature conservation are complied with at all stages of flood risk management".

The guidelines recommend a hierarchy of regional, strategic and site-specific flood-risk assessments in, a tiered approach to flood risk management. This ensures that the level of information is appropriate to the scale and nature of the flood-risk issues and the location and type of development proposed. The stages and scales of flood risk assessment comprise:

- Regional Flood Risk Appraisal (RFRA) – a broad overview of flood risk issues across a region to influence spatial allocations for growth in housing and employment as well as to identify where flood risk management measures may be required at a regional level to support proposed growth.
- Strategic Flood Risk Assessment (SFRA) – an assessment of all types of flood risk informing land use planning decisions to enable the Planning Authority to allocate appropriate sites for development, whilst identifying opportunities for reducing flood risk.
- Site Specific Flood Risk Assessment (FRA) – site or project specific flood risk assessment to consider all types of flood risk associated with the site and propose appropriate site management and mitigation measures to reduce flood risk to and from the site to an acceptable level.

With the above objectives in mind, the key aim of this Barnhill SFRA was therefore to:

- Produce Flood Risk Mapping and Flood Zoning Mapping for the Barnhill LAP (Study Area);
- Prepare recommendations in relation to the location and type of zoning and land-use proposals which are appropriate to the study area;
- Prepare recommendations on the need for further detailed site specific Flood Risk Assessments or Justification Testing that may be required if development is to proceed;
- Assess and report on any submissions received as part of the public consultation process.

SECTION 2

Flood Risk Management Guidelines

2. FLOOD RISK MANAGEMENT GUIDELINES

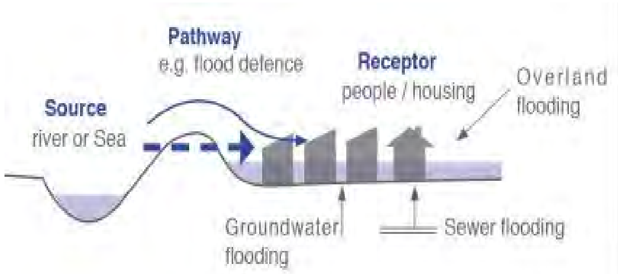
2.1 Definition of Flood Risk

Flood risk is generally accepted to be a combination of the likelihood (or probability) of flooding and the potential consequences arising. Flood risk can be expressed in terms of the following relationship:

Flood Risk = Probability of Flooding x Consequences of Flooding

The assessment of flood risk requires an understanding of the sources, the flow path of floodwater and the people and property that can be affected. The source - pathway - receptor model, shown below in Figure 2.1, illustrates this and is a widely used environmental model to assess and inform the management of risk.

Figure 2.1 Source Pathway Receptor Model



2.1.1 Likelihood of Flooding

Likelihood or probability of flooding of a particular flood event is classified by its annual exceedance probability (AEP) or return period (in years). A 1% AEP flood indicates the flood event that will occur or be exceeded on average once every 100 years and has a 1 in 100 chance of occurring in any given year.

Return period is often misunderstood to be the period between large flood events rather than an average recurrence interval. Annual exceedance probability is the inverse of return period as shown in Table 2.1.

Table 2.1 Probability of Flooding

Return Period (Years)	Annual Exceedance Possibility (%)
2	50
100	1
200	0.5
1000	0.1

Considered over the lifetime of development, an apparently low-frequency or rare flood has a significant probability of occurring. For example:

- A 1% flood has a 22% (1 in 5) chance of occurring at least once in a 25-year period - the period of a typical residential mortgage;

- And a 53% (1 in 2) chance of occurring in a 75-year period - a typical human lifetime.

2.1.2 Consequences of Flooding

Consequences of flooding depend on the hazards caused by flooding (depth of water, speed of flow, rate of onset, duration, wave-action effects, water quality) and the vulnerability of receptors (type of development, nature, e.g. age-structure, of the population, presence and reliability of mitigation measures etc.).

Figure 2.2 Flood Zones
(Flood Risk Management Guidelines)

2.2 Flood Zoning Descriptions

In the "The Planning System and Flood Risk Management Guidelines" the core principle is to adopt a risk based sequential approach to managing flood risk. This Sequential Approach is illustrated in Figure 2.3. The sequential approach is applied on the basis of the identification of flood zones as shown in Figure 2.2;

Flood Zone A
- Lands with a high probability of flooding;
- Subject to flooding in the 1 in 100 year return period storm event (1% AEP) – rivers;
- Subject to flooding in the 1 in 200 for year return period event (0.5% AEP) – coastal/ tidal areas.

Flood Zone B
- Lands with a moderate probability of flooding;
- Subject to flooding in the 1 in 1000 year return period storm event (0.1% AEP) – rivers;
- Subject to flooding in the 1 in 1000 for year return period event (0.1% AEP) – coastal/ tidal areas.

Flood Zone C
- Lands with a low probability of flooding;
- Subject to flooding only for events storm greater than the 1 in 1000 year return period (0.1%AEP).

It is important to note that the Flood Zones indicate flooding from fluvial and tidal sources and do not take other sources, such as groundwater or pluvial, into account, so an assessment of risk arising from such sources should also be made.

It is also important to note that the definition of the Flood Zones is based on an undefended scenario and does not consider the presence of flood protection structures such as flood walls or embankments. This is to allow for the fact that there is a residual risk of flooding behind the defences due to overtopping or breach and that there may be no guarantee that the defences will be maintained in perpetuity.

Figure 2.3 Sequential Approach to Flood Risk Management

Table 3.3 of the Planning System and Flood Risk Management Guidelines gives a detailed classification of vulnerability of different types of development. These are detailed in Table 3.1 of the Guidelines, and are summarised as:

- Highly vulnerable; includes residential properties, essential infrastructure and emergency service facilities;
- Less vulnerable; includes retail and commercial uses and local transport infrastructure;
- Water compatible; includes open space, outdoor recreation and associated essential infrastructure.

Based on these classifications the matrix of vulnerability in Table 3.3 indicates when development is appropriate in a Flood Zone and when a "Justification Test" should be applied.

Table 3.3 Matrix of Vulnerability versus Flood Zone

	Flood Zone A	Flood Zone B	Flood Zone C
Highly vulnerable development (including essential infrastructure)	Justification Test	Justification Test	Appropriate
Less vulnerable development	Justification Test	Appropriate	Appropriate
Water-compatible development	Appropriate	Appropriate	Appropriate

The Justification Test is designed to rigorously asses the appropriateness, or otherwise, of developments in Flood Zone A and B. The test is comprised of two processes; the Plan-making Justification Test, and the Development Management Justification Test. The first part of the jusiticiation is underaken as part of the SFRA process. The latter is undertaken as part of the Site Specific FRA at planning application stage where it is intended to develop land that is at moderate or high risk of flooding.

SECTION 3

Barnhill Flood Risk Assessment

3. BARNHILL FLOOD RISK ASSESSMENT

3.1 Introduction

The Barnhill LAP site is located circa 3km from Blanchardstown Town Centre, 4.1km from Blanchardstown Main Street and 12.4 km from O'Connell Street, Dublin. It is situated directly south of Hansfield Rail Station and the Dunboyne to Clonsilla Rail Line, and, west of the Royal Canal and the Dublin-Maynooth Railway Line, and, east of the R149. The lands are flat, in agricultural use and characterised by field boundaries comprised of hedging and native tree species. The site location is shown in Figure 3.1 below.

Figure 3.1 Site Location

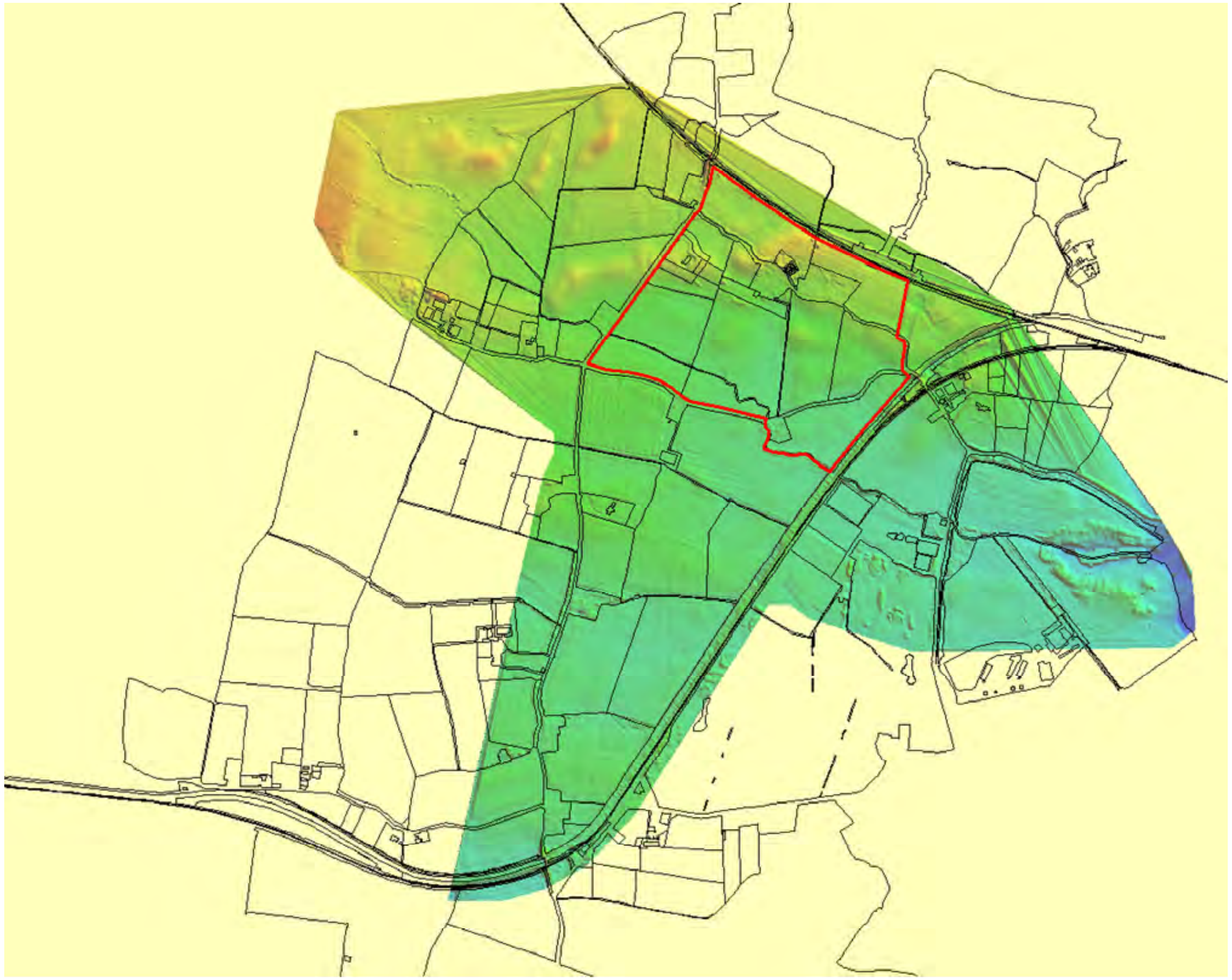


Figure 3.2 Site Boundary

3.2 Site Descrpition

The plan area of the subject site is approximately 45.64ha (hectares).

The site is bordered to the north by a railway line, to the west by a local access road, to the south by a local access road and open fields, and to the east by Royal Canal and a railway line beyond, Figure 3.2.

The site largely consists of arable land with a farm located within the northern part and a cottage within the south.

An unnamed stream (referred to as Barnhill Stream in this report for ease of reference) enters the site from the west under a local access road, runs in an open channel in a south-easterly direction through the site before entering a long culvert under Royal Canal and railway at the eastern boundary of the site. Downstream of the railway, the stream continues to flow in a south-easterly directions towards the River Liffey.

The unnamed stream enters the site from the west through three culverts; a 1.2m wide arch culvert and twin 600mm pipes located at a slightly higher level, Photo 3.3.1. The open channel of the stream in this area is about 3m wide and 2m deep. The stream enters a 1.2m diameter culvert and then a 1.7m wide arch culvert under the local road close to the southern boundary of the site, Photo 3.3.2. Further downstream, it enters a long culvert under the canal and railway.

The size of the culvert is believed to be 1m in diameter.

It was not possible to access the inlet of the long culvert during site walkover, due to dense vegetation, Photo 3.3.3. However, the culvert inlet appeared to be submerged at the time of the visit, although flows in the stream were not particularly high. Downstream of the railway, the stream enters an arch culvert under local access road, Photo 3.3.4.

A topographical survey of the site and surrounding areas were provided to us for this study. A Digital Terrain Model (DTM) was produced from the data and the extent of coverage is shown in Figure 3.2. The data appear to give a reasonable representation of the existing ground profile and was considered suitable for the purposes of the current assessment. Level contours based on this are shown in Figure 3.3. Ground level within the site varies between 61m AOD in the north to 56m AOD in the south and 59m AOD in the north-east to 60m AOD in the south-west. There is an elevated area within the northern part of the site where ground levels rise to 63m AOD.

With the exception of the small northern edge of the site, surface water runoff from the site drains to the unnamed stream.

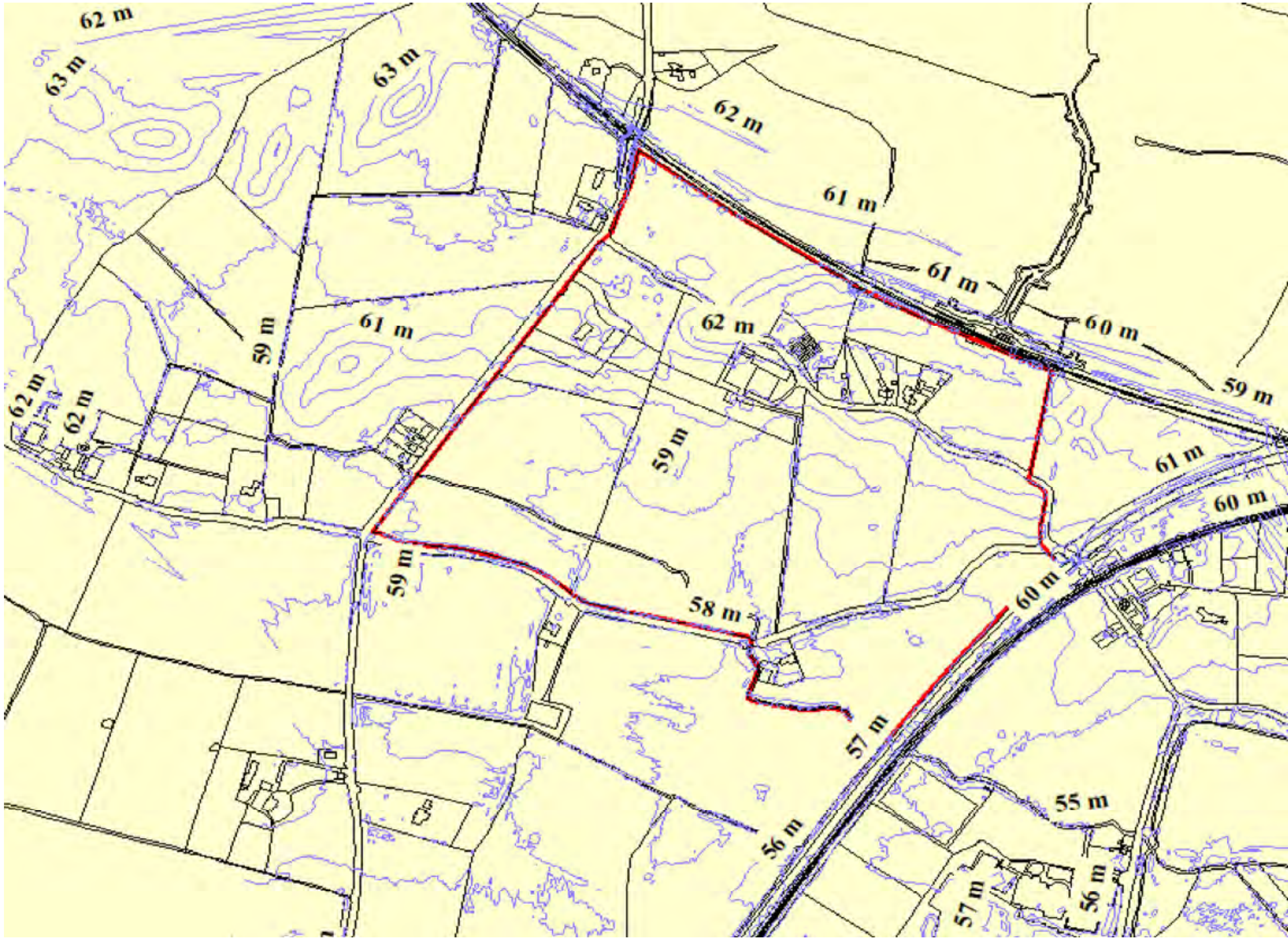


Figure 3.3 Topography based on topographic survey

Photo 3.3.1 Three culverts under road at western boundary

Photo 3.3.2 Arch culvert under local access road near southern boundary

Photo 3.3.3 Upstream of canal and railway culvert

Photo 3.3.4 Downstream culvert under canal and railway

3.3 Hydrological Analysis

A hydrological assessment was undertaken to estimate peak design flows for the watercourse that flows through the site. Design hydrographs were also estimated.

The standard flow estimation method employed is the Office of Public Works Flood Studies Update 3 variable (OPW FSU 3V) method. This is based on estimation of an index flood (QMED) using catchment descriptors and statistical pooling group analysis to estimate growth factor for a range of return periods. For ungauged catchments, the QMED value estimated using catchments descriptors can then be adjusted with a suitable gauged pivotal (donor) catchment, if applicable. However, it should be noted that this method has not been specifically designed for catchments of less than 25km² but, similar to the UK Flood Estimation Method statistical method, studies (FSU WP4.2, 2012) have shown the results to be better than the older methods commonly used, such as the Institute of Hydrology Small Catchment Method (IH124).

The alternative method for smaller catchments is the FSU 4.2a regression method (FSU WP4.2, 2012). This is an equation based on catchment descriptors that has been developed specifically for use in smaller catchments. This method has also been used as part of this assessment for comparison.

3.3.1 Estimation of Design Flows for Barnhill Stream

The catchment area for Barnhill Stream is approximately 5.85km² at the Royal Canal Way (downstream boundary of the site). The catchment area and descriptors were obtained from the OPW Rainfall and Flood Estimation application that is accessed via the FSU web portal. The catchment is shown in Figure 3.4 and the extracted catchment descriptors are shown in Table 3.1.

Table 3.1 Catchment Descriptions

Parameter	Value
Location Number	09_1660_6
Contributing Catchment A	5.848km²
BFISOIL	0.6621
SAAR	766.28 mm
FARL	1
DRAIND	1.187 km/km²
S1085	3.2408 m/km
ARTDRAIN2	0
URBEXT	0
Centroid distance	74.9115 km
coordinates	[-717277.0823, 7053859.8346]

Flows were estimated using the FSU V3 and FSU 4.2a methods. The results for the 100 year return period flood vary between 1.8m³/s and 3.14m³/s and are shown in Table 3.2.

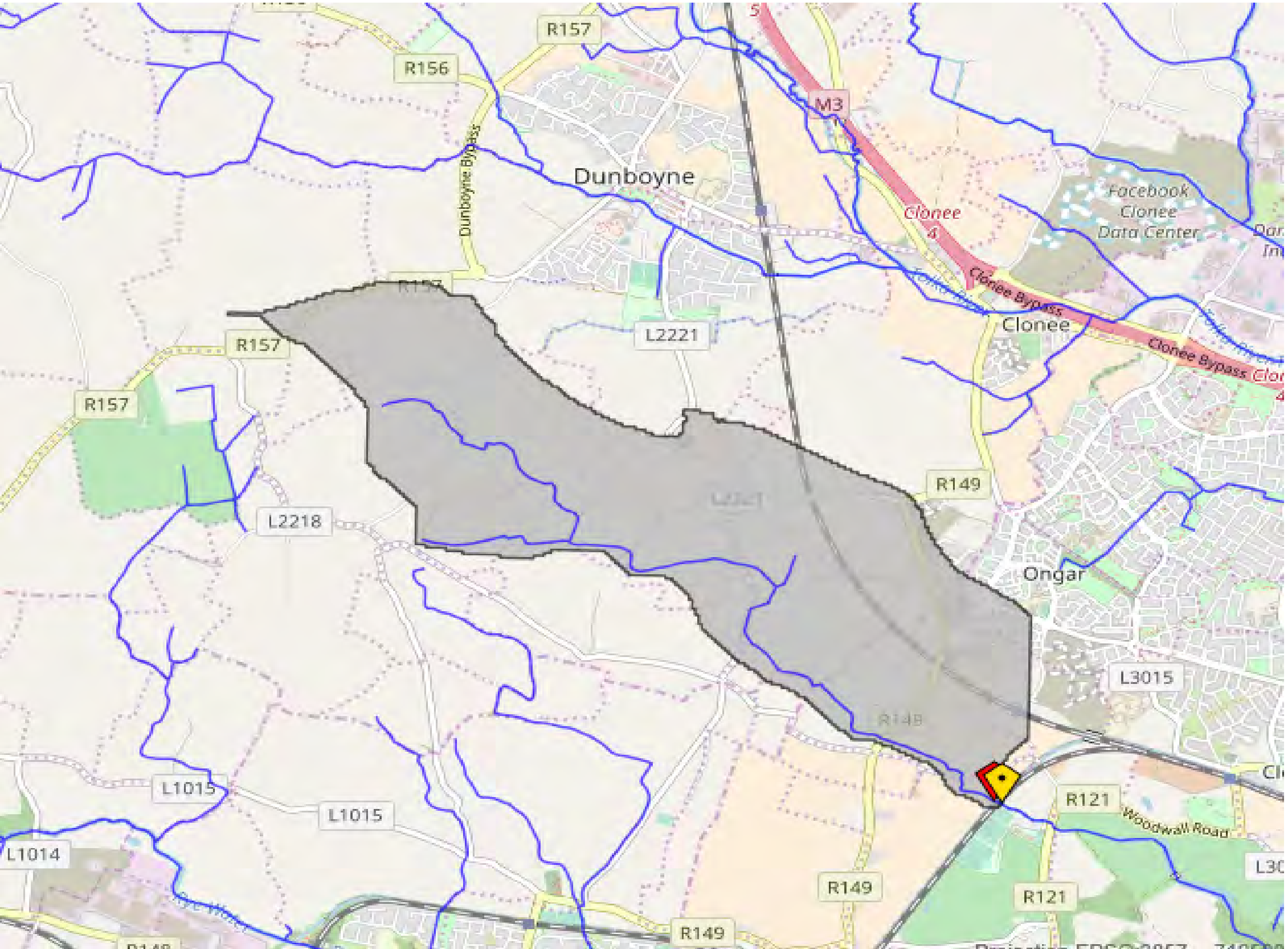


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Figure 3.4 Catchment area for Barnhill Stream

The FSU V3 method uses data from similar, gauged catchments to estimate design flows. Being based on observed, gauged data this method is generally considered more accurate than others, if used correctly.

First the QMED is estimated for the subject catchment. The QMED estimated using catchment descriptors was 0.73m^3/s. Adjusting the QMED based on a similar gauged catchment increased the QMED value by 30% to 0.95m^3/s. The QMED was adjusted using pivotal catchment 09001 Leixlip. This was the closest possible pivotal catchment geographically, although not necessarily hydrologically. The Slope, Urban and SAAR parameters were noted to be closer than other potential pivotal catchments. Moreover, a comparison was undertaken and using this pivotal catchment results in the highest adjusted QMED. As the QMED has a larger impact on the final estimated peak flow, the donor catchment that provided the highest QMED was thought to be the most appropriate.

A pooling group was devised using the online OPW FSU 3V website. A number of pooling groups were tested. The one that produced the highest growth factor was settled on. It was determined that deleting some of the less representative catchments resulted in a reduction in estimated growth factor. For this reason, these catchments were kept in to be conservative.

The software then calculates a number of growth curves including the GEV (Generalised Extreme Value), GLO (Generalised Logistic) and LN3 (Generalised Log Normal Distribution). The LN3 growth curve resulted in the most conservative 1 in 100 year flows, although the 1 in 1000 year estimation was slightly lower than the GLO estimation. The GLO estimation was used for the 1 in 1000 year flow.

For smaller catchments, the FSU 4.2a can be used to estimate the QMED from the catchment descriptors. Using this method, the QMED for the catchment was estimated as 0.53m^3/s. The same growth curves as those estimated using the FSU 3V method were then used to estimate peak flows. The LN3 growth curve resulted in the most conservative flows, in all but the 1 in 1000 year event. These estimates are shown in Table 3.2.

Table 3.2 Flood Flow Estimates for Barnhill Stream

Estimation Method	QMED (M^3/s)	1 in 100-year flow (m^3/s)	1 in 1000-year return period (m^3/s)
FSU 3V - QMED[1]	0.73	2.4	3.7
fsu 3v - Adjusted QMED[2]	**0.95**	**3.14**	**4.75**
FSU 4.2a QMED [3]	0.53	1.8	2.7

Flows estimated using the LN3 growth curve (Except the 1000, estimated using the GLO curve) which was the most conservative of those estimated. Notes:

1. QMED estimated from catchment descriptors
2. QMED estimated from catchment descriptors and adjusted using a pivotal gauged catchment. See main text.
3. QMED estimated using the FSU 4.2a regression equation for small catchments of less than 25km².

The results show that using the FSU 3V adjusted QMED results in the highest estimated peak flows. These flows were used for the modelling undertaken in Section 3.4. Flows estimated for other return periods, using the FSU 3 V adjusted QMED method, are provided in Table 3.3.

Climate change estimates make an allowance for a 20% increase in flow in line with the Mid-Range future scenario as per Table 3.1 of the OPW Climate Change Sectoral Adaptation Plan Flood Risk Management 2015-2019.

Table 3.3 Design flows for Barnhill Stream – Other return periods

1 in 10-year flow (m^3/s)	1 in 25-year flow (m^3/s)	1 in 50-year flow (m^3/s)
1.86	2.36	2.74

3.3.1 Hydrologocal Anlysis

Hydrograph shapes used for the analysis are based upon those derived from gauged pivotal catchments. They are estimated using the relevant OPW Rainfall and Flood Estimation application that is accessed via the FSU web portal.

For Barnhill Stream, the hydrograph was derived using pivotal catchment 30020 BALLYHUNIS. This is the second closest catchment hydrologically (with respect to the hydrograph) and estimated one of the flashiest responses of all possible pivotal catchments. Smaller catchments tend to have flashier responses than the larger catchments that are gauged. The final design hydrograph adjusted using the pivotal catchment was very similar, although slightly shorter, than that estimated using catchment descriptors. The hydrograph is of an approximate 60 hour duration. The design hydrograph for the 1 in 100 year event is shown in Figure 3.5. The 1 in 1000 year flood hydrograph was extrapolated based on the same shape.

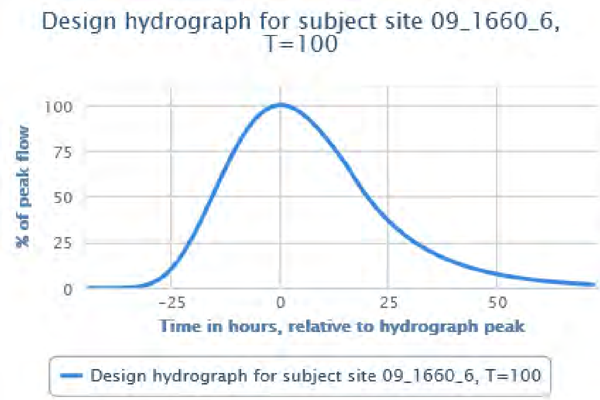


Figure 3.5 1 in 1000 year deisng hydrography at site

3.4 Mathematical Modelling

3.4.1 Barnhill Stream

The stream and associated floodplains were modelled using the Flood Modeller Pro software package. This is a standard river modelling package wide used for simulating water levels, flows and flood extent along river channels and floodplains. A one-dimensional (1D) model was developed of the main channel of the stream and this was linked to a two-dimensional (2D) model representing adjacent floodplains. The linked model allows flood waters freely to pass between the two model domains, depending on relative water levels. All structures (culverts/bridges) within the study area were represented in the 1D model.

3.4.2 1D Model Development

A 1D model of the Barnhill Stream was developed covering approximately 2km length of the stream, from a point some 500m upstream to a point some 700m downstream of the site, Figure 3.6.

A DTM (Digital Terrain Model) is available of this length of the stream. Channel cross sections from the DTM was extracted at 10m intervals. From these, 102 cross sections were selected to represent the main channel over the modelled reach. Cross section locations were selected to capture hydraulic characteristics of the stream. Final cross section spacing varied between 20m and 40m. Cross-sections were extracted perpendicular to the direction of the flow. Interpolated cross sections were not required.

There are four structures on the stream within the modelled reach; three road bridges/culverts and the canal and railway culvert. All four structures are included in the 1D model using dimensions and invert levels, etc. provided in the topographical survey provided supported by observations made during site walkover. Table 3.4 provides details of how the structures were represented in the model. Spill units were added at structures to direct overtopping flows back into the channel downstream. CUL1 through to CUL3 are three culverts that convey flows under a road just upstream of the site. CUL4 is a structure that lies within the site. This structure is a circular culvert upstream that discharges into a sprung arch. The site walkover suggests that these two structures may be separate with flows daylighting for a short distance. The structures were represented as a continuous structure to avoid stability issues and difficulties in representing the channel between the two structures, which was overgrown. It is unlikely that this would have a significant impact on model results.

The model uses a flow hydrography at the upstream boundary and a normal depth at the downstream boundary. The flow hydrograph is based on the shape shown in Figure 3.4, adjusted for peak flow to represent different return period flows. Initial model runs indicated that in order to achieve stable initial conditions, a minimum flow of the order of 0.8-0.9m^3/s is required. This flow stays well within the banks of the stream and can be conveyed through the long culvert under the canal/railway without significant surcharging. As the minimum design flow considered is at least twice of this, using such an initial flow does not affect the results of any of the design flow runs undertaken.

The downstream boundary gradient was set in line with the surveyed average bed slope in this part of the stream.

The locations of georeferenced channel cross-sections used in the 1D model are shown in Figure 3.6. The locations of the modelled structures are also shown on this figure.

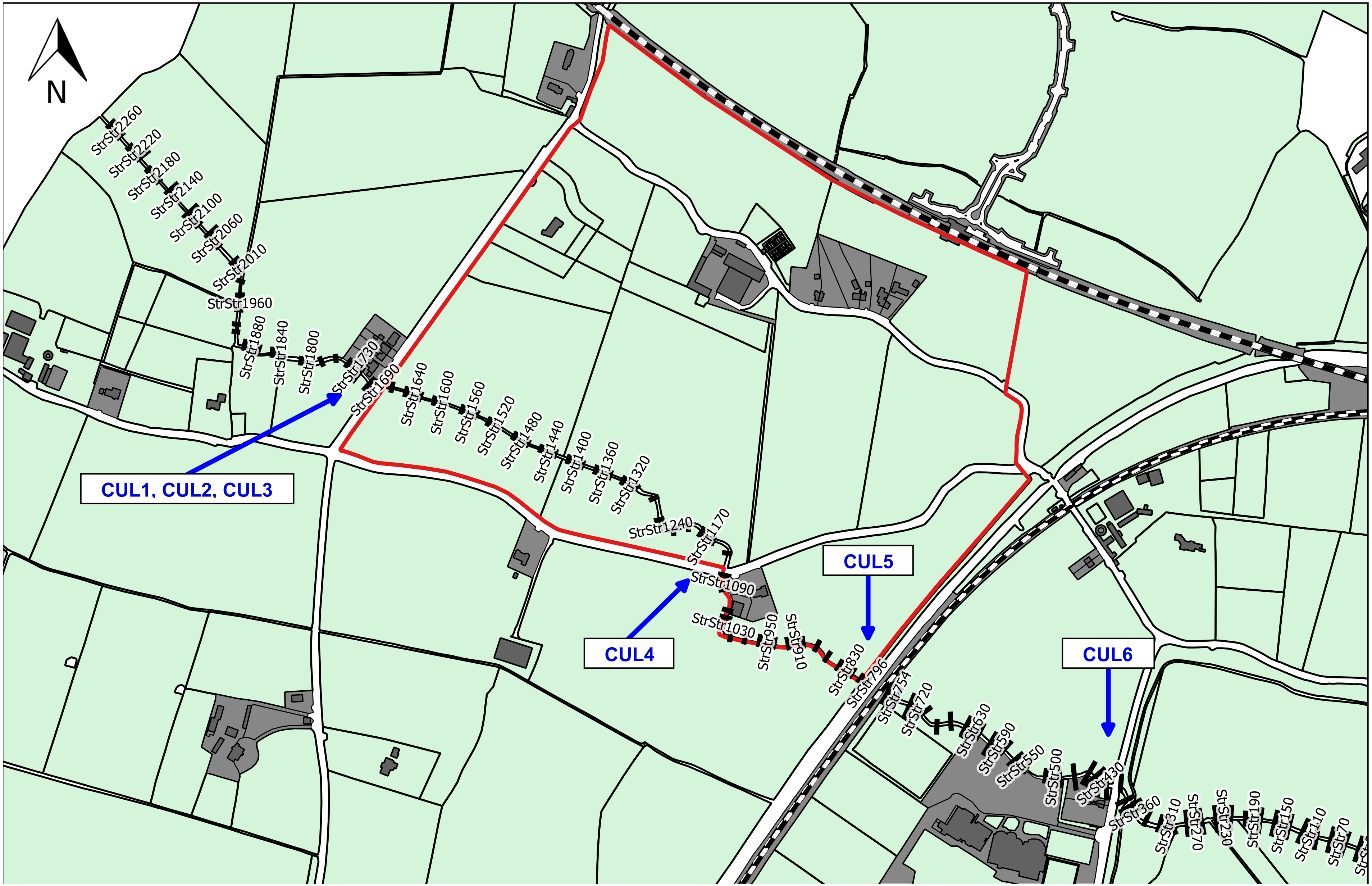


Figure 3.6 Extent of 1D model and locations of channel cross sections

Table 3.4 Culvert parameters used in the model

Structure	Culvert	#	Dimensions	Unit/ Method	Location
1	CUL1 CUL2	3	CUL1 = 1.2 x 1.2m CUL2 = 0.6m Ø CUL3 = 0.6m Ø	CUL1 = Rect. Conduit CUL2 = Circ. Conduit CUL3 = Circ. Conduit	Upstream of site
2	CUL4	1	Upstream = 1.2m Ø Downstream = 1.7 x 1.7m	Upstream=Circ. Conduit Downstream=Sprung arch	In site
3	CUL5	1	1m Ø	Circ. Conduit	Downstream boundary
4	CUL6	1	1.4 x 1.4m	Rect. Conduit	Downstream of site

The main parameters used in the model include:

Roughness (Manning's n):

- Values of 0.07 for the main channel, to represent a heavily-vegetated channel with some debris and stones in the bed.
- Values of 0.1, for the overbank areas of the channel to represent the heavy brush present along the river bank.
- Values of 0.02 for structures to represent a concrete/brick finish.

Roughness values were based on observations made during the site walkover and experience with similar sites.

The model was developed to run for a number of return periods including: 1 in 10-year, 1 in 25-year, 1 in 50-year, 1 in 100-year and 1 in 1000-year. The 1 in 100-year and 1 in 1000-year events were also run with an additional 20% allowance for climate change.

As part of the proposed development a new access road is proposed. This was represented in the 2D domain for the four most extreme flood events: 1 in 100-year, 1 in 1000-year, 1 in 100-year plus climate change and 1 in 1000-year plus climate change. Climate change was accounted for by increasing flows by 20%.

3.4.3 2D Model Development

All floodplains where flood waters would spill when the channel banks are overtopped are represented in 2D. These areas are represented as "Active Areas", for which calculations are carried out. The 2D model does not undertake any calculations for any areas outwith the specified Active Areas. In order to reduce model run times, Active Areas were shaped similar to the predicted flood extent, with the Active Area boundary being just outside the predicted maximum extent.

Each active area was represented with a regular grid, varying in size between 1m and 4m. Areas within the site were represented using 2m or 2.5m grid size, while areas further upstream were represented with a coarser grid.

A total of four domains (Active Areas) were developed to represent flows spilling out of the main channel of the watercourse. Two domains were represented to the north of the channel to receive flows from the left bank of the watercourse (looking downstream) with a further two represented to the south of the channel to intercept flows spilling over the right bank. Domains were named "North-West", "North-East", "South" and "West". These are shown in Figure 6. The "North-West" domain was run with a 1m grid size, the "North-East" domain with a 2m grid size, the "South" domain with a 2.5m grid size and the "West" domain with a 4m grid size.

The Manning's n roughness values for all domains were set at a global value of 0.05 to represent long grass.

The model was run using timestep of between 0.25 seconds and 0.5 seconds, depending on domain. Generally, the timestep was set approximately 4 times smaller than the grid size used.

Initial model runs indicated that for floods exceeding 1 in 100 year return period, flows could reach the high point to the south-west of the site on the north side of the canal flowing which ground levels drop to the south-west and west. Flood waters overtopping this area then follows the fall of the land and spreads to large areas to the south-west and west. The topography in this area is such that flood waters would flow beyond the boundaries of LiDAR data shown in Figure 3.2. An open flow boundary was introduced at the south-west corner of the south Active Area. A Normal Depth boundary was used at this location which allowed any flows reaching the boundary to leave the model domain, with no flows entering the site from the boundary. This as a standard approach used for free outflow boundaries. This approach does not affect the predictions within the site. However, flood maps presented in this report show no flooding outside of this boundary, and this should be interpreted as no information is given on flooding beyond the boundary.

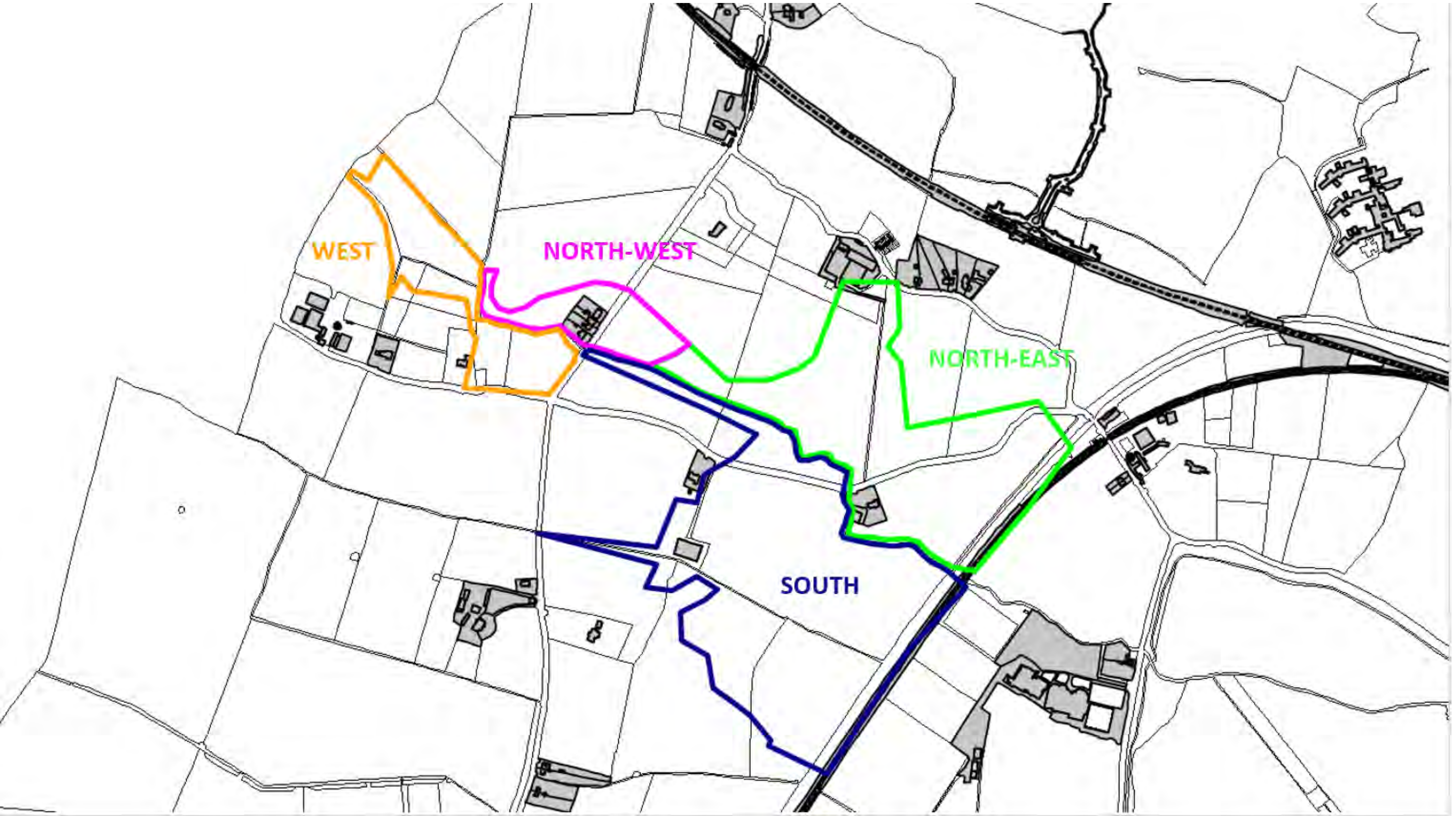


Figure 3.7 2D Model Domains

There is ditch running along the south side of the road running along the western boundary of the site. Close to the residential properties, the ditch is 2-3m wide and 1-1.5m deep. This ditch is represented in the model.

3.4.4 Model Results

The predicted flood extents for the modelled events are shown in the flood maps provided in Appendix A.

The results show that there are large areas of low-lying land located to the north and south of the watercourse that are liable to flooding. This is largely caused by the limited capacity of the 1m diameter long culvert under the canal and railway. This culvert can pass approximately 1.5m^3/s flow before flood waters start backing up and inundating the low-lying areas on both banks of the stream. Although, the peak flow passed through the culvert increases with the increased water level upstream of the culvert, most flows in excess of the culvert capacity are stored upstream of the canal. This inundates large parts of the site as shown on the flood maps provided in Appendix A.

Table 3.5 shows maximum estimated water depths on the fields to the south of the site (1), in the south-eastern site corner (2), and on the access road within the south-eastern part of the site (3). While the location of maximum depth varies the approximate location of each point is shown in Figure 3.8.

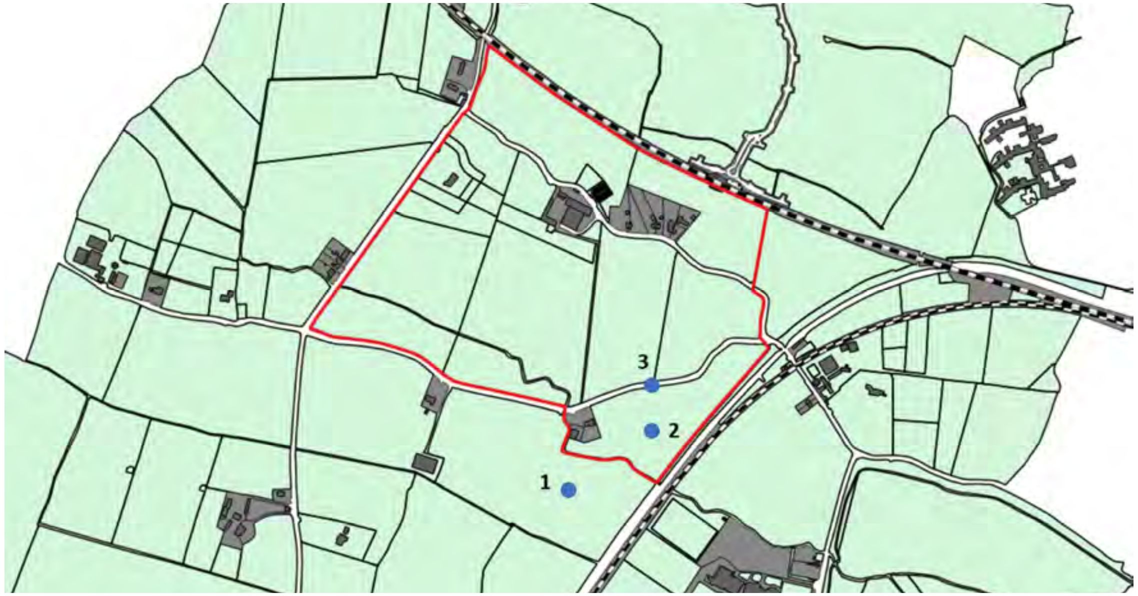
The predicted peak water levels at each cross section are provided in Appendix B. As would be expected, flood depths and water levels increase in line with the severity of the flood event.

Table 3.5 Predicated flood depths at points shown on Figure 3.8

Point	10-Year Flood Depth (m)	100-Year Flood Depth (m)	1000-Year Flood Depth (m)
1	0.35	1.1	1.3
2	.03	1	1.2
3	0	0.9	1.1

Model results indicate that for floods in excess of 1 in 100 year return period, flood waters overtop the left hand bank of the stream (looking downstream) just outside the western boundary of the site and flood existing residential properties and adjacent road. Flood waters then spill into the ditch which runs in a south-westerly direction along the south side of the road and discharges into the stream. The modelling undertaken has assume that the ditch is clear of vegetation and debris. Modelling shown that the ditch would likely be able to convey the flood waters spilling into it from the adjacent road for floods up to 1 in 1000 year return period. However, the ditch is heavily overgrown (Photo 3.9) and it is possible that such heavy vegetation would reduce its flow conveyance capacity and cause flood waters to overtop the southern bank. Any flows overtopping the south bank of the ditch would run in a south-east direction through the site.

Figure 3.8 Flood Depth Locations



It is suggested that the ditch is maintained to ensure it has the capacity to intercept any flows overtopping the adjacent road. The model results suggest a peak flow of approximately 1m^3/s could overtop the road into the ditch. The overtopping will need consideration during any development of the LAP lands.

Figure 3.9 Ditch running along western boundary looking north

3.5 Model Sensitivity

A model sensitivity analysis provides an illustration of the effect of changing key model parameters on the important model outputs (in this case flood levels, extents and depths). If model parameters are varied within the range of possible input values, then a sensitivity analysis can also provide an indication of uncertainty associated with the model predictions.

A sensitivity analysis was undertaken considering the following parameters;

- Manning's "n" values for the 2D domains increased from 0.05 to 0.07 (i.e., 40% increase). The main channel roughness value used for all simulations was 0.07, increasing to 0.1 at the top of banks. These were considered sufficiently high and no changes to these values were made.
- Culvert/bridge blockage; assumed to be 25% for all the culverts, except the one downstream of the site, as blocking this culvert would not affect water level predictions at site.

Both runs were carried out for the 1 in 1000 year flood.

Model runs for different flows already carried out show sensitivity to variation in flow.

Downstream boundary of the model was set sufficiently away from the site so that any reasonable changes to boundary conditions in this area would not affect the model predictions at site.

The impact of increasing the Manning's "n" values by 40% was predicted to be an increased up to 0.05m in peak water level at site, with the average being 0.002m. This does not cause any noticeable difference to flood extent shown in Appendix A for the 1000 year flood.

The impact of 25% culvert/bridge blockage causes water level at site to rise by 0.04m, rising to 0.1m further upstream. The resulting flood map is shown in Appendix A. This indicates that culvert blockage cause slightly larger flood extent.

3.6 Proposed Road Scheme

Model runs were carried out with the proposed road in place. A number of maps in Appendix A show model results for 100 and 1000 year without and with climate change. These indicate that the road embankment will displace some flood waters during events in excess of 1 in 25 years return period. The estimated displaced water volumes are shown in Table 3.6.

It is suggested that compensatory storage is provided for the displaced water so that the road scheme will have neutral effect or betterment on flooding risk to others. Possible areas where such compensatory storage could be provided are shown in Figure 3.9. Compensatory storage should replicate the present-day flood mechanism, i.e. should come into operation at 1 in 25 year flood level and continue to provide storage up to and including 1000 year flood level.

Table 3.6 Volume of water displaced due to proposed road

Area	Storage Volume Lost (m^3)	
	100 Year	1000 Year
North of Stream	936	1713
South of Stream	15	315

Figure 3.9 Possible locations where compensatory storage can be provided

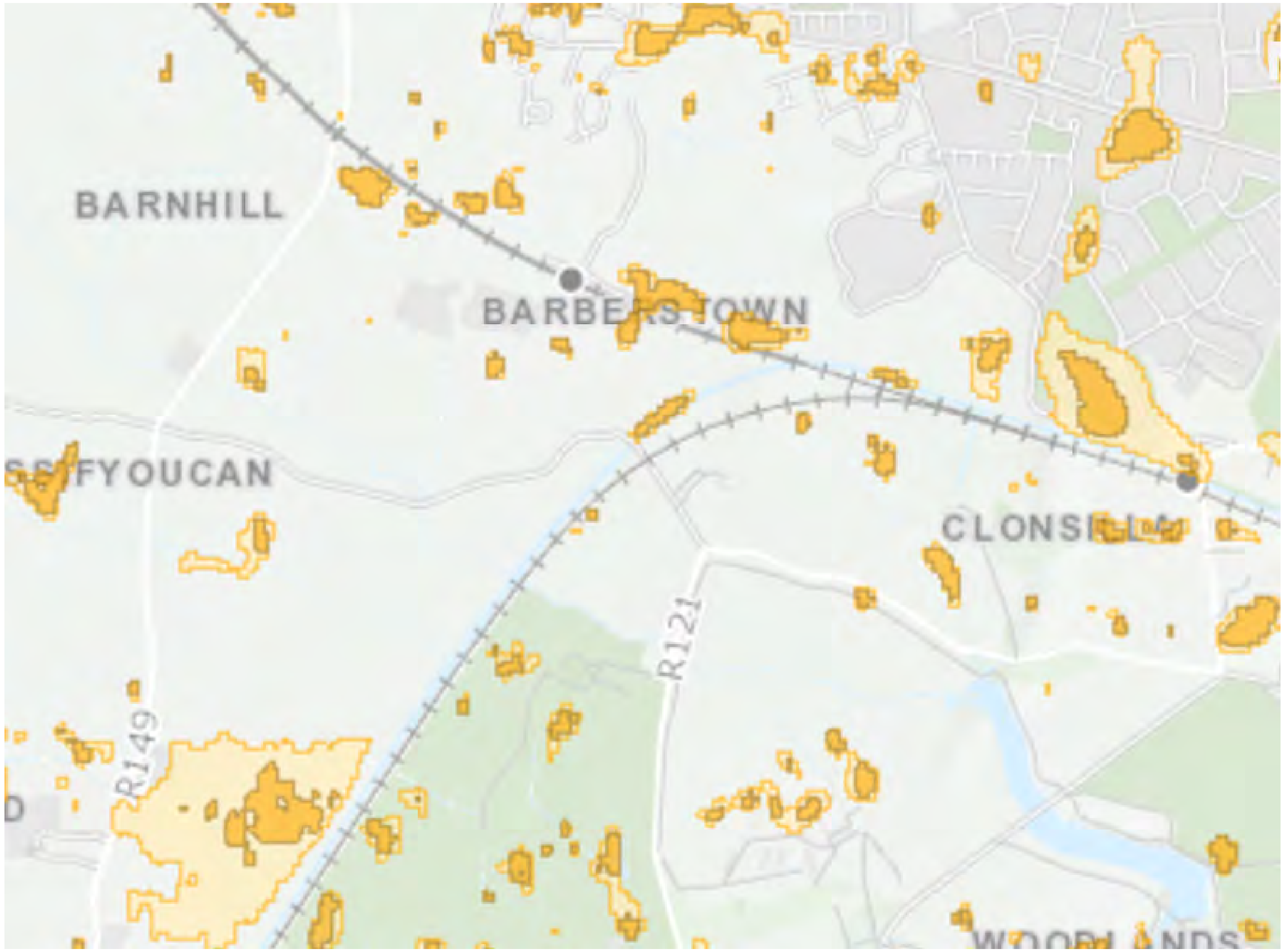


Figure 3.10 Pluvial risk zones within the plan area

3.7 Pluvial Flood Risk

Pluvial flooding occurs when the soakage capacity of the soil or drainage infrastructure has been exceeded during periods of intense rainfall. At these times, water can collect at low points in the topography and cause flooding. Based on the existing topography of local plan area extents, there is a potential risk of pluvial flooding. Pluvial flood risk in this area can be addressed by the provision of an appropriate storm water collection network. Figure 3.10 contains the known pluvial risk zones within the plan area extents.

SECTION 4

Conclusions & Recommendations

CONCLUSIONS & RECOMMENDATIONS

Background

- The flood modelling shows that there are large areas of low-lying lands located to the north and south of the existing stream that are liable to flooding.
- The flooding is largely caused by the limited capacity of the culvert under the canal and railway.
- The highest predicted flood depths in the 100 year RP event are bewteen 0.9 and 1m, including an allowance for climate change.
- The highest predicted flood depths in the 1000 year RP event are between 1.1 and 1.3m, including an allowance for climate change.

Flood Zoning

The Flood Risk Mapping in Appendix A should be used to determine the appropriate zoning for the site in accordance with the Flood Risk Management Guidelines:

- Areas within the 1000 year RP flood plain can be considered in Flood Zone B.
- Areas within the 100 year RP flood plain can be considered in Flood Zone A.

Proposed Road Scheme

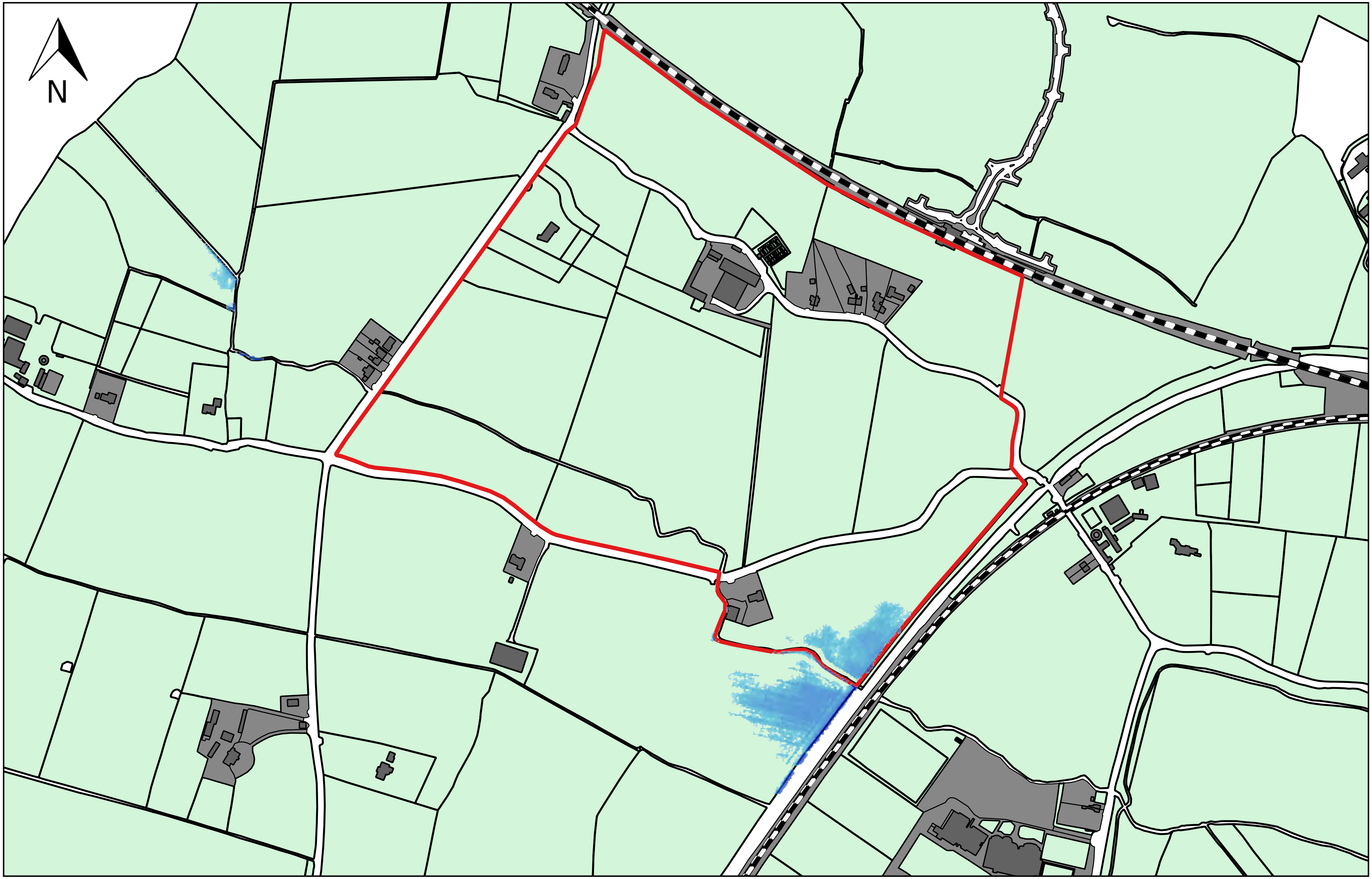
Analysis was undertaken of the proposed road scheme to determine the effect on the flood plain. The analysis indicates that the road embankment will displace some flood water during events in eccess of the 1 in 25 year return period. It is suggested that compensatory storage be provided for and possible areas where such storage could be provided have been indicated in the report

Key Recommendations

- Planning zoning within the LAP should reflect the flood mapping presented in this report and the flood zoning recommendations set out in the Flood Risk Management Guidelines.
- Ongoing maintenance of the stream and culverts is required to mimimise flood risk.
- Any planning applications in the study area should include a detailed justification test in accordance with the Flood Risk Management Guidelines.

APPENDIX A

Flood risk mapping



PROJECT: BARNHILL SFRA **DRAWING:** 10-YEAR	**STATUS:** DRAFT **ISSUE:** KC1407-FM-10-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	0 100 200 m Scale 1 in 6,500 @ A4	Comhairle Contae Fhine Gall Fingal County Council

PROJECT: BARNHILL SFRA **DRAWING:** 25-YEAR	**STATUS:** DRAFT **ISSUE:** KC1407-FM-25-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	0 100 200 m Scale 1 in 6,500 @ A4	**Comhairle Contae Fhine Gall** Fingal County Council

PROJECT: BARNHILL SFRA **DRAWING:** 50-YEAR	**STATUS:** DRAFT **ISSUE:** KC1407-FM-50-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	0 100 200 m Scale 1 in 6,500 @ A4

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Fingal County Council

PROJECT: BARNHILL SFRA **DRAWING:** 100-YEAR CC ROAD	**STATUS:** DRAFT **ISSUE:** KC1407-FM-100-CC-RD-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	0 100 200 m Scale 1 in 6,500 @ A4	Comhairle Contae Fhine Gall Fingal County Council

PROJECT: BARNHILL SFRA **DRAWING:** 100-YEAR + CC	**STATUS:** DRAFT **ISSUE:** KC1407-FM-100-CC-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	Comhairle Contae Fhine Gall Fingal County Council

PROJECT: BARNHILL SFRA	**STATUS:** DRAFT	**V1** - 28/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	Comhairle Contae Fhine Gall Fingal County Council
DRAWING: 100-YEAR ROAD	**ISSUE:** KC1407-FM-100-RD-V2	**V2** - 03/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	

PROJECT: BARNHILL SFRA **DRAWING:** 100-YEAR	**STATUS:** DRAFT **ISSUE:** KC1407-FM-100-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	0 100 200 m Scale 1 in 6,500 @ A4	Comhairle Contae Fhine Gall Fingal County Council

PROJECT: BARNHILL SFRA **DRAWING:** 1000-YEAR CC ROAD	**STATUS:** DRAFT **ISSUE:** KC1407-FM-1000-CC-RD-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	Comhairle Contae Fhine Gall Fingal County Council

PROJECT: BARNHILL SFRA **DRAWING:** 1000-YEAR CC	**STATUS:** DRAFT **ISSUE:** KC1407-FM-1000-CC-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	0 100 200 m Scale 1 in 6,500 @ A4	**Comhairle Contae Fhine Gall** Fingal County Council

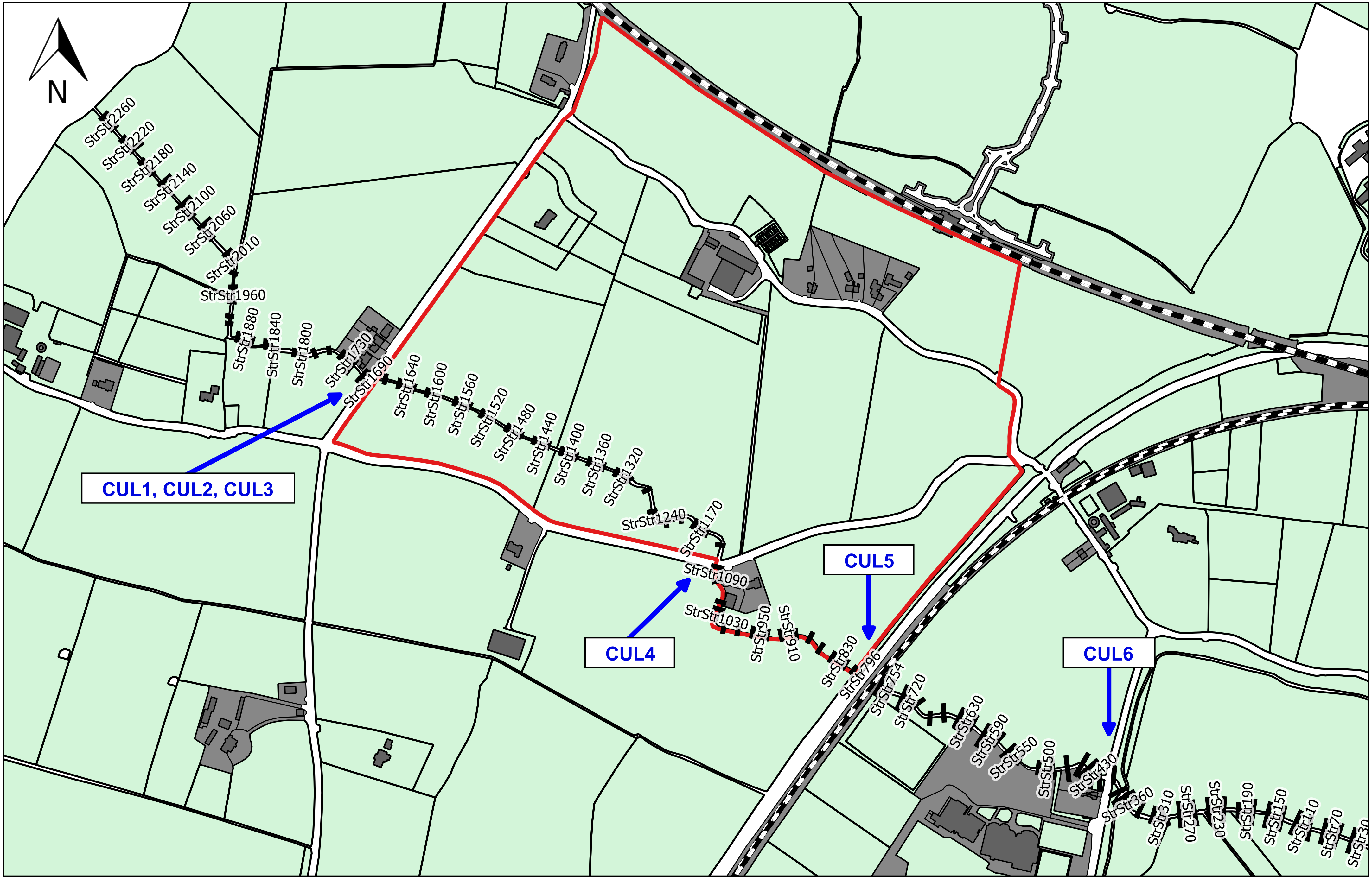
PROJECT: BARNHILL SFRA **DRAWING:** 1000-YEAR ROAD	**STATUS:** DRAFT **ISSUE:** KC1407-FM-1000-RD-V2	**V1** - 28/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 03/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	0 100 200 m Scale 1 in 6,500 @ A4	Comhairle Contae Fhine Gall Fingal County Council

PROJECT: BARNHILL SFRA **DRAWING:** 1000-YEAR	**STATUS:** DRAFT **ISSUE:** KC1407-FM-1000-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	Comhairle Contae Fhine Gall Fingal County Council

PROJECT: BARNHILL SFRA **DRAWING:** 1000-YEAR 25% BLOCK	**STATUS:** DRAFT **ISSUE:** KC1407-FM-1000-BLK25%-V1	**V1** - 28/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	0 100 200 m Scale 1 in 6,500 @ A4	Kaya Consulting Limited

APPENDIX B

Modelling cross section locations



PROJECT: BARNHILL SFRA **DRAWING:** 1D CROSS-SECTIONS	**STATUS:** DRAFT **ISSUE:** KC1407-XS-V2	**V1** - 27/03/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK **V2** - 18/10/18 - **Drawn:** GP - **Checked:** YK - **Approved:** YK	0 100 200 m Scale 1 in 6,500 @ A4	**Comhairle Contae Fhine Gall** Fingal County Council

Section	Predicted peak water level (existing - NO new road) (m AOD)							Predicted peak water level (with new ROAD) (mAOD)			
	Return Period							Return Period			
	10	25	50	100	100+CC	1000	1000+CC	100	100 CC	1000	1000 CC
StrStr2260	60.27	60.37	60.43	60.49	60.54	60.6	60.63	60.49	60.54	60.59	60.62
StrStr2240	60.21	60.31	60.37	60.42	60.48	60.54	60.57	60.42	60.48	60.53	60.57
StrStr2220	60.11	60.21	60.26	60.3	60.35	60.39	60.43	60.30	60.35	60.39	60.42
StrStr2200	60.04	60.14	60.19	60.22	60.26	60.29	60.32	60.22	60.26	60.29	60.32
StrStr2180	60.01	60.1	60.14	60.17	60.2	60.23	60.25	60.17	60.20	60.23	60.25
StrStr2160	59.98	60.07	60.11	60.14	60.17	60.19	60.21	60.14	60.17	60.20	60.22
StrStr2140	59.84	59.93	59.98	60.02	60.06	60.1	60.14	60.02	60.06	60.11	60.15
StrStr2100	59.62	59.73	59.79	59.83	59.89	59.97	60.03	59.83	59.89	59.97	60.05
StrStr2080	59.57	59.68	59.74	59.78	59.86	59.94	60.02	59.78	59.86	59.95	60.03
StrStr2060	59.52	59.63	59.68	59.73	59.81	59.91	60	59.73	59.81	59.92	60.02
StrStr2040	59.49	59.59	59.65	59.69	59.78	59.89	59.99	59.69	59.79	59.90	60.00
StrStr2010	59.47	59.59	59.64	59.69	59.79	59.89	59.99	59.69	59.79	59.90	60.00
StrStr1980	59.44	59.56	59.63	59.68	59.78	59.88	59.98	59.68	59.78	59.89	60.00
StrStr1960	59.41	59.52	59.6	59.66	59.78	59.89	59.99	59.66	59.78	59.90	60.00
StrStr1940	59.12	59.22	59.28	59.34	59.43	59.55	59.63	59.34	59.43	59.56	59.65
StrStr1920	58.87	58.98	59.05	59.12	59.22	59.37	59.44	59.12	59.22	59.39	59.47
StrStr1910	58.81	58.93	59	59.08	59.17	59.32	59.37	59.08	59.17	59.34	59.41
StrStr1880	58.76	58.88	58.95	59.03	59.11	59.28	59.32	59.03	59.11	59.30	59.37
StrStr1860	58.75	58.88	58.96	59.03	59.1	59.28	59.33	59.03	59.10	59.30	59.37
StrStr1840	58.65	58.76	58.83	58.91	58.99	59.23	59.27	58.91	58.98	59.24	59.31
StrStr1800	58.38	58.49	58.58	58.68	58.78	59.07	59.13	58.68	58.77	59.08	59.16
StrStr1770	58.23	58.35	58.45	58.56	58.66	58.98	59.06	58.56	58.65	59.01	59.09
StrStr1750	58.17	58.28	58.37	58.48	58.59	58.93	59.02	58.48	58.57	58.96	59.04
StrStr1730	58.1	58.22	58.32	58.44	58.54	58.92	59.02	58.44	58.53	58.94	59.02
StrStr1710	58.07	58.2	58.31	58.42	58.53	58.91	59.02	58.42	58.52	58.93	59.02
StrStr1690	58.07	58.2	58.31	58.42	58.53	58.91	59.01	58.42	58.51	58.93	59.02
SP1_US	58.07	58.2	58.31	58.42	58.53	58.91	59.01	58.42	58.51	58.93	59.02
Cul1_In	58.07	58.2	58.31	58.42	58.53	58.91	59.01	58.42	58.51	58.93	59.02
Cul1_US	57.96	58.06	58.13	58.22	58.37	58.48	58.59	58.22	58.28	58.52	58.62
Cul1_DS	57.95	58.04	58.1	58.17	58.38	58.37	58.48	58.17	58.21	58.41	58.51
Cul2_In	58.07	58.2	58.31	58.42	58.53	58.91	59.01	58.42	58.51	58.93	59.02
Cul2_US	58	58.1	58.18	58.27	58.38	58.58	58.69	58.27	58.33	58.62	58.71
Cul2_DS	57.95	58.04	58.1	58.17	58.38	58.37	58.48	58.17	58.21	58.41	58.51
Cul3_In	58.07	58.2	58.31	58.42	58.53	58.91	59.01	58.42	58.51	58.93	59.02
Cul3_US	58	58.1	58.18	58.27	58.38	58.58	58.69	58.27	58.33	58.62	58.71
Cul3_DS	57.95	58.04	58.1	58.17	58.38	58.37	58.48	58.17	58.21	58.41	58.51
SP1_DS	57.95	58.04	58.1	58.17	58.38	58.37	58.48	58.17	58.21	58.41	58.51
StrStr1660	57.95	58.04	58.1	58.17	58.38	58.37	58.48	58.17	58.21	58.41	58.51
StrStr1640	57.73	57.86	57.95	58.03	58.37	58.23	58.34	58.03	58.07	58.30	58.40
StrStr1620	57.67	57.81	57.9	57.98	58.37	58.17	58.27	57.98	58.02	58.25	58.34
StrStr1600	57.64	57.77	57.86	57.94	58.37	58.11	58.21	57.94	57.97	58.20	58.29
StrStr1560	57.58	57.7	57.79	57.87	58.36	58.01	58.08	57.87	57.89	58.12	58.20
StrStr1540	57.57	57.69	57.77	57.85	58.37	57.98	58.04	57.85	57.87	58.10	58.17
StrStr1520	57.55	57.67	57.75	57.82	58.27	57.93	57.98	57.82	57.84	58.06	58.13
StrStr1480	57.52	57.62	57.69	57.75	57.91	57.84	57.88	57.75	57.77	58.00	58.05
StrStr1473	57.49	57.59	57.67	57.73	57.9	57.8	57.85	57.73	57.74	57.96	58.01
StrStr1440	57.32	57.46	57.54	57.61	57.65	57.73	57.76	57.61	57.65	57.84	57.91
StrStr1420	57.17	57.36	57.44	57.52	57.6	57.71	57.76	57.52	57.60	57.76	57.83
StrStr1400	57.13	57.32	57.4	57.47	57.56	57.66	57.71	57.47	57.56	57.71	57.77
StrStr1380	57.11	57.3	57.37	57.44	57.52	57.61	57.65	57.44	57.53	57.67	57.72
StrStr1360	57.09	57.27	57.35	57.4	57.49	57.57	57.61	57.41	57.50	57.63	57.69
StrStr1340	57.06	57.25	57.32	57.37	57.46	57.54	57.58	57.37	57.47	57.60	57.65
StrStr1320	57.03	57.23	57.29	57.35	57.45	57.54	57.59	57.35	57.46	57.59	57.65
StrStr1300	57	57.2	57.26	57.31	57.42	57.51	57.56	57.32	57.43	57.55	57.60
StrStr1270	56.96	57.16	57.22	57.29	57.39	57.49	57.54	57.30	57.40	57.51	57.56
StrStr1240	56.94	57.14	57.2	57.27	57.39	57.48	57.53	57.29	57.39	57.50	57.56
StrStr1210	56.91	57.12	57.17	57.26	57.38	57.48	57.53	57.28	57.39	57.49	57.55
StrStr1190	56.89	57.1	57.15	57.26	57.38	57.48	57.53	57.28	57.39	57.49	57.55
StrStr1170	56.89	57.1	57.15	57.26	57.38	57.48	57.53	57.28	57.39	57.49	57.55
StrStr1150	56.88	57.09	57.14	57.26	57.38	57.48	57.53	57.28	57.39	57.49	57.55
StrStr1120	56.85	57.07	57.13	57.26	57.38	57.48	57.53	57.28	57.39	57.48	57.55
SP2_US	56.85	57.07	57.13	57.26	57.38	57.48	57.53	57.28	57.39	57.48	57.54
Cul4_In	56.85	57.07	57.13	57.26	57.38	57.48	57.53	57.28	57.39	57.48	57.54
Cul4_US	56.66	56.94	57.1	57.26	57.38	57.48	57.53	57.27	57.39	57.48	57.53
Cul4_DS	56.61	56.9	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.47	57.53
Cul4_USA	56.61	56.9	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.47	57.53
Cul4_DSA	56.6	56.9	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.47	57.53
Jun_1090	56.6	56.9	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.47	57.53
SP2_DS	56.6	56.9	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.47	57.53
StrStr1090	56.6	56.9	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.47	57.53

Section	Predicted peak water level (existing - NO new road) (m AOD)							Predicted peak water level (with new ROAD) (mAOD)			
	Return Period							Return Period			
	10	25	50	100	100+CC	1000	1000+CC	100	100 CC	1000	1000 CC
StrStr1070	56.59	56.9	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.48	57.53
StrStr1040	56.58	56.89	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.48	57.53
StrStr1030	56.58	56.89	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.47	57.53
StrStr990	56.58	56.89	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.48	57.53
StrStr970	56.57	56.89	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.47	57.53
StrStr950	56.57	56.89	57.09	57.26	57.38	57.48	57.54	57.27	57.39	57.47	57.53
StrStr930	56.57	56.89	57.09	57.26	57.38	57.48	57.53	57.27	57.39	57.48	57.53
StrStr910	56.57	56.89	57.09	57.26	57.38	57.48	57.54	57.27	57.39	57.47	57.53
StrStr890	56.57	56.9	57.09	57.26	57.38	57.49	57.54	57.27	57.39	57.48	57.53
StrStr870	56.57	56.9	57.09	57.26	57.38	57.49	57.55	57.27	57.39	57.48	57.54
StrStr850	56.58	56.9	57.09	57.26	57.39	57.5	57.55	57.28	57.39	57.48	57.54
StrStr830	56.57	56.89	57.09	57.27	57.39	57.5	57.55	57.28	57.40	57.48	57.54
StrStr810	56.58	56.9	57.09	57.27	57.39	57.42	57.49	57.28	57.39	57.48	57.54
StrStr796	56.58	56.91	57.11	57.29	57.41	57.54	57.65	57.29	57.43	57.49	57.62
SP3_US	56.58	56.91	57.11	57.29	57.41	57.54	57.65	57.29	57.43	57.49	57.62
Cul5_In	56.58	56.91	57.11	57.29	57.41	57.54	57.65	57.29	57.43	57.49	57.62
Cul5_US	56.19	56.43	56.57	56.7	56.79	56.88	56.98	56.70	56.80	56.85	56.96
Cul5_DS	55.48	55.53	55.57	55.6	55.62	55.64	55.65	55.60	55.62	55.65	55.66
Jun_754	55.48	55.53	55.57	55.6	55.62	55.64	55.65	55.60	55.62	55.65	55.66
SP3_DS	55.48	55.53	55.57	55.6	55.62	55.64	55.65	55.60	55.62	55.65	55.66
StrStr754	55.48	55.53	55.57	55.6	55.62	55.64	55.65	55.60	55.62	55.65	55.66
StrStr740	55.39	55.45	55.5	55.53	55.55	55.58	55.58	55.53	55.56	55.58	55.59
StrStr720	55.13	55.21	55.25	55.29	55.32	55.34	55.35	55.29	55.32	55.36	55.37
StrStr700	55	55.08	55.13	55.16	55.18	55.2	55.21	55.16	55.18	55.23	55.24
StrStr670	54.95	55.04	55.08	55.11	55.14	55.16	55.17	55.12	55.14	55.18	55.19
StrStr650	54.92	55.01	55.05	55.09	55.11	55.13	55.14	55.09	55.11	55.16	55.17
StrStr630	54.88	54.98	55.02	55.06	55.08	55.1	55.11	55.06	55.08	55.13	55.14
StrStr610	54.86	54.96	55	55.04	55.06	55.08	55.09	55.04	55.06	55.10	55.11
StrStr590	54.84	54.94	54.99	55.02	55.04	55.07	55.08	55.02	55.05	55.08	55.09
StrStr570	54.83	54.93	54.98	55.01	55.04	55.06	55.07	55.02	55.04	55.07	55.08
StrStr550	54.83	54.93	54.97	55.01	55.03	55.05	55.06	55.01	55.03	55.07	55.08
StrStr530	54.82	54.92	54.96	55	55.02	55.04	55.06	55.00	55.02	55.06	55.07
StrStr500	54.8	54.91	54.95	54.99	55.01	55.03	55.04	54.99	55.01	55.04	55.05
StrStr480	54.79	54.89	54.94	54.97	54.99	55.01	55.03	54.97	55.00	55.02	55.03
StrStr460	54.76	54.86	54.91	54.95	54.97	54.99	55	54.95	54.97	55.00	55.01
StrStr440	54.75	54.85	54.9	54.94	54.96	54.98	54.99	54.94	54.96	54.99	55.00
StrStr430	54.74	54.84	54.89	54.93	54.95	54.97	54.98	54.93	54.95	54.98	54.99
StrStr409	54.72	54.83	54.88	54.92	54.94	54.96	54.98	54.92	54.94	54.96	54.97
SP4_US	54.72	54.83	54.88	54.92	54.94	54.96	54.98	54.92	54.94	54.96	54.97
Cul6_In	54.72	54.83	54.88	54.92	54.94	54.96	54.98	54.92	54.94	54.96	54.97
Cul6_US	54.66	54.76	54.8	54.83	54.85	54.86	54.87	54.83	54.85	54.86	54.87
Cul6_DS	54.65	54.74	54.78	54.8	54.82	54.84	54.84	54.81	54.82	54.84	54.85
Jun_390	54.65	54.74	54.78	54.8	54.82	54.84	54.84	54.81	54.82	54.84	54.85
SP4_DS	54.65	54.74	54.78	54.8	54.82	54.84	54.84	54.81	54.82	54.84	54.85
StrStr390	54.65	54.74	54.78	54.8	54.82	54.84	54.84	54.81	54.82	54.84	54.85
StrStr370	54.63	54.72	54.76	54.78	54.8	54.81	54.82	54.79	54.80	54.81	54.82
StrStr360	54.62	54.71	54.75	54.77	54.79	54.81	54.81	54.78	54.79	54.80	54.81
StrStr350	54.62	54.71	54.74	54.77	54.79	54.8	54.81	54.77	54.79	54.80	54.81
StrStr330	54.33	54.4	54.43	54.46	54.47	54.48	54.49	54.46	54.47	54.48	54.49
StrStr310	54.03	54.07	54.1	54.12	54.14	54.15	54.16	54.13	54.14	54.16	54.16
StrStr290	53.95	54	54.03	54.05	54.06	54.08	54.08	54.05	54.06	54.09	54.09
StrStr270	53.94	53.98	54.01	54.03	54.05	54.06	54.07	54.04	54.05	54.07	54.08
StrStr250	53.72	53.77	53.8	53.82	53.83	53.85	53.85	53.82	53.84	53.85	53.86
StrStr230	53.57	53.63	53.66	53.68	53.7	53.71	53.72	53.68	53.70	53.71	53.71
StrStr210	53.56	53.62	53.65	53.67	53.68	53.7	53.7	53.67	53.68	53.69	53.70
StrStr190	53.55	53.61	53.64	53.66	53.68	53.69	53.7	53.66	53.68	53.68	53.69
StrStr170	53.52	53.58	53.6	53.62	53.64	53.65	53.65	53.62	53.64	53.64	53.65
StrStr150	53.46	53.51	53.54	53.56	53.57	53.58	53.59	53.56	53.57	53.57	53.57
StrStr130	53.43	53.49	53.51	53.53	53.54	53.55	53.56	53.53	53.54	53.54	53.54
StrStr110	53.4	53.45	53.48	53.49	53.5	53.51	53.52	53.49	53.50	53.49	53.50
StrStr90	53.35	53.4	53.42	53.44	53.45	53.46	53.46	53.44	53.45	53.43	53.43
StrStr70	53.32	53.38	53.4	53.42	53.43	53.44	53.44	53.42	53.43	53.40	53.41
StrStr50	53	53.04	53.05	53.07	53.07	53.08	53.08	53.07	53.07	53.12	53.12
StrStr30	52.74	52.77	52.79	52.8	52.8	52.81	52.82	52.80	52.81	52.90	52.90

APPENDIX C

Sample model structure

Barnhill Stream – sample model structure

Cross-Section	Type	Description
StrStr2260	RIVER	First cross-section in model – Some 500m upstream of site
		Series of cross-sections to represent areas up until the site
StrStr1690	RIVER	Cross-section just upstream of site upstream of CUL1-CUL3
Cul1_US	CONDUIT	RECTANGULAR (UPSTREAM)
Cul1_DS	CONDUIT	RECTANGULAR (DOWNSTREAM)
Cul2_US	CONDUIT	CIRCULAR (UPSTREAM)
Cul2_DS	CONDUIT	CIRCULAR (DOWNSTREAM)
Cul3_US	CONDUIT	CIRCULAR (UPSTREAM)
Cul3_DS	CONDUIT	CIRCULAR (DOWNSTREAM)
SP1_US	SPILL	Spill to represent overtopping flows
StrStr1660	RIVER	Cross-section just downstream of CUL1-CUL3, within site
…		Series of cross-sections within site
StrStr1380	RIVER	Cross-section within site
StrStr1360	RIVER	Cross-section within site
…		Series of cross-sections within site
StrStr1120	RIVER	Cross-section just upstream of CUL4
Cul4_In	CULVERT	INLET
Cul4_US	CONDUIT	CIRCULAR (UPSTREAM)
Cul4_DS	CONDUIT	CIRCULAR (DOWNSTREAM)
Cul4_USA	CONDUIT	SPRUNGARCH (UPSTREAM)
Cul4_DSA	CONDUIT	SPRUNGARCH (DOWNSTREAM)
Cul4_DSA	CULVERT	OUTLET

Cross-Section	Type	Description
SP2_US	SPILL	Spill to represent overtopping flows
StrStr1090	RIVER	Cross-section just downstream of CUL4
…		Series of cross-sections within site
StrStr796	RIVER	Cross-section just upstream of CUL5
Cul5_In	CULVERT	INLET
Cul5_US	CONDUIT	CIRCULAR (UPSTREAM)
Cul5_DS	CONDUIT	CIRCULAR (DOWNSTREAM)
Cul5_DS	CULVERT	OUTLET
StrStr754	RIVER	Cross-section just upstream of CUL5 and the site
…		Series of cross-sections downstream of the site
StrStr30	RIVER	Last cross-section in the model, 700m downstream of the site

RIVER = Cross, Section, CONDUIT = Culvert/ Conduit Structure

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