Cork Line Level Crossings

Appendix 9A Flood Risk Assessment

Iarnród Éireann

March 2021

Cork Line Level Crossings

Project No:	32111000
Document Title:	Appendix 9A Flood Risk Assessment
Revision:	P02
Date:	March 2021
Client Name:	Iarnród Éireann
Project Manager:	Alex Bradley
Author:	Ana Silva

Jacobs U.K. Limited
Artola House
3rd & 4th Floors
91 Victoria Street
Belfast
BT1 4PN
T +44 (0)28 9032 4452
F +44 (0)28 9033 0713
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
P01	September 2019	Draft Stage 1 and 2 FRA	AS	PH	PH	NS
P02	October 2020	Updated to include Stage 3 FRA	AS	PH	PH	NS
P03	March 2021	For Issue to An Bord Pleanála	HC	NS	NS	AB

Contents

1. Introduction

1.1 Introduction and Background

This Flood Risk Assessment considers seven level crossings which are within a 24km section of the Dublin – Cork Railway line between Limerick Junction and Mallow straddling the Cork/Limerick county boundary.

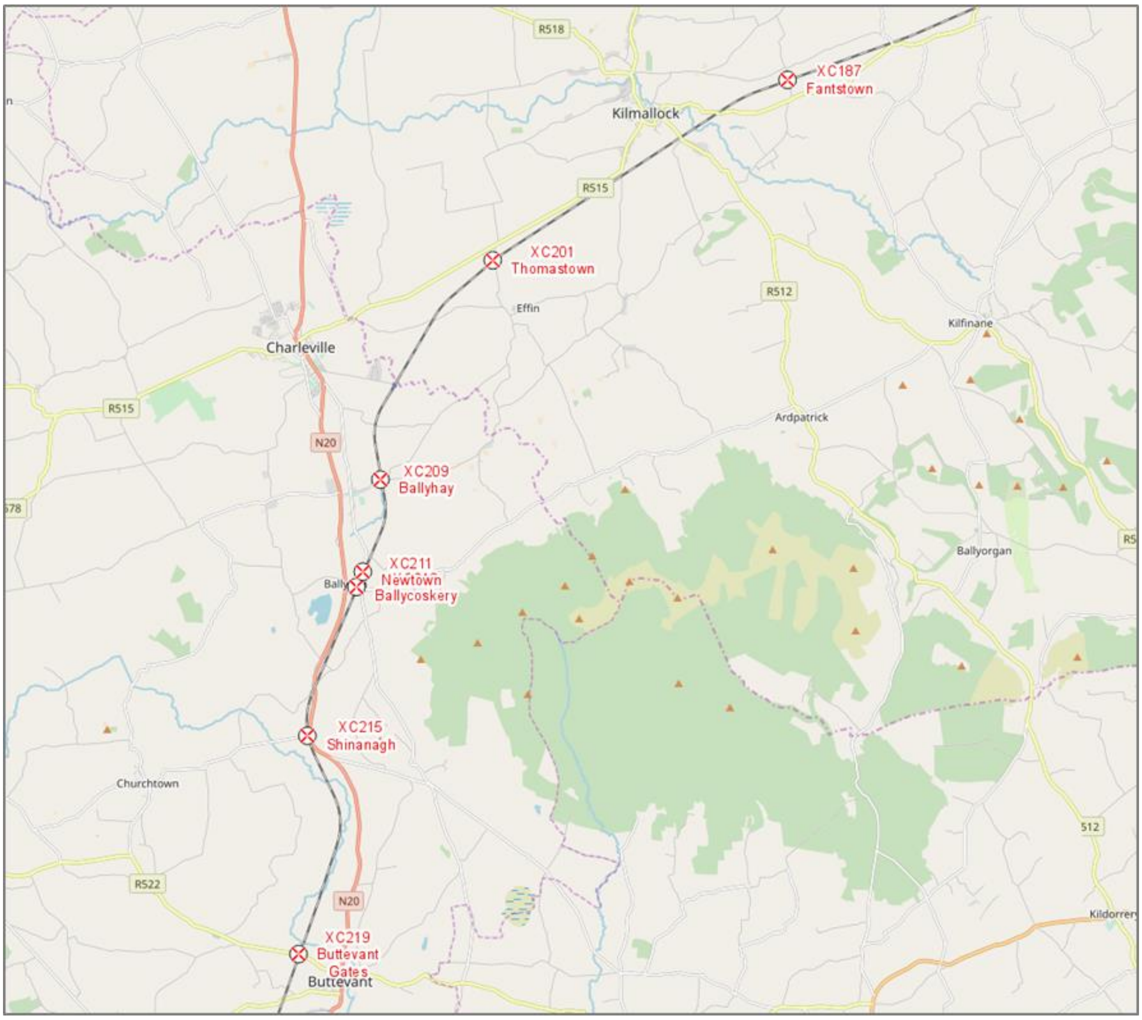
Level crossings XC187 Fantstown and XC201 Thomastown are in County Limerick, located directly south of Limerick City close to the Cork-Limerick border, while the remaining sites are located in County Cork, directly north of Mallow.

In March 2018, the board of Iarnród Éireann approved the preparation of a feasibility study into the elimination/de-manning of the 7no. remaining manned level crossings (namely: XC187 Fantstown, XC201 Thomastown, XC209 Ballyhay, XC211 Newtown, XC212 Ballycoskery, XC215 Shainanagh and XC219 Buttevant) on the Dublin - Cork Railway Line. In September 2019, a Preliminary Design Report was developed by Jacobs on behalf of Iarnród Éireann.

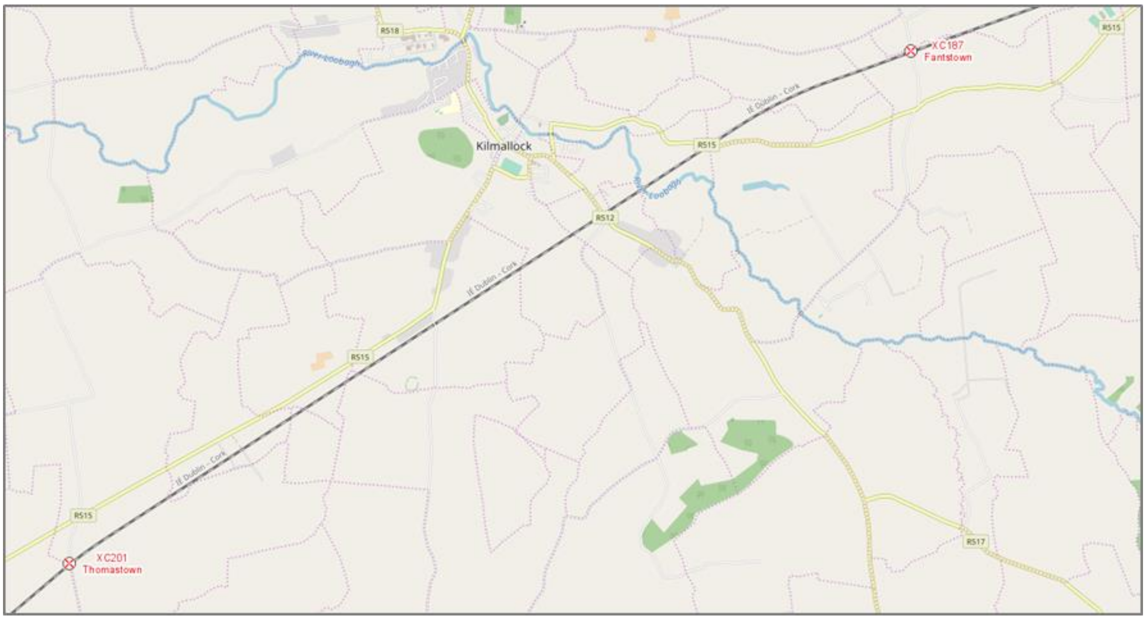
This report describes a flood risk assessment that has been prepared in accordance with Section 28 of the Planning and Development Act 2000 and the Guidelines on the Planning System and Flood Risk Management, 2009 and solely considers the proposed schemes for the de-manning of these level crossings.

The locations of the level crossings are shown in Inset Figure 1.1 to Inset Figure 1.4.

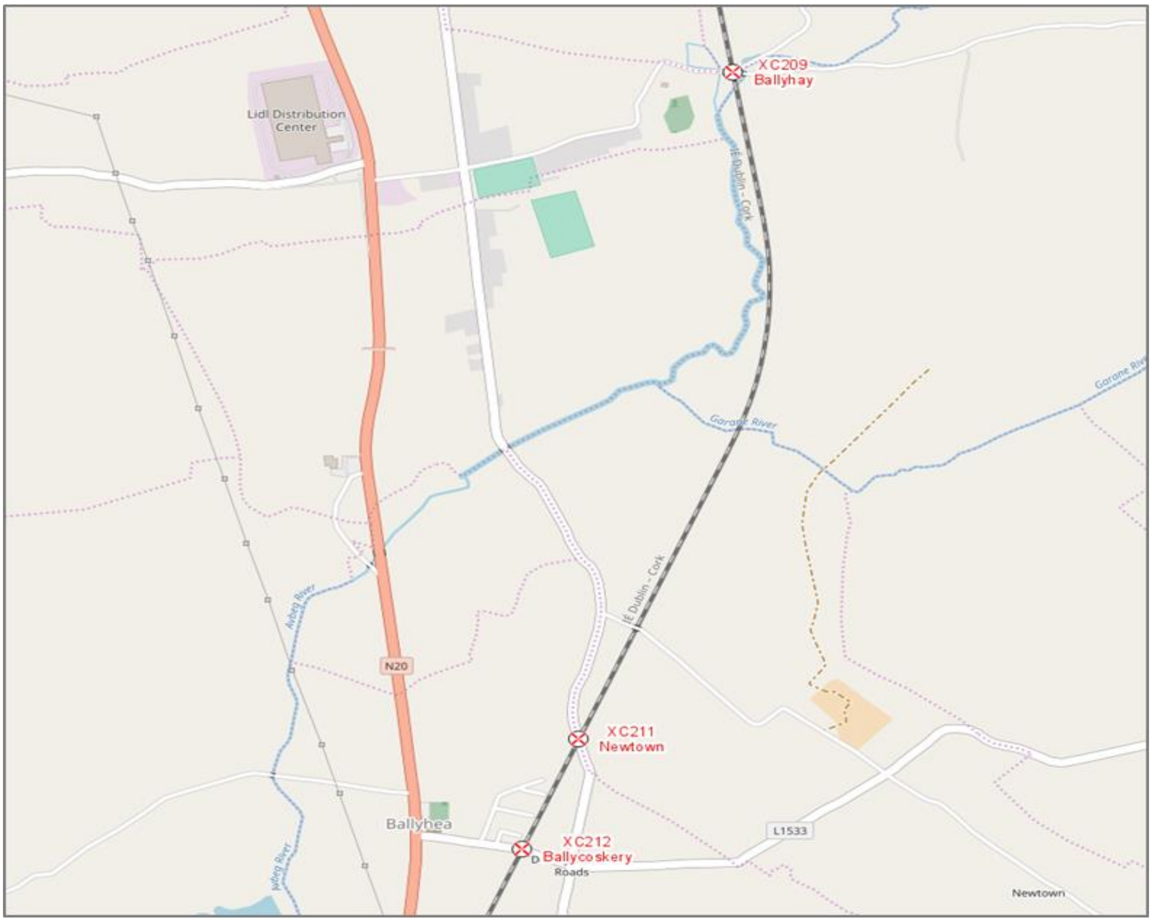
Inset Figure 1.1: Level Crossing Sites (Overview)



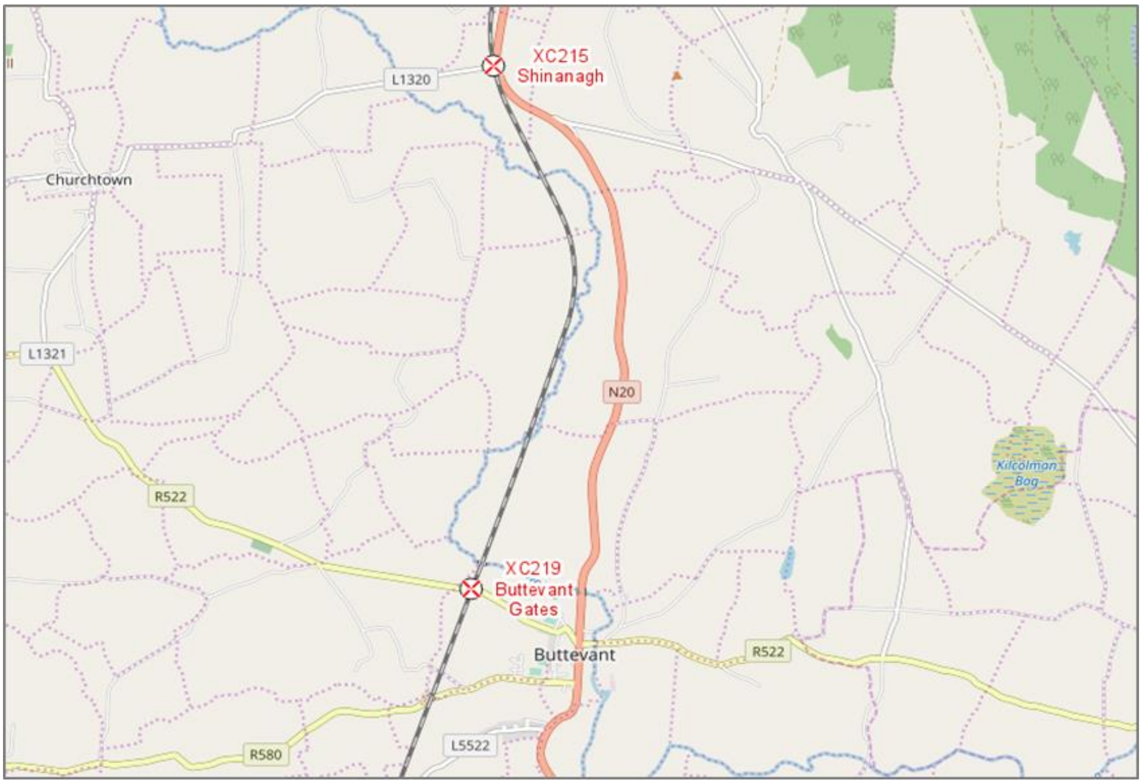
Inset Figure 1.2 Manned Level Crossing Sites (XC187 Fantstown and XC201 Thomastown)



Inset Figure 1.3: Level Crossing Sites (XC209 Ballyhay, XC211 Newtown and XC212 Ballycoskery)



Inset Figure 1.4: Level Crossing Sites (XC215 Shinangh and XC219 Buttevant)



1.2 Proposed Project Description

1.2.1 New Above Ground Infrastructure

Out of the 7 level crossings, 3 (XC201 Thomastown, XC212 Ballycoskery and XC219 Buttevant) are proposed to have new road-over-rail bridge s to enable continuous uninterrupted access across the rail line.

The proposal layout drawings for each level crossing are provided in Volume 4, Figures 2C to 8C.

XC187 Fantstown and XC209 Ballyhay involve limited works. For XC187 Fantstown, the works are close the level crossing. At XC209 Ballyhay, the works comprise replacement of the existing manned crossing with a remote monitored CCTV solution.

Details of the level crossings and respective proposed solutions are provided in Table 1.1 below.

Table 1.1 Proposed Project at each Level Crossing

Location	Infrastructure	Description
XC187 Fantstown	N/A	Straight Closure: Alternative route along existing roads to existing road-over-rail bridge approx. 3km to the north east.
XC201 Thomastown	1no. road-over-rail bridge.	New road-over-rail bridge: Tie in to existing local road to south and new junction on Regional Road R515 to north. Carriageway widths are proposed to match existing widths for safety reasons. Following consultation with Limerick City and County Council Roads Department as well as submissions made by members of the public, the structure has been widened so that minimal works would be required to accommodate a future widened carriageway.
XC209 Ballyhay	CCTV solution	Replace the existing manned level crossing with a remote monitored CCTV solution.
XC211 Newtown	New access road.	New Access Road: Immediately east of the existing road-over-rail bridge to the north of XC211 Newton; tie in to existing Local road to the east of XC211 Newtown. This alignment was chosen following public consultation and concerns raised about the initial proposal for a new access road tie in from the rear of the Beechwood Grove housing estate to the local road west of the XC211 Newtown level crossing.
XC212 Ballycoskery	1 no. road-over-rail bridge, 1no. parapet wall.	New road-over-rail bridge: Tie in to existing local road to East and West, new carpark proposed for existing school. Tie- in to Beechwood Housing Estate and Ballyhea National School to North and existing Local road to south.
XC215 Shinanagh	Tie-in to existing road-over-rail bridge. 2no. retaining walls Upgrade of existing junction on N20	New access road to tie-in to existing road-over-rail bridge approx. 1km to the north.
XC219 Buttevant	1no. road-over-rail bridge, 1no. portal frame road over river bridge, 1no. ditch box culvert, 1no.access road box culvert, 2no. retaining walls.	New road-over-rail bridge. Tie in to existing regional road to east and west.

1.2.2 Elimination of Existing Above Ground Infrastructure

All existing level crossings will be closed permanently, with the exception of XC209 Ballyhay.

Short sections of existing highway leading up to the existing level crossings at XC201 Thomastown, XC211 Newtown, XC212 Ballycoskery, XC215 Shinanagh, and XC219 Buttevant will be removed and landscaped.

1.2.3 Receptor Vulnerability

For the purpose of this assessment, the proposed Project is characterised into the following categories:

- All works associated with the railway line itself and regionally important transport infrastructure will be considered as Highly Vulnerable Developments. Any works associated with this development will be located outside of Flood Zone B (0.1% AEP flood event) or subject to a Justification Test;
- All works associated with local access roads will be considered Less Vulnerable Development. Any works associated with this development will be located outside of Flood Zone A (1% AEP flood event) or subject to a Justification Test.
- All works associated with landscaping and drainage i.e. swales will be considered as Water Compatible Development. Any works associated with this development can be located within Flood Zone A (1% AEP flood event).

All works must avoid any increase in flood risk elsewhere.

1.3 Report Structure

The flood risk assessment is structured as follows:

- Section 2 sets out the Flood Risk Assessment Methodology.
- Section 3 outlines the findings of the Stage 1 flood risk assessment (flood risk identification), identifying potential flood risk to the level crossing sites.
- Section 4 presents the findings of the Stage 2 flood risk assessment (initial flood risk assessment), assessing the impact of flooding on the proposed Project.
- Section 5 presents the findings of the Stage 2 flood risk assessment (initial flood risk assessment), assessing the impact of flooding from the proposed Project.
- Section 6 presents the findings of the Stage 3 flood risk assessment (detailed flood risk assessment), where appropriate, to evaluate the site-specific flood mechanisms and verify the need for, and inform the design of, any mitigation measures.
- Section 7 considers the proposed upgrade works and the flood risk assessment in the context of the sequential approach to development planning.
- Section 8 presents the conclusions.

1.4 Flood Risk Assessment Methodology

The '*Planning System and Flood Risk Management: Guidelines for Planning Authorities*' document outlines the key principles that should be considered when assessing flood risk to proposed Project sites. It recommends that the following staged approach should be adopted:

1) Stage 1: Flood risk identification

- To identify whether there may be any flooding or surface water management issues relating to the proposed Project sites that warrant further investigation.

2) Stage 2: Initial flood risk assessment

- To confirm the sources of flooding that may affect the proposed Project sites, to appraise the adequacy of existing information and to determine what surveys and modelling approach is appropriate to match the spatial resolution required and complexity of the flood risk issues. This stage involves the review of existing studies, to assess flood risk and to assist with the development of FRM measures.

3) Stage 3: Detailed flood risk assessment

- To provide a quantitative appraisal of potential flood risk to a proposed or existing development, of its potential impacts on flood risk elsewhere and of the effectiveness of any proposed mitigation measures. This will typically involve use of an existing or construction of a hydraulic model across a wide enough area to appreciate the catchment wide impacts and hydrological process involved.

1.5 Stage 1: Flood Risk Identification

1.5.1 General

This stage assesses the existing flood risk to the sites. This is a desk-based exercise using existing information from a range of sources. The objective of the Stage 1: Flood Risk Identification Assessment, is to identify whether there may be any flooding or surface water management issues relating to the sites that warrant further investigation.

1.5.2 Flood Information Sources

OPW National Flood Hazard Mapping

The OPW National Flood Hazard Mapping (www.floodinfo.ie) identifies the following five flood events within 2.5km of each site (Inset Figure 1.5). The associated minutes and mapping are provided in Appendix A.

1) Awbeg, Liscarroll Road – Buttevant (possibly affects XC219 Buttevant)

Recurrent flooding. Fluvial source. Meeting held in 2005. Flooding relates to Flood Ref 507 in the associated minutes and mapping.

2) Mill Pond, Buttevant Recurring (possibly affects XC219 Buttevant)

Recurrent flooding. Fluvial Source. Meeting held in 2005. Gravel ground bubbles up through the ground. Flooding relates to Flood Ref 501 in the associated minutes and mapping.

3) Clashnabuttry, Buttevant (possibly affects XC219 Buttevant)

Recurrent flooding. Low lying land source. Meeting held in 2005. Flooding relates to Flood Ref 510 in the associated minutes and mapping.

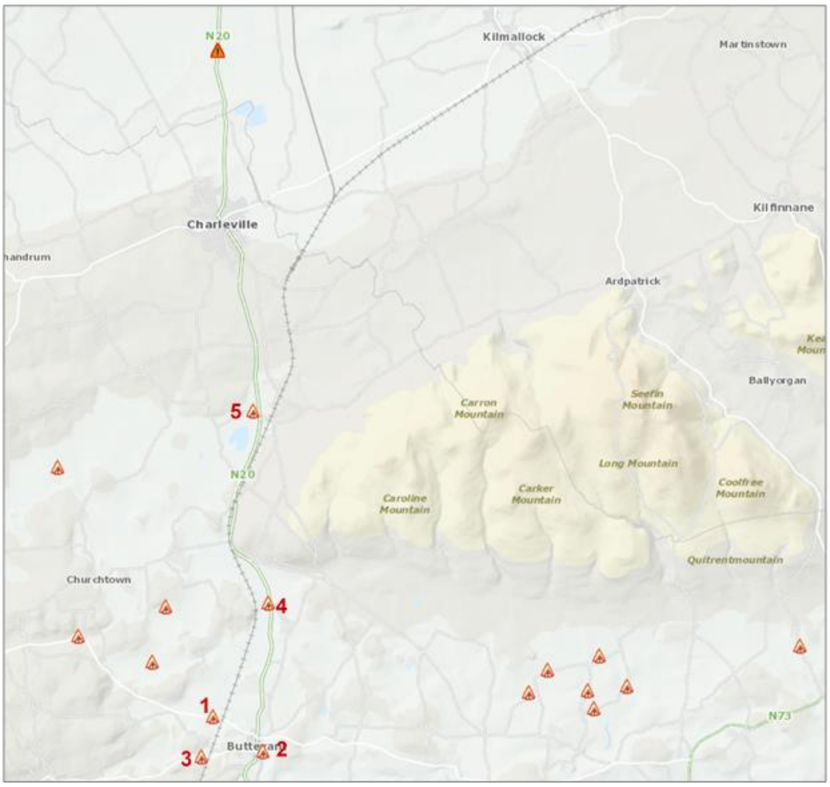
4) Awbeg N20 Road, Kilbronbey, Velvetstown (possibly affects XC215 Shinanagh)

Recurrent flooding. Fluvial source. Meeting held in 2005. Flooding relates to Flood Ref 517 in the associated minutes and mapping.

5) Ballyhea, Buttevant (N20) (possibly affects XC212 Ballycoskery and XC211 Newtown)

Recurrent flooding. Flood source unknown. Meeting held in 2005. Flooding relates to Flood Ref 503 in the associated minutes and mapping.

Inset Figure 1.5: Past Flood Events within 2.5km from Each Site



The sites XC201 Thomastown and XC187 Fantstown have no recorded past flood events in their vicinity. The sites are mostly located in isolated rural areas and there are few records describing these past flood events. No past records identified relate to direct flooding at these sites.

Historical and Anecdotal Evidence

A high-level search was undertaken to identify additional historic or anecdotal evidence of flooding in and around the study areas, however no records were identified which detail flooding at the level crossing locations.

XC187 Fantstown Site

A few newspaper articles were identified documenting flooding in the town of Kilmallock (closest town to the level crossing site) from the River Maigue sub-catchment, however no records were identified which detail flooding at this level crossing.

XC201 Thomastown Site

A few newspaper articles were identified documenting flooding in the town of Charleville and Kilmallock (closest towns to the level crossing site) from the River Maigue sub-catchments, however no records were identified which detail flooding at this level crossing.

XC209 Ballyhay Site

A few newspaper articles were identified documenting flooding in the town of Charleville (closest town to the level crossing site) from the River Maigue sub-catchments, however no records were identified which detail flooding at this level crossing.

XC211 Newtown/XC212 Ballycoskery Site

No records were identified which detail flooding at these level crossings.

XC215 Shinanagh Site

No records were identified which detail flooding at this level crossings.

XC219 Buttevant Site

The XC219 Buttevant site is located adjacent to the Awbeg River. One record was found on a social media website, Twitter, alerting to floods on the Liscarroll to Buttevant Road (R522) on the 14th of March 2018. This is consistent with Flood Event 5 detailed previously within Section 3.2.1. There are no further reports of past floods in any articles, however reference to a former pond associated to an old corn mill around Buttevant town is made.

This reference states that even nowadays, when pluvial episodes occur, the river floods into what used to be the pond, now a floodplain. However, it is not thought that this flooding affects the level crossing.

OPW Preliminary Flood Risk Assessment Mapping (PFRA)

The OPW National PFRA mapping has been reviewed to identify potential sources of flooding from fluvial and pluvial sources. This mapping should be used with caution due to the grid size being relatively coarse, which limits its accuracy.

XC187 Fantstown Site

The PFRA outputs show this site to be within the 1% AEP fluvial flood extent, which equates to Flood Zone A.

The PFRA mapping indicates that pluvial flood risk up to and including the 0.1% AEP pluvial extreme event is restricted to localised depressions situated away from the site. This was verified through site visits and topographic survey. The risk from pluvial flooding is therefore considered to be low.

XC201 Thomastown Site

The PFRA mapping indicates the site is not located within an area of fluvial flood risk (0.1% or 1% AEP flood events).

The PFRA mapping indicates that pluvial flood risk up to and including the 0.1% AEP pluvial extreme event is restricted to localised depressions situated away from the site. This was verified through site visits and topographic survey. The risk from pluvial flooding is therefore considered to be low.

XC209 Ballyhay Site

The PFRA mapping indicates that part of the site is located within the 1% AEP fluvial flood extent, which equates to Flood Zone A.

The PFRA mapping indicates that pluvial flood risk up to and including the 0.1% AEP pluvial extreme event is restricted to localised depressions situated away from the site. This was verified through site visits and topographic *survey. The risk from pluvial flooding is therefore considered to be low.*

XC211 Newtown/XC212 Ballycoskery Site

PFRA mapping indicates that XC212 Ballycoskery is proximate to the 1% AEP fluvial flood extent, which equates to Flood Zone A.

The PFRA mapping indicates that pluvial flood risk up to and including the 0.1% AEP pluvial extreme event is restricted to localised depressions situated away from the site. This was verified through site visits and topographic survey. The risk from pluvial flooding is therefore considered to be low.

XC215 Shinanagh Site

The PFRA mapping indicates the site is not located within an area of fluvial or pluvial flood risk (0.1% or 1% AEP flood events).

XC219 Buttevant Site

The PFRA outputs show the proposed Project to be within the 1% AEP fluvial flood extent, which equates to Flood Zone A.

The PFRA mapping indicates that pluvial flood risk up to and including the 0.1% AEP pluvial extreme event is restricted to localised depressions located within the site.

CFRAM Mapping

The level crossing sites are not located within the extents assessed by the OPW Catchment Flood Risk Assessment and Management (CFRAM) Study.

Geological Survey Ireland mapping – Groundwater

Geological Survey Ireland (GSI) mapping has been used to analyse if any of the sites might be affected by, or affect, groundwater wells and springs; karst landforms and/or groundwater source protection areas and zones of contribution.

XC187 Fantstown Site

There is a dug well located nearby. No other groundwater formations to be affected by the proposed Project at this site.

XC201 Thomastown Site

Dug wells and Boreholes were identified proximate to the site. No other groundwater formation nearby.

XC209 Ballyhay Site

No groundwater formations near this site.

XC211 Newtown/XC212 Ballycoskery Site

No groundwater formations near these sites.

XC215 Shinanagh Site

Spring karst landform located nearby to the XC215 Shinanagh level crossing. No other groundwater formation nearby.

XC219 Buttevant Site

An agriculture and domestic use borehole is located nearby and reaches the area underneath this site and respective proposed Project.

OSI Historic 6" Mapping

OSI Historic 6" maps have been reviewed to identify any historic sources of flooding which have the potential to impact on the sites. This may include historic development, historic drainage features, or other relevant information. No features have been identified which impact on the assessment of flood risk at the locations of the level crossing sites.

Previous Flood Risk Assessments

Under the Planning and Development Act 2000, each Planning Authority is obliged to make a Development Plan every six years. These Local Area Plans (LAP) were developed for the surrounding towns (Fermoy Municipal District, Kilmallock, as well as for Mallow Electoral Area) of the level crossing sites.

Mallow Electoral Area LAP

The Flood Risk Management Plan for the Buttevant settlement in 2011 developed in the Mallow Electoral Area LAP identified Flood Zones A and B in the areas at risk that follow the path of the Awbeg River. The proposed access road solution for the XC219 Buttevant site is located within both flood zones A and B.

Proposed Kilmallock LAP 2019 - 2015

The Flood Risk Management Plan for Kilmallock (2019-2025) developed in the proposed Kilmallock LAP identified flood zones within the town's limits. No specific concern is raised regarding the XC201 Thomastown and XC187 Fantstown level crossing sites in this Plan.

Fermoy Municipal District LAP 2019 - 2015

The flood risk management plan for Charleville identified flood zones within the town's limits. No specific concern is raised regarding the XC201 Thomastown and XC209 Ballyhay level crossing sites in this Plan.

1.5.3 Stage 1 Flood Risk Assessment Summary

XC187 - Fantstown

This site is considered to be at high risk of fluvial flooding. A low risk of flooding from all other sources has been identified. A Stage 2 Flood Risk Assessment would normally be required. However, as the works in this location comprise removal of the existing level crossing meaning the permanent removal of a flood vulnerable asset, **no further flood risk assessment is required**.

XC201 - Thomastown

This site is considered to be at low risk of flooding from all sources. The detailed proposals include a drainage strategy which uses sustainable drainage systems (SUDS) to manage surface water to ensure no net increase in runoff from existing rates. **No Stage 2 Flood Risk Assessment is required.**

XC209 - Ballyhay

This site is considered to be a less vulnerable development and is at high risk of fluvial flooding. A low risk of flooding from all other sources has been identified. **A Stage 2 Flood Risk Assessment is required**, although only minimal infrastructure in the form of a control building for the CCTV is proposed.

XC211/212 – Newtown/Ballycoskery

This site is considered to be at moderate risk of fluvial flooding. A low risk of flooding from all other sources has been identified. **A Stage 2 Flood Risk Assessment is required.**

XC215 - Shinanagh

This site is considered to be at low risk of flooding from all sources. The detailed proposals include a drainage strategy which uses sustainable drainage systems (SUDS) to manage surface water. **No Stage 2 Flood Risk Assessment is required.**

XC219 - Buttevant

This site is considered to be at high risk of fluvial flooding and at low risk of flooding from all other sources. **A Stage 2 Flood Risk Assessment is required.**

1.6 Stage 2: Initial Flood Risk Assessment – Potential Impacts to the proposed Project

This section assesses the risk of flooding to XC209 Ballyhay, XC211/212 Newtown and Ballycoskery and XC219 Buttevant from all sources once the proposed Project has been completed, which is used to develop a broad understanding of the overall flood risk associated with the proposed Project.

1.6.1 Potential Sources of Flooding

Potential sources of flooding, as listed below:

- Coastal – flooding from the sea;
- Fluvial – flooding from rivers and watercourses;
- Estuarine – flooding from a combination of fluvial and coastal;
- Pluvial – flooding that is caused by runoff during high rainfall events;
- Artificial Drainage Systems – flooding that occurs as a result of surcharging or blocking of drainage networks;
- Reservoirs and other artificial sources – flooding from the water stored in reservoirs, channels or other artificial structures; and
- Groundwater – flooding when water normally stored below the ground rises above surface level or into below ground spaces (such as basements).

1.6.2 Coastal Flood Risk

Coastal flooding is caused by high sea levels with/without a surge tide, resulting in the sea overflowing onto the land. Coastal flooding is influenced by three main factors, which often work in combination. These are:

- **High tide levels** - associated with the astronomical cycle.
- **Storm surges** - where sea levels are raised by areas of low barometric pressure such as depression weather systems.
- **Wave action** - this is dependent on wind speed and direction, as well as local topography and exposure.

All 7 sites are located between the Mallow and Charleville towns (North Co. Cork) and near Kilmallock town (South Co. Limerick). It can be concluded that as all sites are located inland and at a minimum elevation of 96.0mAOD there is low flood risk to the proposed sites from coastal sources.

1.6.3 Fluvial Flood Risk

The Stage 1 assessment indicated a high potential risk of fluvial flooding to XC209 Ballyhay, XC211 Newtown/XC212 Ballycoskery and XC219 Buttevant.

XC209 - Ballyhay

The proposal for XC209 Ballyhay is for the existing level crossing to be upgraded to a CCTV controlled level crossing. The proposed Project and method of installation of the CCTV will have no permanent or temporary impact on fluvial flooding and the CCTV infrastructure itself will not be susceptible to flooding.

A new Relocatable Equipment Building (REB) will be constructed to the north of the existing level crossing. The building will be constructed within the footprint of an existing building that is to be demolished.

Whilst the proposed REB will be at risk of flooding, it will be designed to flood resilient including the provision of Individual Property Protection Measures (IPP) and all electrical switchboards to be elevated and IP67 rated so that they will remain operational if subjected to immersion in flood water.

The proposed works also remove the existing requirement for the level crossing to be manually operated. The new REB and CCTV will mean that the level crossing operates automatically and in all conditions. This will remove the current risk of human exposure to flooding from the required manual operation of the crossing.

Whilst the proposed works will be at risk of flooding, they will be designed with appropriate mitigation to ensure that they are flood resilient. The works also eliminate the current risk from the need for manual operation of a level crossing within a flood zone.

XC211/XC212 – Newtown / Ballycoskery

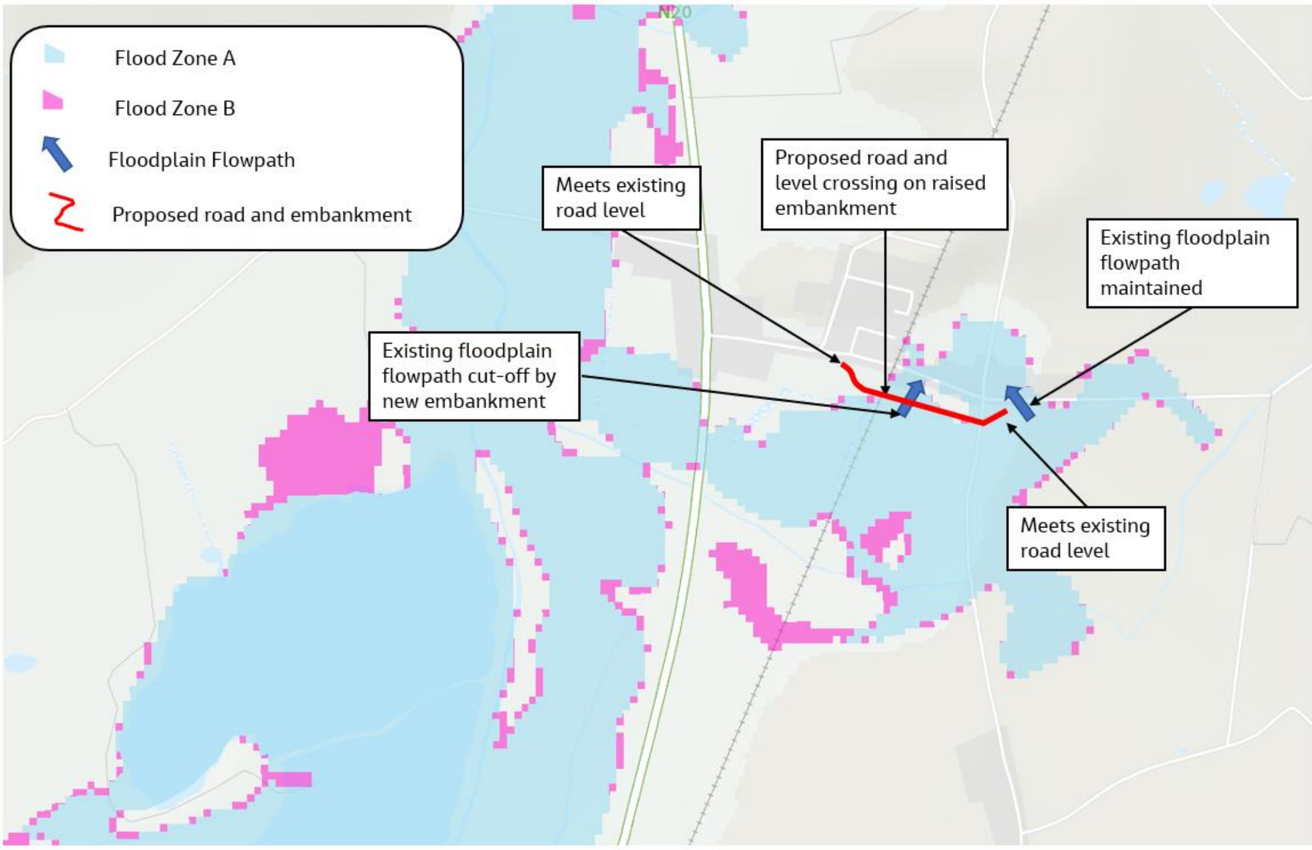
The proposed Project at XC211 Newtown / XC212 Ballycoskery site includes the construction of a new road-over-rail bridge adjacent to a flood risk area (based on PFRA mapping).

Based on aerial photography, the cause of flooding in the PFRA mapping appears to be associated with the Awbeg River, immediately to the west of the N20. Whilst all proposed Project is located to the east of the N20 at this location, PFRA mapping does indicate that the flooding could extend across the road itself and to the east of the N20 in high magnitude events, either directly or via the backing up of tributaries.

The PFRA outputs show the proposed embankment of XC212 Ballycoskery (particularly the western extent) is adjacent to the 1% AEP fluvial flood extent. Historic flooding in the area, as detailed within Section 3.2.1, is generally consistent with this mapping.

Flood Zone Mapping from Cock County Council (Inset Figure 1.6) also shows the proposed works to be located in Flood Zone A.

Inset Figure 1.6 Flood Zone Mapping (Background Mapping Source: Cork County Council)



1% AEP flood levels in the area can be estimated to be maximum 95.7mOD based on the available flood extents. This compares to the finished ground levels for the Proposed Project vary but are typically greater than 98.0mOD throughout. This indicates that the Proposed Project will not be at risk of flooding.

XC219 - Buttevant

The proposed Project at XC219 Buttevant includes the construction of a road-over-rail bridge and part of a new access road within the 1% AEP flood extent, which equates to Flood Zone A. The road-over-rail bridge itself is elevated and is outside Flood Zone A and B, however the access roads will be at risk of flooding.

An initial review of PFRA flood extents and available topographic survey enables an approximation of the 1% AEP and 0.1% AEP flood levels. These are detailed within Table 1.2 below.

Table 1.2 River Awbeg Flood Level Estimation for site XC19 Buttevant

AEP Event	River Awbeg Flood Level (mOD)
1% (1 in 100)	83.0
0.1% (1 in 1000)	84.0

Due to the location of the proposed Project within Flood Zone A, **a Stage 3 Detailed Flood Risk Assessment was recommended**.

This assessment included detailed hydraulic modelling to confirm the level of flood risk and that the proposed Project causes no increase in flood risk elsewhere. The outcomes from the Stage 3 Assessment are presented in Section 6.

1.6.4 Estuarine Flood Risk

The conclusion from the coastal flood risk assessment also apply to the estuarine flood risk, as all 7 sites are located in between the Mallow and Charleville towns (North Co. Cork) and near Kilmallock town (South Co. Limerick). It can be concluded that, as all sites are located inland and at a minimum elevation of 96.0mAOD there is low flood risk to the proposed sites from estuarine sources.

1.6.5 Pluvial Flood Risk

Pluvial flooding occurs during periods of heavy rainfall, when the rainfall rate is greater than the infiltration capacity. It is usually associated with high intensity rainfall events (typically > 30mm/h) resulting in overland flow and ponding in depressions in the topography. In urban situations underground sewerage/drainage systems and surface watercourses may be completely overwhelmed.

The majority sites include highway works which incorporate an impermeable road surface. As such, a camber on the road surface and appropriate drainage features are embedded in the design to reduce the risk of the proposed Project to pluvial flooding. Drainage features are designed in a way to avoid impacting flood risk elsewhere (see Section 5.3).

In addition, PFRA mapping indicates that the sites XC215 Shinanagh and XC219 Buttevant are within or proximate to an area of pluvial flood risk.

XC215 - Shinanagh

XC215 Shinanagh includes works to and adjoining the existing highway network in areas identified as being at risk of pluvial flooding. As noted in Section 3.2.3, the PFRA mapping should be used with caution due to the grid size being relatively coarse and is appropriate for use in high level screening only.

Topographic survey confirmed a single depression to the west of the proposed Project, but beyond the site boundary. A review of aerial photography does not indicate any features / habitat associated with frequent or prolonged inundation. As such, the risk of pluvial flooding to the proposed Project is deemed to be low.

Potential impacts from the proposed Project on pluvial flooding are discussed in Section 5.3.

XC219 - Buttevant

PFRA mapping identifies an area of pluvial flood risk immediately to the south of the proposed highway alignment, on the east of the railway. A review of topographic survey confirms that the existing ground slopes away from the proposed highway in a southerly direction – both verifying the PFRA mapping and also indicating low risk of pluvial flooding to the proposed Project.

In addition, XC219 Buttevant includes a highway raised above the existing ground level and as such the risk from pluvial flooding to this development can further be considered low.

Potential impacts from the proposed Project are discussed in Section 5.3.

1.6.6 Artificial Drainage Systems

Most of the sites are either greenfield or isolated rural areas meaning there are no existing artificial drainage systems present which could give rise to a risk of flooding. Out of these, sites XC187 Fantstown and XC201 Thomastown do not have any artificial drainage systems and have no drainage districts (DD) or arterial drainage systems (ADS) in their vicinities, which could give rise to a risk of flooding.

The sites XC209 Ballyhay and XC215 Shinanagh do not have any artificial drainage systems but do have DD channels (the Awbeg River and tributaries) and benefited land affecting the respective proposed Projects. The impact on any DD channels is assessed under the Fluvial flood risk assessment in Section 4.3.

The sites XC211 Newtown/XC212 Ballycoskery and XC219 Buttevant are located in rural but populated areas, however there have been no historic flooding events associated with the existing drainage systems.

Therefore, the risk from artificial drainage systems flooding to these proposed Projects can be considered **low**.

1.6.7 Reservoirs and Other Artificial Sources

There are no new proposed reservoirs in the Mallow and Kilmallock LAP, and the ones that exist (Castletwonroche, Doneraile, Banteer and Fiddane reservoirs) are not located near the sites.

Taking the absence of past reservoir failures, and the number and average age of reservoirs in Ireland (many hundreds of reservoirs nationally, with an estimated average age of over 30 years), it may be concluded that the likelihood of flooding due to a reservoir breach is **very low**.

1.6.8 Groundwater Flood Risk

No evidence of groundwater flooding has been identified on the existing level crossing sites. Given their proximity to the River Awbeg and River Maigue sub-catchments, it is likely that any groundwater movements beneath the sites, reported in the GSI section 3.2.5 of this report, will be hydraulically connected to the rivers. The risk of groundwater flooding can therefore be concluded to be **low.**

1.6.9 Summary of Flood Risk

Table 1.3 below provides a summary of the potential flood risk from each of the sources of flooding considered to the proposed Project.

Table 1.3 Summary of Flood Risk to Proposed Project on all sites

Source of Flooding	XC212 Ballycoskery	XC201 Thomastown	XC209 Ballyhay	XC211 Newtown	XC215 Shinanagh	XC219 Buttevant
Coastal	Low	Low	Low	Low	Low	Low
Fluvial	Moderate	Low	High	Moderate	Low	High
Estuarine	Low	Low	Low	Low	Low	Low
Pluvial	Low	Low	Low	Low	Low	Low
Artificial Drainage Systems	Low	Low	Low	Low	Low	Low
Reservoirs and Other Artificial Sources	Very Low	Very Low	Very Low	Very Low	Very Low	Very Low
Groundwater	Low	Low	Low	Low	Low	Low

General considerations for all sites include:

- The sites are not at risk of coastal flooding due to inland location and elevation of at least 96.0mAOD.
- The sites are not at risk of estuarine flooding due to inland location.
- The sites are not at risk of flooding from reservoirs or other artificial sources because they are not proximate to these sources of flood risk.
- The sites are not at risk of flooding from Artificial Drainage Systems as they are greenfield sites and no artificial drainage is present.
- The sites are not at risk from groundwater flooding since all groundwater movements are hydraulically connected to the rivers nearby.

1.6.10 Flood Risk due to Climate Change

Future climate change is predicted to give rise to an increased risk of flooding through rising sea levels, an increase in river flows, and an increase in the frequency and intensity of extreme rainfall events. The OPW has identified two potential scenarios for the impacts of climate change referred to as the Mid-Range Future Scenario (MRFS) and High-End Future Scenario (HEFS). Table 1.4 summarises the predicted impacts of both scenarios on sea levels, river flows and rainfall depths over the next 100-years.

Table 1.4 Climate Change Forecasts

Parameter	Mid-range Future Scenario (MRFS)	High-End Future Scenario (HRFS)
Mean Sea Level Rise	+500mm	+1000mm
River Flows	+20%	+30%
Extreme Rainfall Depths	+20%	+30%

The Mid-Range Future Scenario (MRFS) scenario is intended to represent the 'likely' future scenario based on a range of forecasts. For the purposes of this flood risk assessment, the potential impact of climate change on flood risk to the level crossings' sites have been made relative to the MRFS scenario. Table 1.5 summarises the potential impacts of climate change on the level crossings' sites.

Table 1.5 Climate Change Impacts

Source of Flooding	Likely Impacts of Climate Change	Discussion
Coastal	No Impact	No change due to the location of all sites inland meaning they will not be at risk from coastal flooding despite the predicted increase in sea levels as per Table 4.2.
Fluvial	Increased risk of flooding	Predicted future climate change will cause an increase in the flows in the Awbeg River, the proposed Project at XC209 Ballyhay, XC212 Ballycoskery and XC219 Buttevant that are already within or adjacent to areas of fluvial flood risk could be affected by flooding with an increased frequency and magnitude.
Estuarine	No Impact	No change due to the location of all sites being inland meaning they will not be at risk from estuarine flooding despite the predicted increase in sea levels as per Table 4.2.
Pluvial	Increased risk of flooding	Future climate change will result in increased rainfall depths and extents, and this has the potential to increase the risk of pluvial flooding to the sites. Any new highway drainage would however be designed to allow for the effects of future climate change.
Artificial Drainage Systems	No Change	All additional stormwater drainage required on the sites/proposed Projects will be designed to cater for the effects of future climate change.
Groundwater	No Change	No change. Climate change is unlikely to have a significant impact on groundwater flooding in the area and, given the proximity of sites to the River Awbeg and River Maigue sub-catchments, it is likely that any groundwater movements beneath the sites will continue to be hydraulically connected to the rivers.

1.7 Stage 2: Initial Flood Risk Assessment – Potential Impacts from the proposed Project

Section 4 considered the risk of flooding to the proposed Project. This section considers the potential change in flood risk to the surrounding areas arising from the proposed Project and, where appropriate, considers the necessary mitigation to ensure no increase in the risk of flooding.

1.7.1 Impacts on Coastal and Estuarine Flooding

As per section 4.2 and 4.4, all 7 sites are located in between the Mallow and Charleville towns (North Co. Cork) and near Kilmallock town (South Co. Limerick). It can be concluded that as all sites are located inland the proposed Project will not affect the risk of coastal or estuarine flooding.

1.7.2 Impacts on Fluvial Flooding

The Stage 1 assessment indicated a high potential risk of fluvial flooding to the XC209 Ballyhay, XC211 Newtown/XC212 Ballycoskery and XC219 Buttevant proposed sites.

These proposed Projects have the potential to increase the risk of fluvial flooding elsewhere, depending on the nature of the works and their location. Proposed Projects to sites XC201 Thomastown and XC215 Shinanagh do not intrude on any existing watercourse and will not create a significant obstruction to flow within the floodplain network. Therefore, it is considered that these sites will not impact on the existing fluvial risk.

It is noted that the introduction of new impermeable areas could potentially increase the volume and peak flow of surface runoff reaching watercourses and could therefore contribute to an increase in flood risk. This potential impact has been assessed and designed out (embedded mitigation) through the proposed drainage strategy, that ensures maximum outflow is capped at existing greenfield runoff rates resulting in no increase in fluvial flood risk. The drainage strategy is discussed in more detail in Section 5.3.

An assessment of potential fluvial flood risk impacts from sites XC209 Ballyhay, XC211 Newtown/XC212 Ballycoskery, and XC219 Buttevant is made below.

XC209 – Ballyhay

The proposal for XC209 Ballyhay is for the existing level crossing to be upgraded to a CCTV controlled level crossing. No significant construction works are proposed and the method of installation of the CCTV will have no permanent or temporary impact on fluvial flooding.

A new Relocatable Equipment Building (REB) will be constructed to the north of the existing level crossing. This is located within the footprint of and replaces an existing building. Given this, the development can be assessed as having no impact (positive or negative) on fluvial flood risk to the surrounding area.

XC211/XC212 - Newtown/Ballycoskery

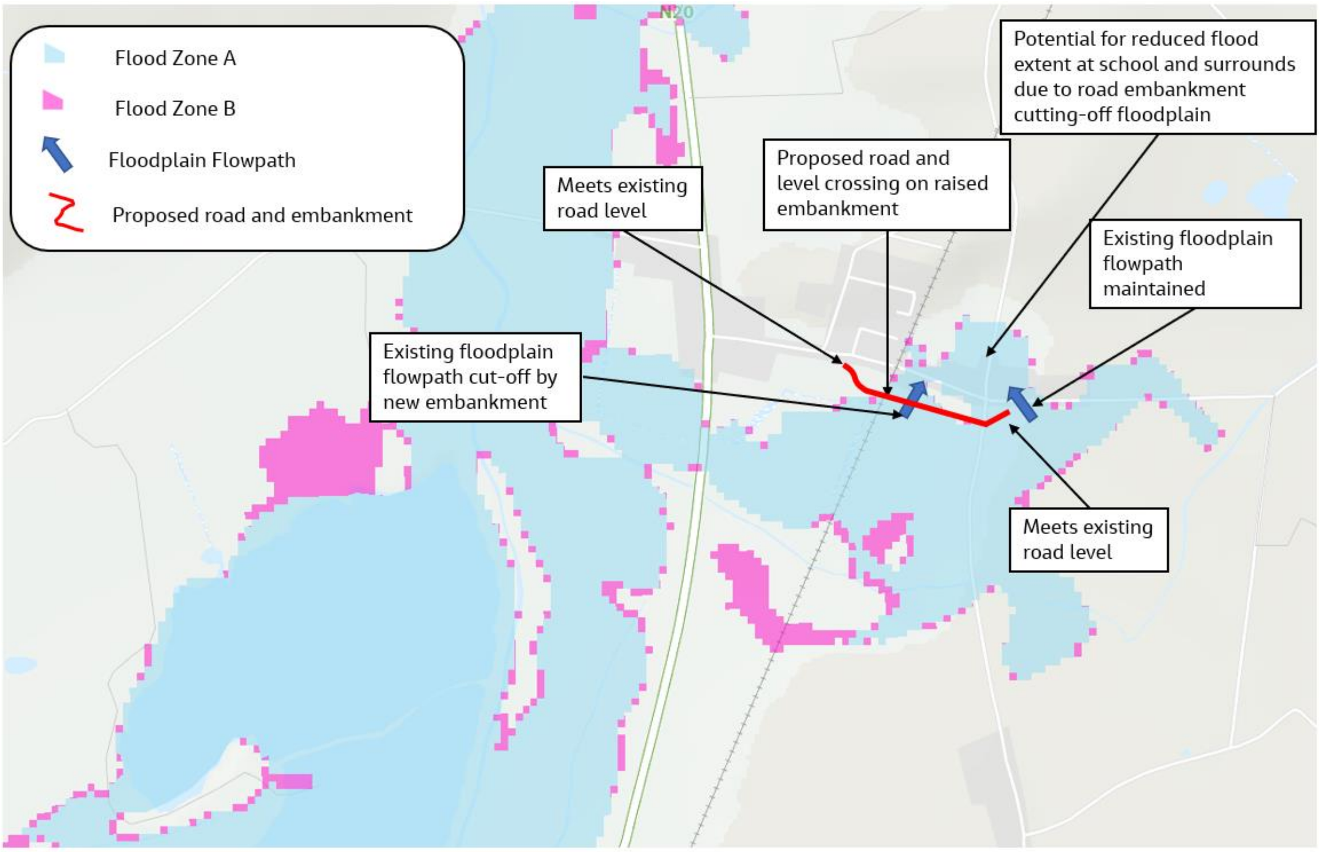
The proposed Project at XC211 Newtown / XC212 Ballycoskery site includes the construction of a new road-over-rail bridge adjacent to a flood risk area (based on PFRA mapping).

Based on aerial photography, the cause of flooding in the PFRA mapping appears to be associated with the Awbeg River, immediately to the west of the N20. Whilst all of the proposed Project is located to the east of the N20 at this location, PFRA mapping does indicate that the flooding could extend across the road itself and to the east of the N20 in high magnitude events, either directly or via the backing up of tributaries.

The PFRA outputs show the proposed embankment of XC212 Ballycoskery (particularly the western extent) is adjacent to the 1% AEP fluvial flood extent. Historic flooding in the area, as detailed within Section 3.2.1, is generally consistent with this mapping.

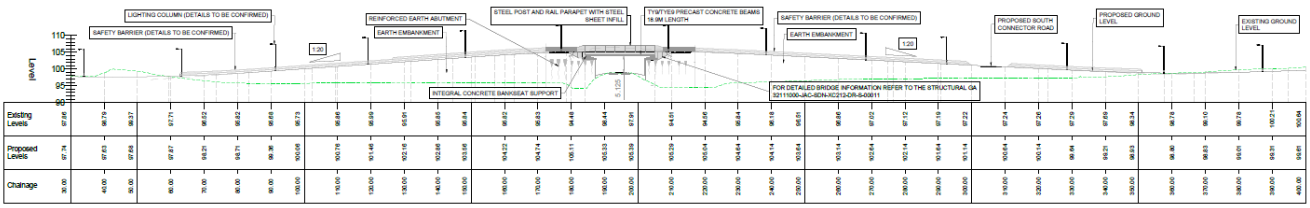
1% AEP flood levels in the area have been estimated to be approximately 95.7mOD based on available flood mapping; see Inset Figure 1.7.

Inset Figure 1.7 Floodzone Mapping for Ballycoskery (Base Mapping Source: Cork County Council)



Inset Figure 1.8below shows a section through the proposed works. The minimum ground level is 98.3mOD where the new road meets the existing road (to the east), rising up to 105.4m OD where the railway line is crossed on a bridge.

Inset Figure 1.8 Long Section through Proposed Road and Embankment



The proposed road and embankment have the potential to cut-off a small section of the existing floodplain. As shown in Inset Figure 1.7, flows will be prevented from running north, parallel to the railway line. Flows will still however be able to bypass the works to the east as they spill over the existing road. There is therefore the potential for a small decrease in the risk of flooding to school.

The proposed works are therefore assessed to have a negligible to potential beneficial impact on flooding.

XC219 - Buttevant

The proposed Project at XC219 Buttevant includes the construction of a road-over-rail bridge and part of a new access road within the 1% AEP flood extent, which equates to Flood Zone A. The location of the proposed Project within Flood Zone A mean there is a potential impact on existing water levels in a flood event. Upstream and downstream receptors include a few properties, the R522 itself, local roads, and agricultural land.

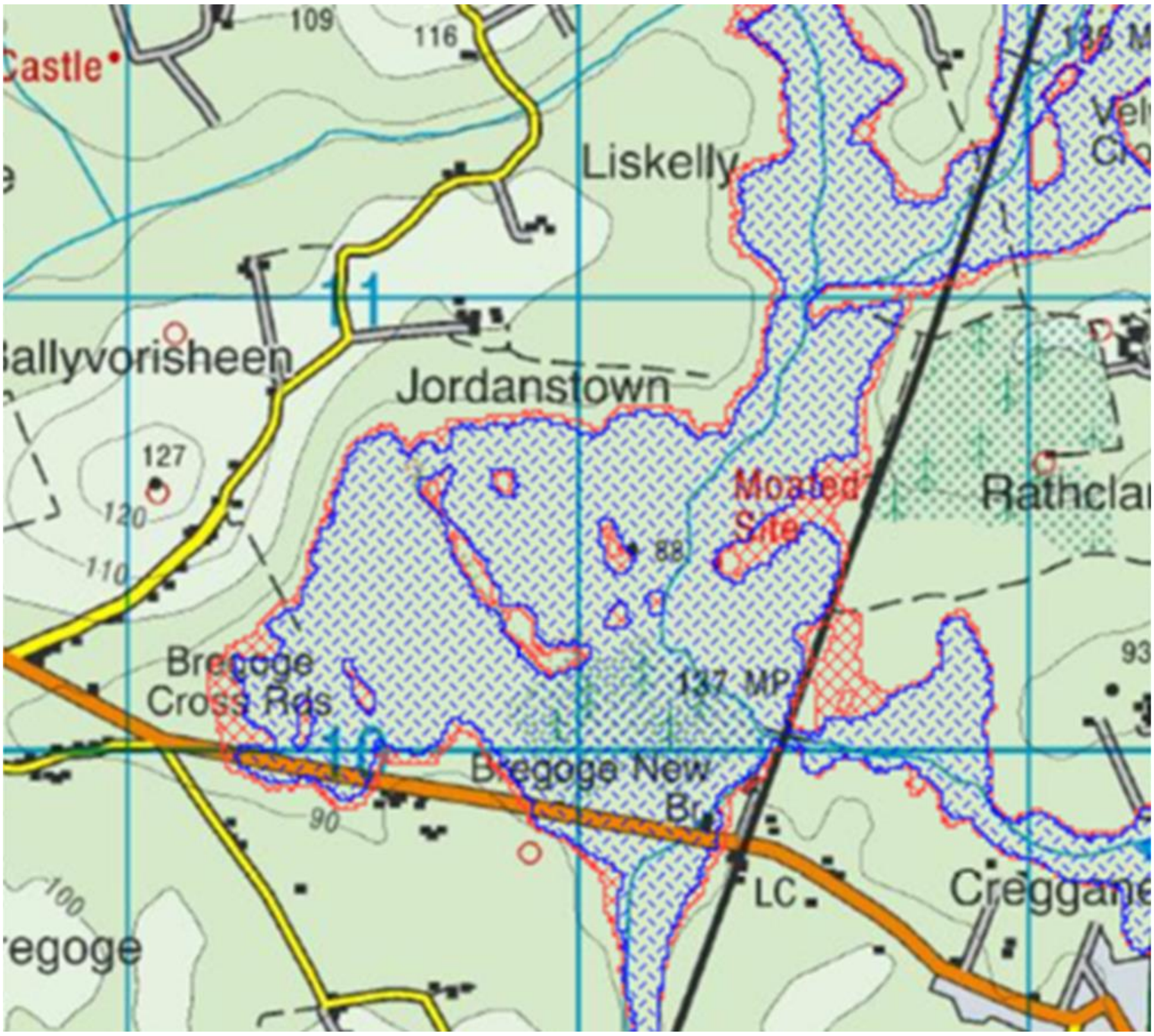
An initial review of PFRA flood extents and available topographic survey enables an approximation of the 1% AEP and 0.1% AEP flood levels. These are detailed within Table 1.6below.

Table 1.6: Pepperhill Stream Flood Level Estimation for site XC219 Buttevant

AEP Event	Pepperhill Stream Flood Level (mOD)
1% (1 in 100)	83.0
0.1% (1 in 1000)	84.0

Cork County Council provided indicative maps showing flood extents based on historic flooding (Inset Figure 1.9). These are consistent with and assist in verifying the PFRA mapping at a high level.

Inset Figure 1.9 Past Flood Events within 2.5km From Buttevant



Due to the location of the proposed Project within Flood Zone A, a **Stage 3 Detailed Flood Risk** was completed, supported by detailed hydraulic modelling, to verify the impacts of the works on flood risk (see Section 6).

1.7.3 Impacts on Pluvial Flooding

As noted previously, the majority of sites include highway works which incorporate an impermeable road surface. In most cases, areas of greenfield or undeveloped land are being used, leading to an increase in impermeable areas.

As such, appropriate drainage features are embedded in the design to mitigate the potential impact of the proposed Project on pluvial flooding.

In general, the highway drainage design encompasses over the edge drainage, in keeping with *NRA TB 13 – Revised Road Drainage Standards*, supplemented with additional features to accommodate the presence of structures or site constraints where necessary. New swale ditches are proposed, located at the toe of the road embankments, that will then drain back to existing watercourses or connecting ditches. This drainage strategy maximises attenuation and facilitates pollution control as part of a SuDS management chain.

The swale features will be grassed, with shallow side slopes and a long-wetted perimeter to reduce flow rates and velocities. Typically, they will be underlain by a filter material and perforated pipe to provide a second stage of treatment. The width of the swale varies between 3 and 7 metres depending on the site, and the depth (including 0.15 metres freeboard) is up to 0.75 metres and typically less than 0.5 metres. Typical details of the proposals are in keeping with TII Publication Number CC-SCD-00525 (also provided in Inset Figure 1.10 below). Where agricultural or local access must be maintained, a short section of culvert will be constructed beneath the respective junction to ensure connectivity of the swale ditches either side of the access.

The swale ditches will outfall directly or indirectly into water bodies within the River Maigue or River Awbeg sub-catchments respectively. The swales are designed to attenuate surface runoff in the 1% AEP (including climate change) rainfall event and the maximum outflow of the swales will be capped at existing greenfield runoff rates.

XC219 Buttevant

In addition, to the proposed drainage strategy set out above, a section of the highway embankment on XC219 Buttevant is located within the existing floodplain.

Whilst the highway itself is raised, swale ditches (at the toe of the embankment) are not proposed within the existing floodplain as there is a potential for these to be overwhelmed in a fluvial flood event, resulting in a direct pathway between untreated runoff from the highway and the receiving watercourse (Pepperhill Stream). Instead, a gully and pipe network is detailed which will capture surface runoff from the highway. This will discharge into the Pepperhill (indirectly via existing ditches) through an interceptor. The discharge will be capped to existing greenfield rates.

All swale ditches for XC219 Buttevant outfall directly to the Pepperhill Stream.

1.7.4 Impacts on Flooding from Artificial Drainage Systems

Most of the sites are either greenfield or isolated rural areas meaning there are no existing artificial drainage systems present which could give rise to a risk of flooding.

The sites XC209 Ballyhay and XC215 Shinanagh do not have any artificial drainage systems but do have DD channels and benefited land affecting the respective proposed Projects. The DD channel here is the entire Awbeg River and tributaries. Risks to these water bodies has been assessed under fluvial flood risk in Section 5.2.

The sites XC211 Newtown/XC212 Ballycoskery and XC219 Buttevant are located in rural but populated areas, however, there have been no historic flooding events associated with the existing drainage systems. The proposed drainage design does not rely on existing drainage infrastructure and as such no increased pressure is placed on the infrastructure in relation to capacity.

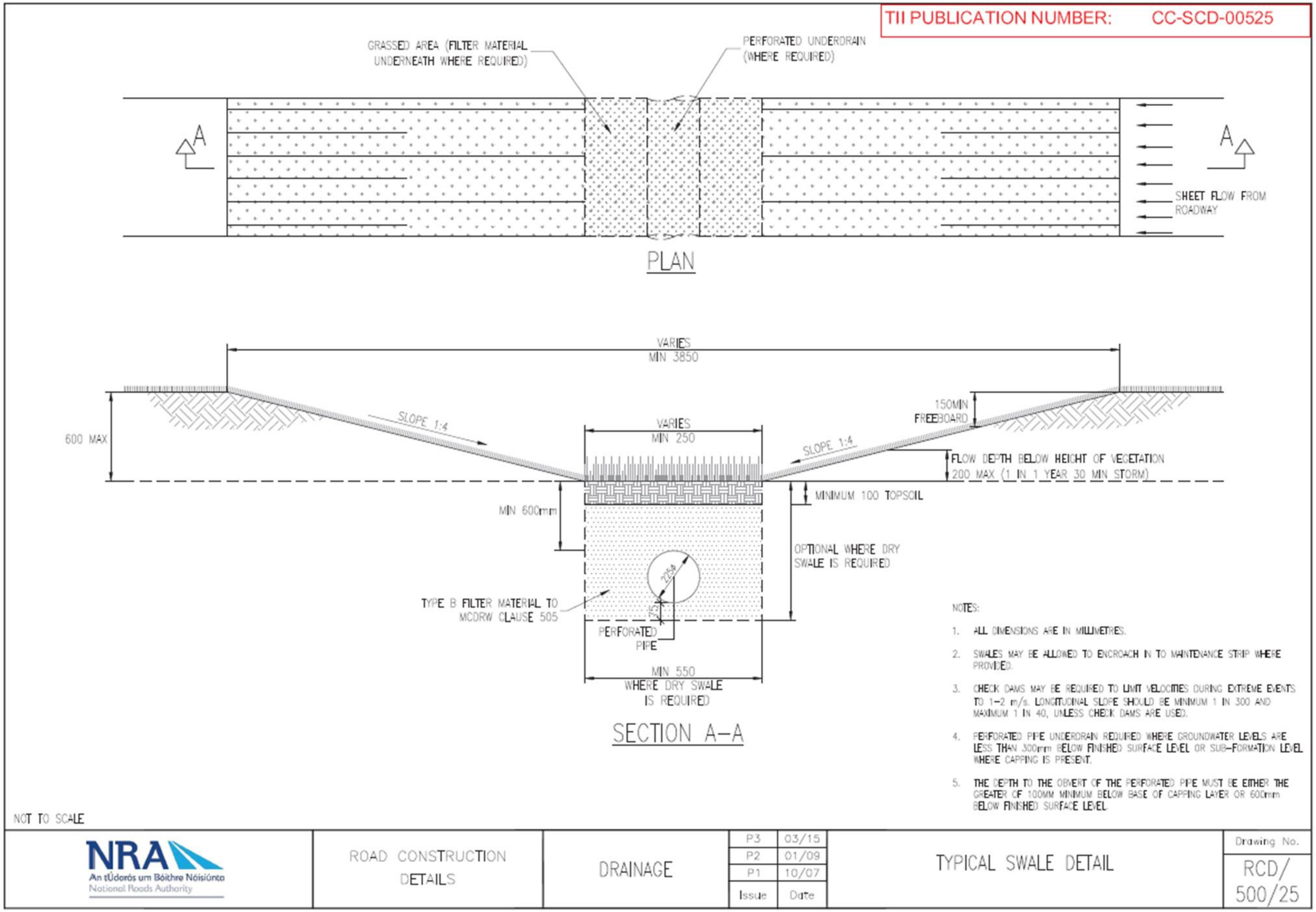
Any increase in impermeable surface areas associated with the upgrade works shall be accounted for in the drainage design (see Section 5.3) ensuring no increase in runoff from the proposed Projects. Therefore, the impact of the proposed Project on artificial drainage systems can be considered to be **low**.

1.7.5 Impacts on Groundwater Flooding

No evidence of groundwater flooding has been identified on the existing level crossing sites. Given their proximity to the River Awbeg and River Maigue sub-catchments, it is likely that any groundwater movements beneath the sites (Section 3.2.5) will be hydraulically connected to the rivers. The risk of groundwater flooding from the proposed Project can therefore be considered in parallel with the assessment made in Section 4.3.

This concluded no or negligible impact at all sites except XC219 Buttevant which **will be subject to a Stage 3 Detailed Flood Risk Assessment** (Section 6).

Inset Figure 1.10 Typical Swale Detail Proposed for Drainage Design (TII Typical Details)



1.8 Stage 3: Detailed Flood Risk Assessment

1.8.1 General

This section follows on from the findings in the Stage 2: Initial flood risk assessment that site XC219 Buttevant be subject to a Stage 3 Detailed Flood Risk Assessment to assess the fluvial flood risk at the site and identify the requirement for any mitigation measures.

A quantitative appraisal of potential flood risk to the proposed Project at XC219 Buttevant is provided, assessing its potential impacts on flood risk elsewhere and of the effectiveness of any proposed mitigation measures. This was undertaken by undertaking a detailed hydrological assessment of flows and constructing a site-specific hydraulic model across the study area to assess the catchment wide impacts and hydrological process involved. The Design Flow Estimation and Hydraulic Modelling reports from which this information is drawn are provided at Appendices B and C of this report.

The works at Buttevant include a new road-over-rail bridge and a tie in to the existing regional road to the east and west.

1.8.2 Hydrological Analysis

Catchment Description

The catchment area draining to the Pepperhill Stream watercourse at the R522 road crossing is 13.9km^2 in size. The Pepperhill Stream flows into the River Awbeg (Major) approximately 300m downstream of the R522 crossing. The River Awbeg to this point has a catchment area of approximately 155km^2. A gauging station (Station 18004 – Ballynamona) is located on the River Awbeg downstream of Buttevant, with a catchment area of 310km^2. The River Awbeg flows to the River Blackwater. The area of interest is within OPW Unit of Management 18. Catchment descriptors referred to in this report are detailed in FSU (2014a).

The catchment of the Pepperhill Stream to the R522 road crossing is moderately steep (S1085=12.9m/km) and relatively permeable (BFISOIL=0.64). There is no impact from reservoirs (FARL=1). The River Awbeg catchment to the confluence with the unnamed tributary is much shallower (S1085=2.1m/km) and similarly permeable (BFISOIL=0.59). There is also no impact from reservoirs (FARL=1).

The catchment of the Pepperhill Stream to the R522 road crossing is almost entirely given over to pasture (>99%). The catchment has not been subject to arterial drainage schemes (ARTDRAIN=0). There is very little urbanisation (URBEXT=0.0009).

The River Awbeg catchment to the confluence with the unnamed tributary is also largely pasture (90%), the remainder of the catchment is covered by forest (10%). The catchment has not been affected by arterial drainage schemes (ARTDRAIN=0). There is no significant urbanisation (URBEXT=0).

Standard average annual rainfall (SAAR) depths are =985mm for the Pepperhill Stream and 986mm for the Awbeg.

The geology in the Pepperhill Stream catchment to the R522 road crossing is similar in nature to that for the River Awbeg (GSI 2019). The bedrock geology consists largely of locally important and regionally important aquifers, a considerable part of which is karstified (diffuse) with extensive faulting. However, most of the bedrock in the catchment is overlain with superficial Till deposits (derived from sandstones and shales). Alluvium deposits are present in the watercourse valleys. Most subsoils are classed as having 'Medium' permeability.

Peak Design Flows

The XC219 Buttevant site on the Pepperhill Stream, immediately upstream of the R522 road crossing near Buttevant is ungauged and too far upstream of the nearest gauging station in the same catchment (Station 18004 on the River Awbeg) to be able to use that station to inform the design flows. The Flood Studies Update (FSU) Qmed regression equation was therefore used to produce an unadjusted synthetic estimate of Qmed.

A growth curve was determined using pooling group analysis with the group containing approximately 500 station-years of pooled data. The derived growth curve was then applied to the Qmed estimate, resulting in peak flow estimates for a number of design flood events with varying annual exceedance probabilities.

The estimation of peak design flows is provided in Table 1.7 below.

Table 1.7 : Peak Design Flows for Pepperhill Stream and River Awbeg

Annual Exceedance Probability (AEP)	Peak Flow (m3/s)	
	Pepperhill Stream	River Awbeg
50%	2.69	20.66
10%	3.96	27.68
5%	4.39	29.95
2%	4.88	32.64
1%	5.23	34.29
1% (MRFS scenario)	6.28	41.15
0.5%	5.58	35.94
0.1%	6.25	39.04

1.8.3 Hydraulic Model

Model Build

A one-dimensional (1D) model was created to enable an assessment of the existing (baseline) conditions, the post-development conditions, and the hydraulic design of the new structure for the preferred design option.

The model was built using the river modelling package Flood Modeller Pro (version 4.6.7). Topographic survey information was used to represent the river cross sections entered in the software whilst a site visit and map observations aided in selecting roughness Manning's 'n' coefficient applied to the watercourse cross-sections.

The modelled reach extends upstream and downstream of the proposed Project on the Pepperhill Stream (approximately 701m) and includes the confluence with the River Awbeg and the immediate reach upstream and downstream (approximately 358m).

The upstream and downstream boundary conditions applied to the model are described in Table 1.8.

Table 1.8 Hydraulic Model Boundary Conditions

Type of Boundary	Flood Modeller Node	Description
Flow-Time Boundary	Pep01_11.4	Flow-Time inflow boundary was applied at the upstream end of the Pepperhill Tributary at node Pep01_11.4
Flow-Time Boundary	Awb01_6.64	Flow-Time inflow boundary was applied at the upstream end of River Awbeg at node Awb01_6.64
Normal Depth Boundary	Awb01_364.55	Normal Depth boundary condition applied to the downstream end of River Awbeg at cross section Awb01_364.55

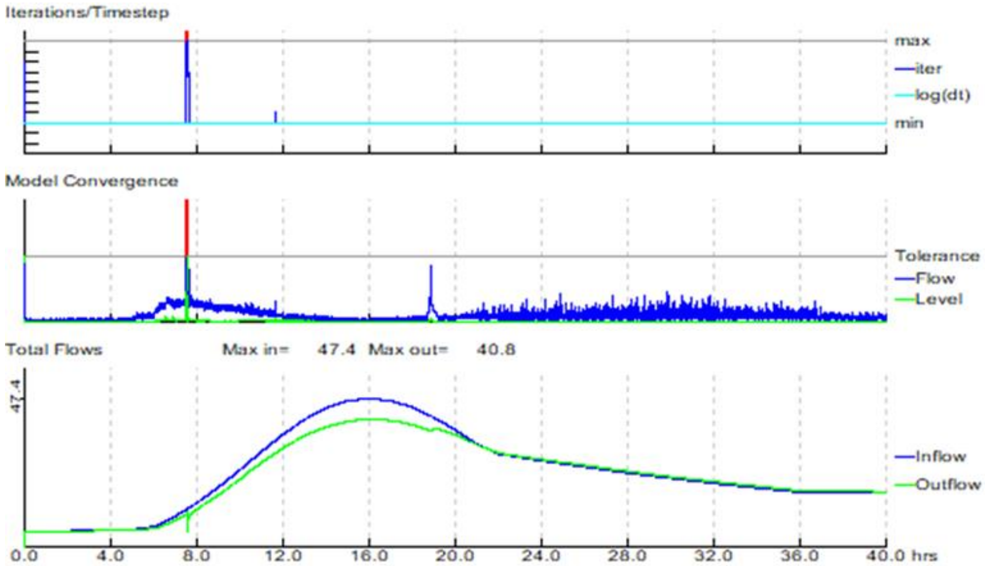
Reservoir units were used, as appropriate, to represent the wider floodplain of the Pepperhill Stream.

Model Verification

Un-steady state-run performance was monitored throughout the model build process to ensure model convergence was achieved. Convergence refers to the ability of the modelling software to arrive at a solution for which the variation of the found solution between successive iterations is either zero or negligibly small and lies within a pre-specified tolerance limit.

As shown in Inset Figure 1.11 and Inset Figure 1.12 below, 1D Flood Modeller Pro convergence for the 1% AEP plus Climate Change event simulation is good. During the baseline model simulations, non-convergence occurs on the rising limb of the hydrograph approximately 8 hours before the peak of the simulation at the time in which water spills from the Pepperhill Stream into the floodplain. This convergence plot is generally typical for all the modelled events in the baseline scenarios. Non-convergence is not observed for the design simulations.

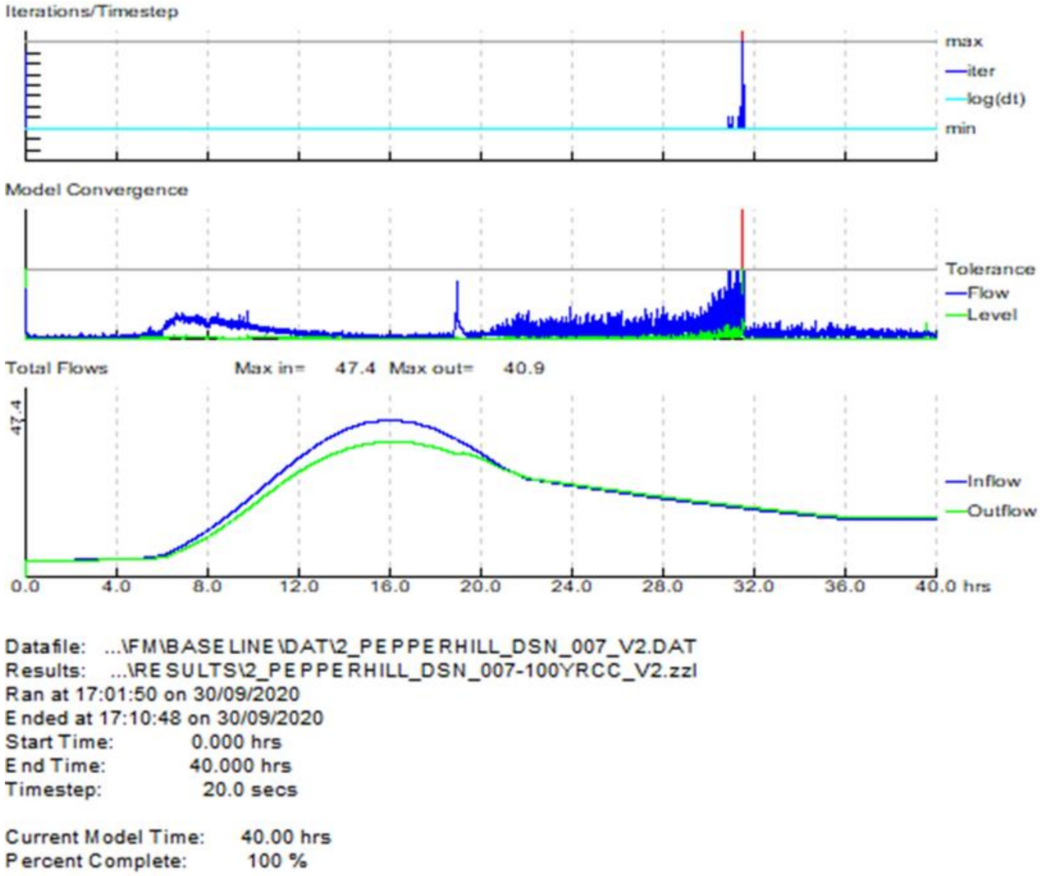
Inset Figure 1.11: 1D Model Convergence – 1% AEP Event Plus Climate Change (Baseline)



Datafile: ...\FM\BASELINE\DAT\2_PEPPERHILL_BSL_006_V2.DAT
Results: ...\RESULTS\2_PEPPERHILL_BSL_006_100YRCC_V2.zzl
Ran at 16:42:17 on 30/09/2020
Ended at 16:50:33 on 30/09/2020
Start Time: 0.000 hrs
End Time: 40.000 hrs
Timestep: 20.0 secs

Current Model Time: 40.00 hrs
Percent Complete: 100 %

Inset Figure 1.12: 1D Model Convergence – 1% AEP Event Plus Climate Change (Scheme)



As the Pepperhill Stream is ungauged and no gauging stations are located on the River Awbeg in the vicinity of the modelled reach, no hydrometric data was available for calibration/validation purposes. Cork County Council provided a map of observed flood extents for the Buttevant area. This mapping was used to verify the results of the baseline 1% AEP flood event and a plan showing good verification between the two can be seen in Inset Figure 1.13below.

Inset Figure 1.13 : Comparison of Observed Flood Events from Cork County Council (left) and Modelled Flood Events (right).

Model boundaries in Inset Figure 1.13 are illustrated in dashed black lines, flood extents illustrated in blue, red shading on right hand side shows higher ground based on LiDAR

In addition, the baseline model estimated water levels of approximately 83.6mOD at the proposed Project for the 1% AEP MRFS flood event. This is consistent with the estimated peak water level of 83.0mOD to 84.0mOD) interpreted from the PFRA mapping (Section 4.3.3).

1.8.4 Summary of impacts on Fluvial Flooding at XC219 Buttevant

Baseline Model Results

Detailed hydraulic modelling was undertaken to estimate peak flood levels of 83.63mOD in the 1% AEP flood event (including climate change) at the site, consistent with past observations of widespread out of bank flooding in the area.

Fluvial flooding in the area is driven by a combination of high flows in the Awbeg River (peak flows of 34.3m^3/s for a 1% AEP flood event) causing backing up of the Pepperhill tributary. High flows in the Pepperhill Stream tributary (peak flows of 5.2m^3/s for a 1% AEP flood event) are less significant in isolation but in combination result in widespread flooding.

A summary of peak water levels for various design events are provided in Table 1.9 below.

Table 1.9: Summary of Baseline Model Results

Location	Peak Water Level (mOD)		
	5% AEP	1% AEP	1% AEP MRFS
Upstream boundary of model	83.59	83.61	83.65
Upstream of side channel confluence	83.58	83.60	83.63
Upstream of proposed bridge / road embankment	83.58	83.60	83.63
Downstream of proposed bridge / road embankment and R522	83.57	83.60	83.63

Location	Peak Water Level (mOD)		
	5% AEP	**1% AEP**	**1% AEP MRFS**
Downstream of side channel confluence	83.42	83.48	83.56
Confluence with Awbeg River	83.36	83.43	83.53
Downstream of Awbeg River rail bridge	83.17	83.23	83.32

1.8.5 Scheme Design Model Results

The hydraulic design of the new bridge over the Pepperhill Stream tributary has been developed with the intention to design out any increase in flood risk to the area (embedded mitigation). The key features of this structure are:

- A new 6m clear span concrete box culvert on the main Pepperhill Stream tributary with embedment depth of 0.5m;
- A new 3m clear span concrete box culvert on the side channel immediately upstream of the R522 with embedment depth of 0.5m;
- Both culverts are aligned to the existing natural channel to avoid artificial modification of the planform;
- Removal of the existing sprung arch culvert on the side channel beneath the R522.

The proposed scheme designed with a soffit level of 84.8mOD, to this provide adequate freeboard above the 1% AEP MRFS flood level.

Detailed hydraulic modelling of the proposed scheme design was undertaken to verify the impact on flood risk in the area. A summary of peak water levels for various design events are provided in Table 1.10 below.

Table 1.10: Summary of Scheme Design Model Results

Location	Peak Water Level (mOD)		
	5% AEP	1% AEP	1% AEP MRFS
Upstream boundary of model	83.585	83.614	83.645
Upstream of side channel confluence	83.575	83.600	83.630
Upstream of proposed bridge / road embankment	83.574	83.599	83.629
Downstream of proposed bridge / road embankment and R522	83.564	83.590	83.623
Downstream of side channel confluence	83.425	83.484	83.559
Confluence with Awbeg River	83.354	83.433	83.532
Downstream of Awbeg River rail bridge	83.163	83.231	83.317

1.8.6 Assessment of impact on fluvial flood risk

Table 6.5 compares the pre and post scheme flood levels. As shown, the proposed scheme has no impact on the risk of flooding with identical pre and post scheme flood levels.

Table 6.1: Summary of Scheme Design Model Results

Location	Peak Water Level (mOD) inc. climate change		
	Baseline (mOD)	**Scheme (mOD)**	**Difference (m)**
Upstream boundary of model (Pepperhill Stream)	83.64	83.64	-0.00
Upstream of side channel confluence (Pepperhill Stream)	83.63	83.63	-0.00

Location	Peak Water Level (mOD) inc. climate change		
	Baseline (mOD)	Scheme (mOD)	Difference (m)
Upstream of proposed bridge / road embankment (Pepperhill Stream)	83.63	83.63	-0.00
Downstream of proposed bridge / road embankment (Pepperhill Stream)	83.62	83.62	-0.00
Downstream of side channel confluence (Pepperhill Stream)	83.56	83.56	+0.00
Pepperhill Stream confluence with Awbeg River	83.53	83.53	-
Downstream of Awbeg River rail bridge	83.32	83.32	-0.00

The proposed road embankment results in the existing R522 highway being raised above the 1% AEP water level (including climate change). At present, the same section of the R522 is at risk of flooding in the same event and has been known to flood in the past as evidenced by OPW National Flood Hazard mapping and anecdotal evidence. As such, increased resilience of the road infrastructure can be identified as a benefit of the proposed Project, and the road embankment itself is located outside of Flood Zone A and B.

1.8.7 Conclusion

The Stage 3 flood risk assessment for XC219 Buttevant concluded that the design of the proposed Project at this site provided resilience to fluvial flooding and the provision of SUDS ensured that there would be no increase in pluvial flooding as result of the proposed new road and road-over-rail bridge.

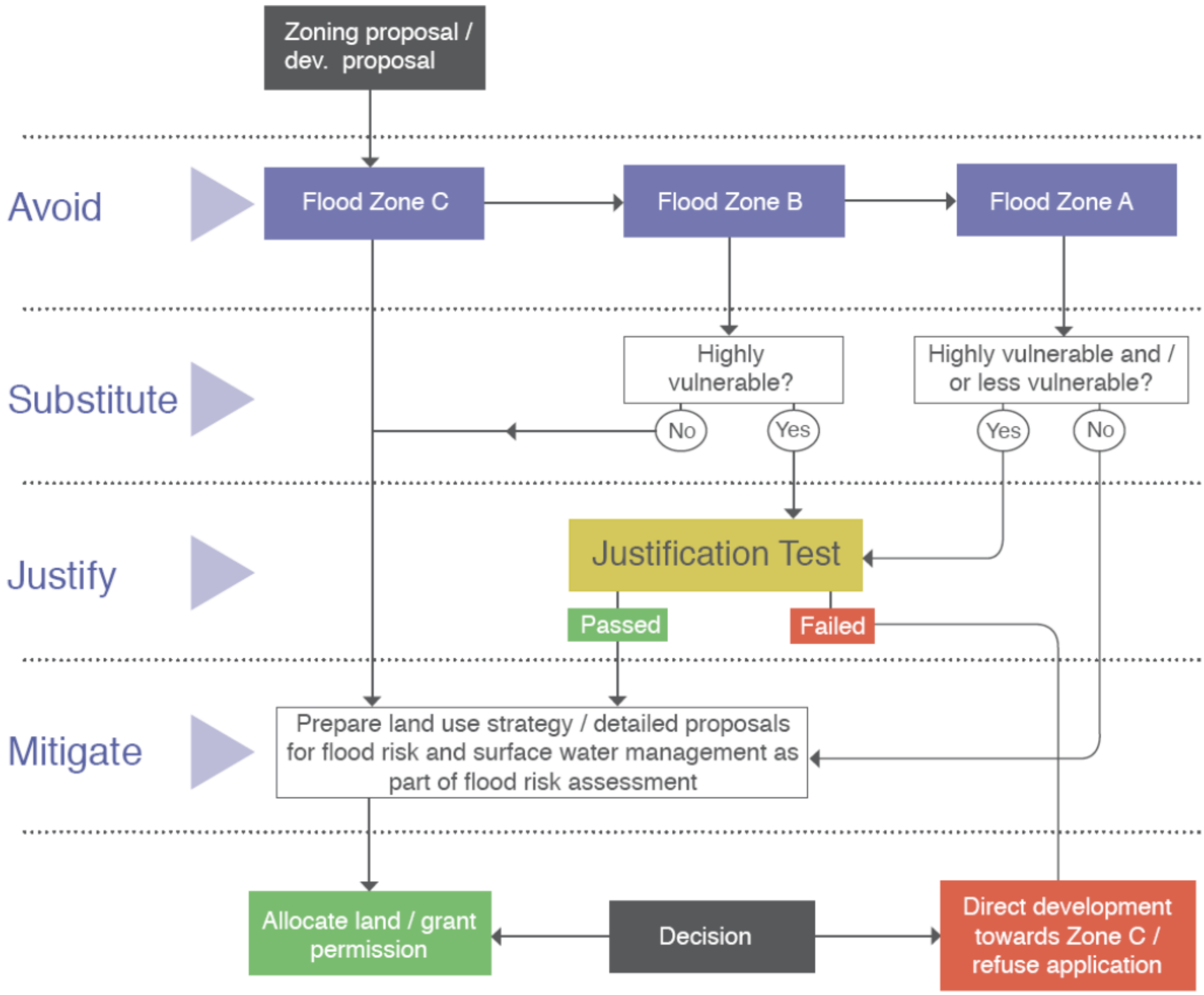
1.9 Sequential Approach to Development Planning

The Planning Guidelines recommend that a Sequential Approach is taken for flood risk management for new developments of this kind. This mechanism is summarised in Inset Figure 1.14 below. Whilst this relates specifically to Flood Zones (which relate to coastal and fluvial flooding), for the purpose of this assessment, the same approach is tailored to other sources of flooding as follows:

- Flood Zone A is assumed to also cover proposed Project at "high" risk of flooding from other sources;
- Flood Zone B is assumed to also cover proposed Project at "moderate" risk of flooding from other sources;
- Flood Zone C is assumed to also cover proposed Project at "low" or "very low" risk of flooding from other sources.

This assessment has been made for all sites as part of the Stage 1 Flood Risk Assessment (Section 3.4).

Inset Figure 1.14 Sequential Approach Mechanisms in the Planning Process



The flood risk assessment of each site is summarised in turn below in the context of this mechanism.

1.9.1 XC187 - Fantstown

The Stage 1 Flood Risk Assessment identified the XC187 Fantstown site to be at high risk of fluvial flooding, with the site located within the 1% AEP flood extent based on PFRA mapping (Flood Zone A). The site is at low or very low risk from all other sources.

The proposed Project at XC187 Fantstown involves the straight closure of the level crossing and the diversion of traffic along an existing road-over-rail bridge approximately 3km to the north east. A Justification Test is not required as no new infrastructure is proposed as part of Fantstown works.

1.9.2 XC201 - Thomastown

The Stage 1 Flood Risk Assessment identified the XC201 Thomastown site to be at low or very low risk from all sources of flood risk.

As all works are located outside of Flood Zone A and B, the proposed Project meets the “Avoid” requirements and is appropriate.

Notwithstanding the low risk of flooding to and from the proposed Project here, surface water from the proposed Project will be managed in accordance with the drainage strategy set out in Section 5.3. The drainage is designed to attenuate surface runoff in the 1% AEP (including climate change) rainfall event and the maximum outflow of the swales will be capped at greenfield runoff rates. This strategy satisfies the "Mitigate" requirements.

1.9.3 XC209 – Ballyhay

The Stage 1 Flood Risk Assessment identified the XC209 Ballyhay site to be at high risk of fluvial flooding, with the site located within the 1% AEP flood extent based on PFRA mapping (Flood Zone A). The site is at low or very low risk of flooding from all other sources.

The proposal for XC209 Ballyhay is for the existing level crossing to be upgraded to a CCTV controlled level crossing. The proposed Project and method of installation of the CCTV will have no permanent or temporary impact on fluvial flooding and the CCTV infrastructure, which includes a control building (REB) will be designed to ensure resilience to flooding with IPP measures IP67 (water submersible) electricity ratings as required. The proposed Project at XC209 Ballyhay is a less vulnerable development, however it is located within Flood Zone A,. A Justification Test is therefore required which is summarised in Table 1.11 below.

Table 1.11 Justification Test XC209 Ballyhay

Criteria to be satisfied	Justification
The subject lands have been zoned or otherwise designated for the particular use or form of development in an operative development plan, which has been adopted or varied taking account	**Criteria met** – the site is already a level crossing and the proposed REB is located within the footprint of an existing building
The development will not increase flood risk elsewhere, and, if practicable, will reduce overall flood risk	**Criteria met** - It has been demonstrated in Section 5 that the development will not increase the flood risk
The development proposal includes measures to minimise flood risk to people, property, the economy and the environment as far as reasonably practicable.	**Criteria met** - the proposed development removes an existing requirement for a manually operated level crossing which is located in a floodplain.
The development proposed includes measures to ensure that residual risks to the area and/or development can be managed to an acceptable level as regards the adequacy of existing flood protection measures or the design, implementation and funding of any future flood risk management measures and provisions for emergency services access.	**Criteria met** - the proposed development is designed to be resilient to flooding. This includes an IP67 rating to allow for submersion by floodwater and individual property protection measures
The development proposed addresses the above in a manner that is also compatible with the achievement of wider planning objectives in relation to development of good urban design and vibrant and active streetscapes.	**Criteria met** – not applicable
Conclusion:	**Justification Test is passed**

1.9.4 XC211 / 212 – Newtown / Ballycoskery

The Stage 1 Flood Risk Assessment identified the XC211 / 212 Newtown / Ballycoskery site to be at moderate risk of fluvial flooding, with the site located proximate to the 1% AEP flood extent based on PFRA mapping (Flood Zone A). The site is at low or very low risk from all other sources.

The Stage 2 Flood Risk Assessment showed that the proposed Project was located within Flood Zone A. It has been designed to be resilient to flooding. A Justification Test is required which is summarised in Table 1.12 below.

Surface water from the proposed Project will be managed in accordance with the drainage strategy set out in Section 5.3. The drainage is designed to attenuate surface runoff in the 1% AEP (including climate change) rainfall event and the maximum outflow of the swales will be capped at greenfield runoff rates. This strategy satisfies the "Mitigate" requirements.

Table 1.12 Justification test XC212 Ballycoskery

Criteria to be satisfied	Justification
The subject lands have been zoned or otherwise designated for the particular use or form of development in an operative development plan, which has been adopted or varied taking account	**Criteria met** – the proposed road and raised crossing of the railway is identified in the Cork County Council Development Plan
The development will not increase flood risk elsewhere, and, if practicable, will reduce overall flood risk	**Criteria met** - It has been demonstrated in Section 5 that the development will not increase the flood risk and could lead to small reduction in flood risk to a school from intercepting floodplain flows
The development proposal includes measures to minimise flood risk to people, property, the economy and the environment as far as reasonably practicable.	**Criteria met** - the proposed development removes an existing requirement for a manually operated level crossing. It also provides and elevated route over the railway which will be accessible during flood conditions.
The development proposed includes measures to ensure that residual risks to the area and/or development can be managed to an acceptable level as regards the adequacy of existing flood protection measures or the design, implementation and funding of any future flood risk management measures and provisions for emergency services access.	**Criteria met** - the proposed development is designed to be resilient to flooding. The road and railway crossing are elevated above estimated flood levels.
The development proposed addresses the above in a manner that is also compatible with the achievement of wider planning objectives in relation to development of good urban design and vibrant and active streetscapes.	**Criteria met** – the proposed road and raised crossing of the railway is identified in the Cork County Council Development Plan
Conclusion:	**Justification Test is passed**

1.9.5 XC215 Shinanagh

The Stage 1 Flood Risk Assessment identified the XC215 Shinanagh site to be at a low or very low risk from all sources of flooding.

As all works are located outside of Flood Zone A and B, the proposed Project meets the “Avoid” requirements and is appropriate.

Notwithstanding the low risk of flooding to and from the proposed Project here, surface water from the proposed Project will be managed in accordance with the drainage strategy set out in Section 5.3. The drainage is designed to attenuate surface runoff in the 1% AEP (including climate change) rainfall event and the maximum outflow of the swales will be capped at greenfield runoff rates. This strategy satisfies the “Mitigate” requirements.

1.9.6 XC219 Buttevant

The Stage 1 Flood Risk Assessment identified the XC219 Buttevant site to be at high risk of fluvial flooding, with the site located within the 1% AEP flood extent based on PFRA mapping (Flood Zone A). The site is at low or very low flood risk from all other sources.

The Stage 2 and 3 Flood Risk Assessment verified that the proposed Project was within Flood Zone A, but that it was resilient to flooding and that no increase in flooding would be caused to other receptors. A Justification Test is therefore required which is summarised in Table 1.13 below.

Table 1.13 Justification Test XC219 Buttevant

Criteria to be satisfied	Justification
The subject lands have been zoned or otherwise designated for the particular use or form of development in an operative development plan, which has been adopted or varied taking account	**Criteria met** – the proposed road and raised crossing of the railway are not zoned. Elimination of manually operated level crossings represents a key objective for Irish Rail. Provision of a new road crossing will significantly reduce risks to road and rail users.
The development will not increase flood risk elsewhere, and, if practicable, will reduce overall flood risk	**Criteria met** - It has been demonstrated in Sections 5 and 6 that the development will not increase the flood risk to surrounding lands
The development proposal includes measures to minimise flood risk to people, property, the economy and the environment as far as reasonably practicable.	**Criteria met** - the proposed development removes an existing requirement for a manually operated level crossing that is located in the floodplain. It also provides and elevated route over the railway which will be accessible during flood conditions.
The development proposed includes measures to ensure that residual risks to the area and/or development can be managed to an acceptable level as regards the adequacy of existing flood protection measures or the design, implementation and funding of any future flood risk management measures and provisions for emergency services access.	**Criteria met** - the proposed development is designed to be resilient to flooding. The road and railway crossing are elevated above estimated flood levels. SuDS measures ensure no net increase in runoff
The development proposed addresses the above in a manner that is also compatible with the achievement of wider planning objectives in relation to development of good urban design and vibrant and active streetscapes.	**Criteria met** – elimination of manually operated level crossings represents a key objective for Irish Rail. Provision of a new road crossing will significantly reduce risks to road and rail users.
Conclusion:	**Justification Test is passed**

1.10 Conclusion

This report is a flood risk assessment of the proposed Project at seven. Cork line level crossing sites. The assessment included desktop investigations into the potential flood risk sources and an assessment of the potential flood risk impacts to and from the proposed Projects. The results of the assessment are detailed within Section 3 (Stage 1 Flood Risk Assessment) for each site respectively; Section 4 and 5 (Stage 2 Flood Risk Assessment for all sites except XC187 Fantstown at which no infrastructure is proposed; and Section 6 (Stage 3 Flood Risk Assessment) for XC219 Buttevant only.

A Stage 3 Flood Risk Assessment was undertaken specifically for XC219 Buttevant to verify that the proposed Project (with embedded mitigation) would cause no increase in flood risk elsewhere.

Each site of the proposed Project has been assessed individually, proportionate to the level of risk identified. The sequential approach to development planning has been adhered to and, where required, a Justification Test carried out. Where justification test were required, all have passed (Section 7).

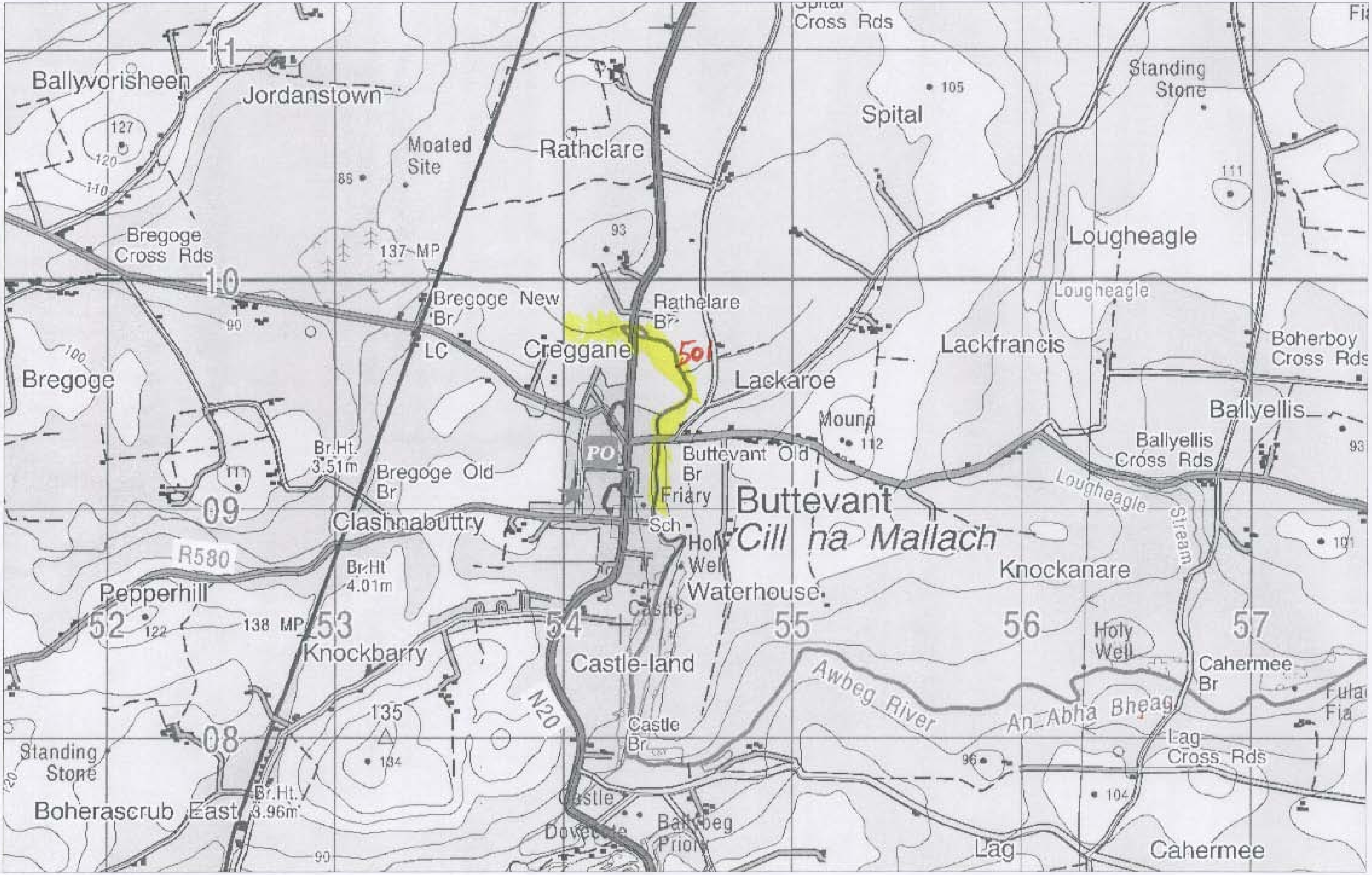
All sites were found to be at a low or very low risk of flooding from all sources except fluvial flooding. A summary of the potential flood risk impacts from the proposed Projects are summarised in Table 1.14below.

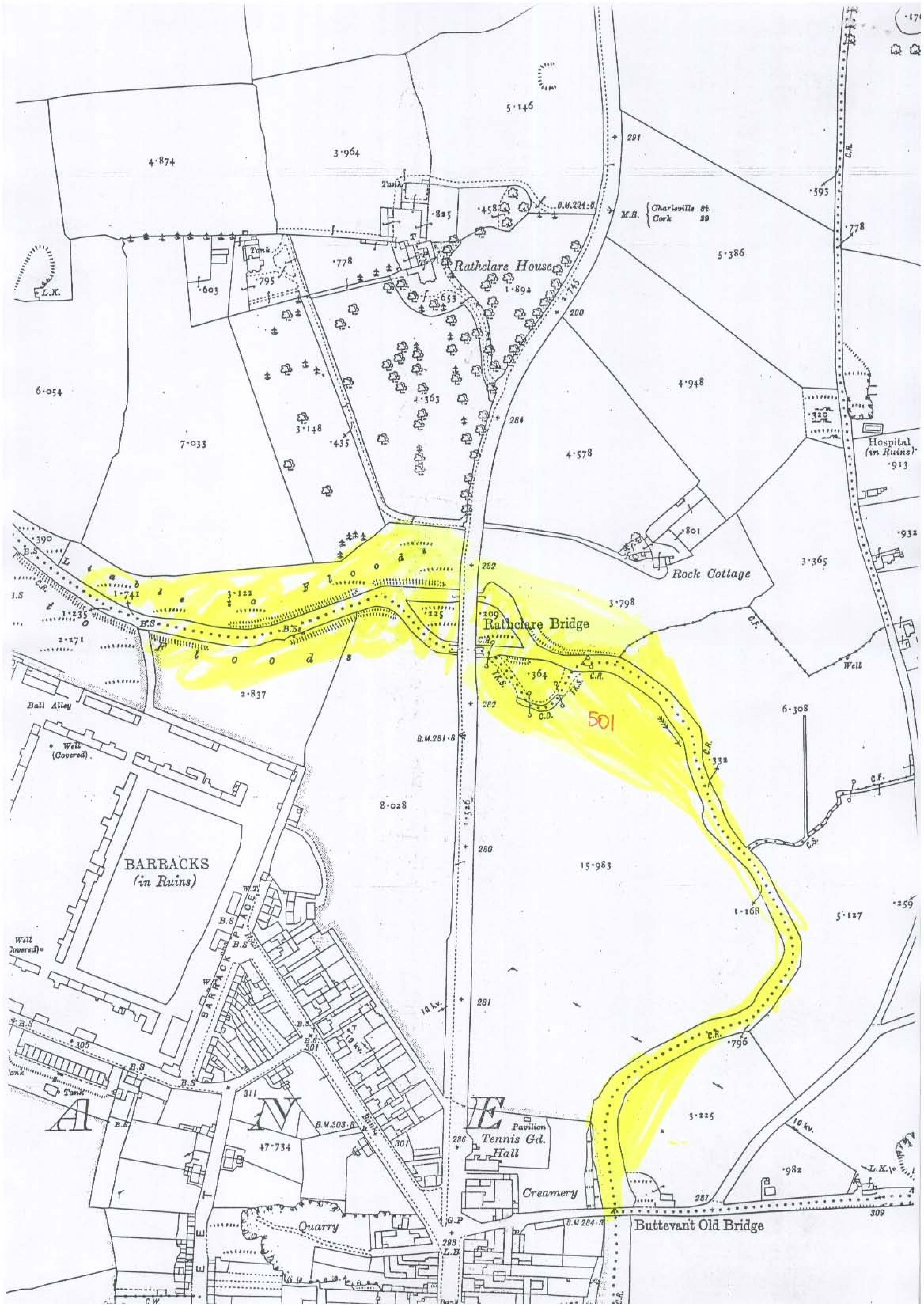
Table 1.14 Summary of potential flood risk impacts on surrounding areas as a result of the proposed Projects on all sites

Flood Risk	Potential Scheme Impact	Discussion & Mitigation (where Required)	Residual Scheme Impact (with mitigation)
Coastal	No impact	The location of all proposed Projects mean they will have no impact on coastal flood risk.	No impact
Estuarine	No impact	The location of all proposed Projects mean they will have no impact on estuarine flood risk.	No impact
Fluvial	Increase	The proposed Project has the potential to increase flood risk elsewhere at XC219 Buttevant. Embedded mitigation in the form of SUDS and restricted flow rate sin surface water drains has been built into the design to reduce the runoff rate to existing greenfield rates. A Stage 3 Flood Risk Assessment supported by hydraulic modelling has verified this (See Appendix B and C of this report).	No impact
Pluvial	Increase	As noted, the upgrade works have the potential to increase the rate of runoff from the creation of additional impermeable surfaces. However, a drainage strategy including the use of swales has been provided to ensure no net increase in surface runoff from the proposed Project to the surrounding area.	No impact
Artificial Drainage Systems	Increase	As noted, the upgrade works have the potential to increase the rate of runoff from the creation of additional impermeable surfaces. However, the proposed Project does not rely on any existing artificial drainage system, and all existing artificial drainage systems are retained.	No impact
Groundwater	No impact	As noted, the upgrade works associated with all 7 sites will not involve significant works below existing ground levels, since most works are road-over-rail bridges , that could lead to an increased risk of flooding from groundwater.	No impact

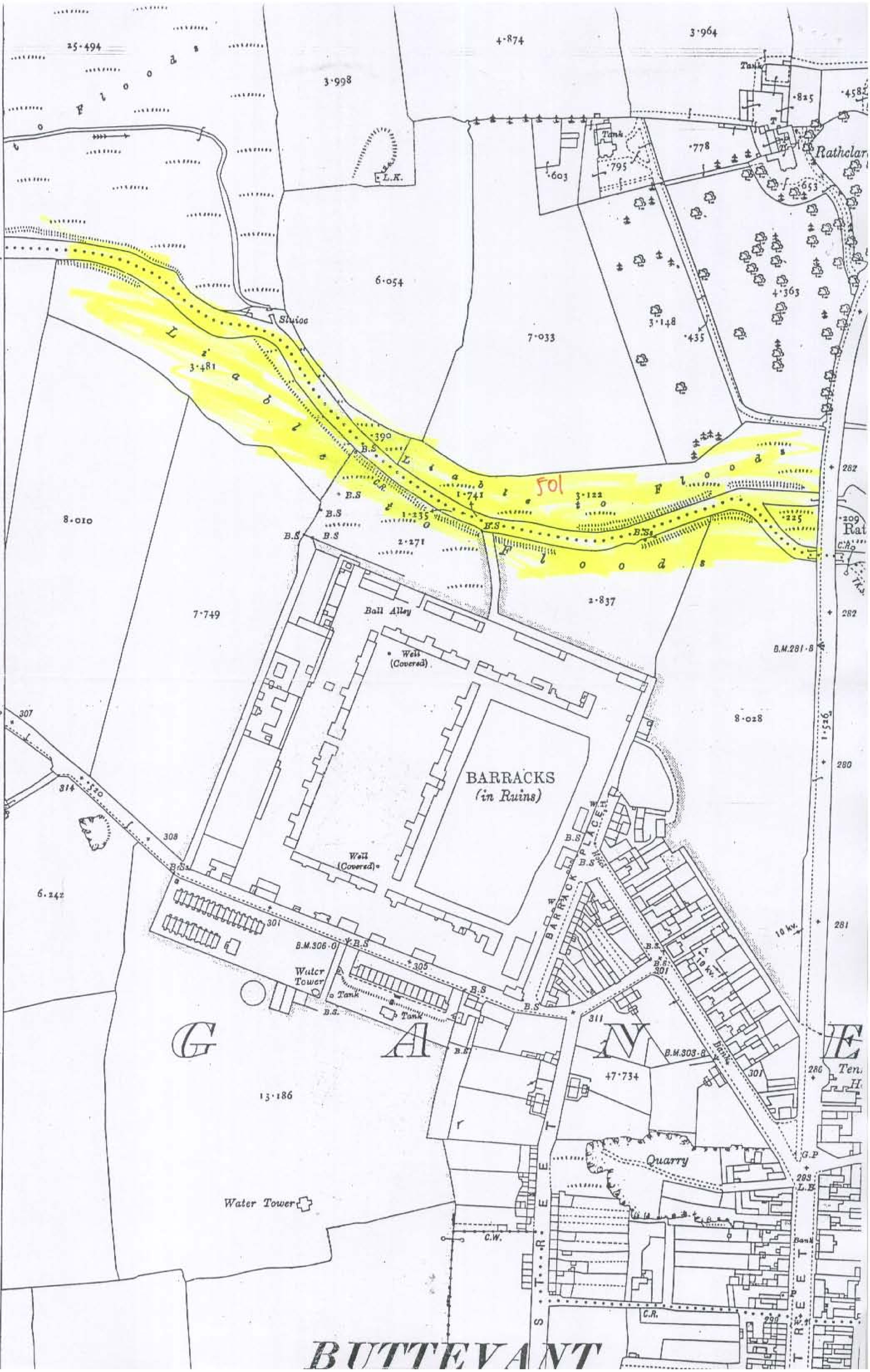
Appendix A. OPW National Flood Hazard Mapping

501- FLOOD ID : 2329

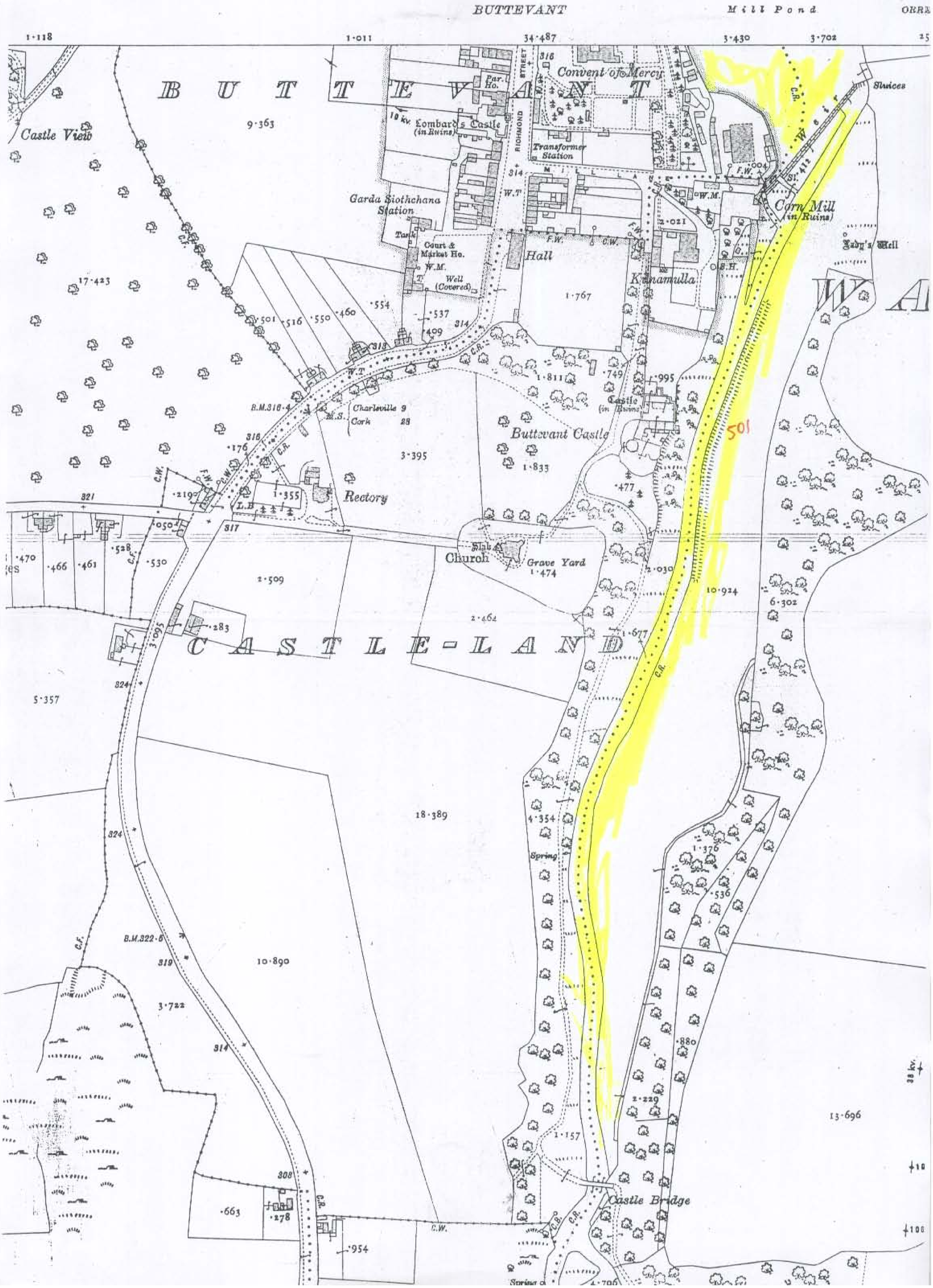




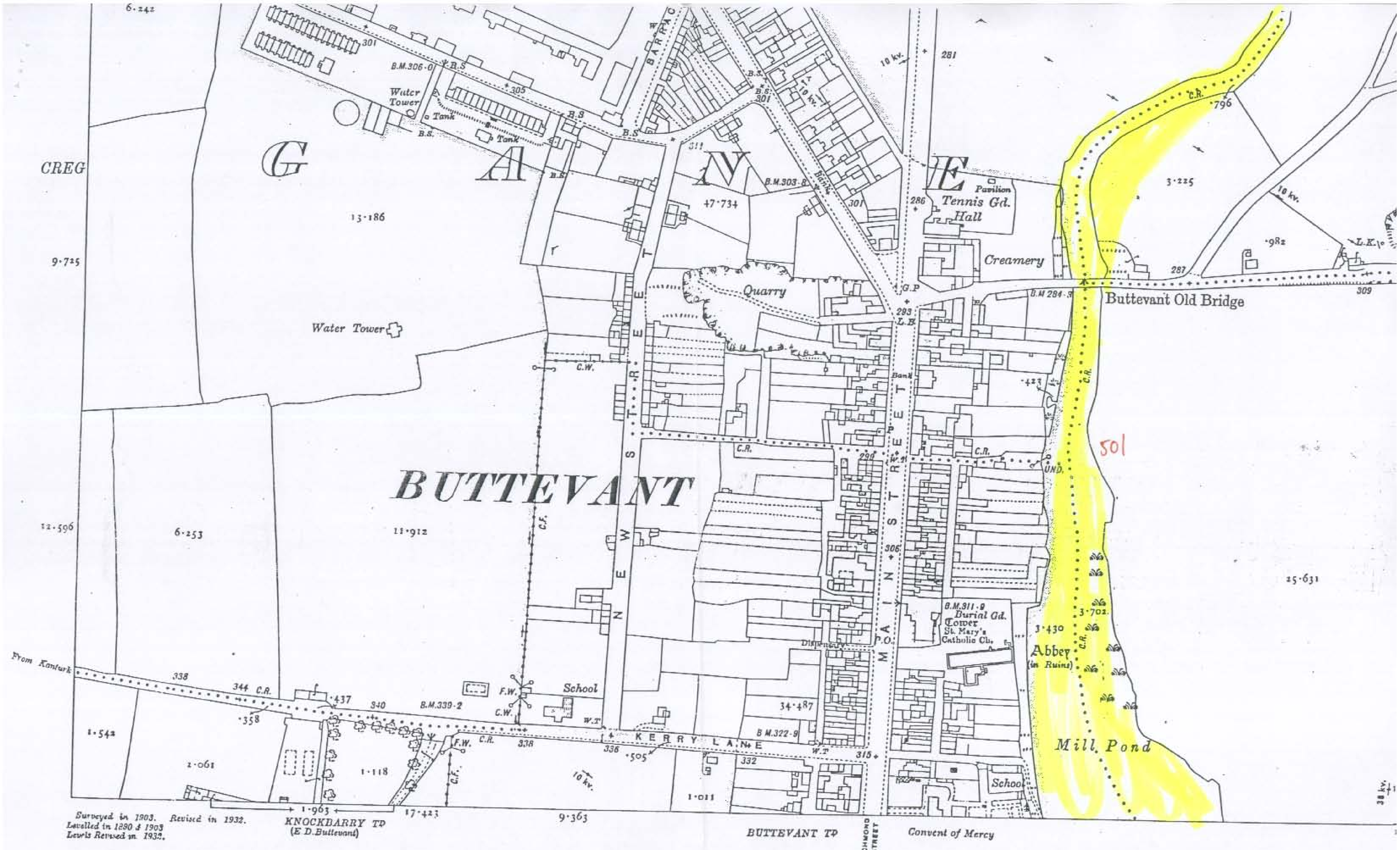
Rathclare House
Rock Cottage
Rathclare Bridge
Liable to Floods
Floods
501
M.S. Charleville 84 Cork 39
Hospital (in Ruins)
BARRACKS (in Ruins)
Ball Alley
Well (Covered)
BARRACK PLACE
Quarry
Tennis Gd.
Pavilion
Hall
Creamery
Buttevant Old Bridge
Well



Awbeg River
Liable to Floods
Sluice
L.K.
Tank
Rathclare
501
Ball Alley
Well (Covered)
BARRACKS (in Ruins)
BARRACK PLACE
Water Tower
Tank
Quarry
XVI.12
ORRERY AND KILMORE BY
From Liscarroll
CREG
STREET
BUTTEVANT



BUTTEVANT
Mill Pond
ORRE
1·118
1·011
34·487
3·430
3·702
BUTTEVANT
Castle View
9·363
Convent of Mercy
Par. Ho.
Lombard's Castle (in Ruins)
RICHMOND STREET
Transformer Station
Sluices
Weir
Corn Mill (in Ruins)
Garda Siothchana Station
Court & Market Ho.
W.M.
Well (Covered)
Hall
Kilnamulla
Lady's Well
WA
17·423
1·767
B.M.316·4
Charleville 9
Cork 28
3·395
Buttevant Castle
Castle (in Ruins)
1·811
1·833
Rectory
1·355
Church
Grave Yard
1·474
501
2·509
10·924
6·302
2·462
CASTLE-LAND
5·357
18·389
4·354
Spring
1·376
B.M.322·6
10·890
3·722
2·229
13·696
1·157
Castle Bridge
·663
·278
·954



CHARACTERISTICS AND SYMBOLS FOR BOUNDARIES, &c.

County	Co. Boro, Ward, Union, Rural & Urban Districts / Towns	Boundary described	Area of parcels given in Statute Acres, thus	4·370	
Barony	When not coincident with other Boundaries	described	Braces indicating that the spaces so connected are included in the same area		
Parish (in Co. Boro & U.Ds. only)	Change of Boundary indicating the point at which the character of a Boundary changes		Antiquities (Site of)	Fort	
Townland			Trigonometrical Station	△	
Ward					

Electric Power Transmission Standards

	Single Circuit	Double Circuit
110 kv.		
38 kv.		
10 kv.		

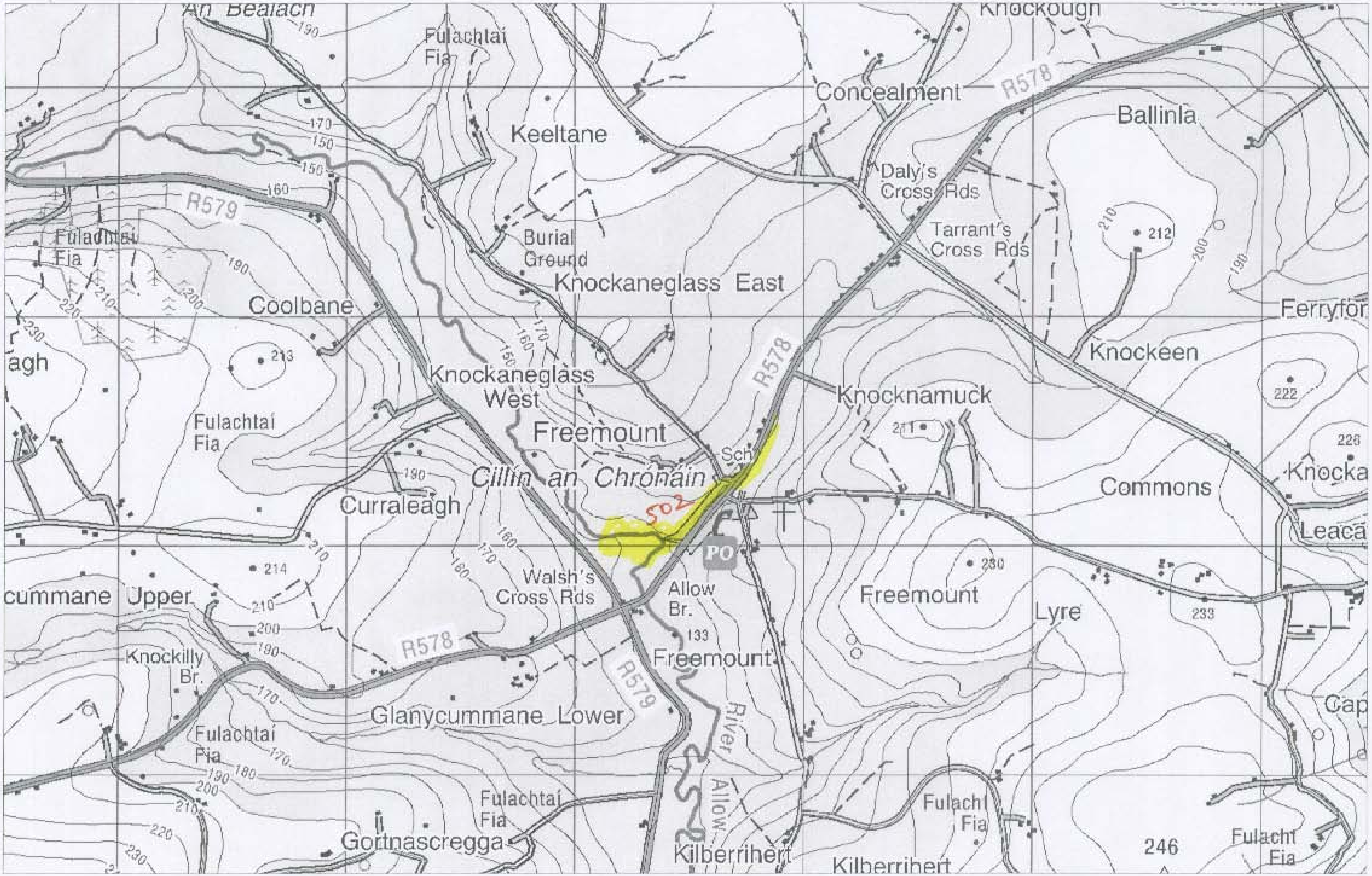
The Representation on this Map of a Road, Track, or Footpath, is no evidence of the existence of a right of way.

For other information see Characteristic Sheet.

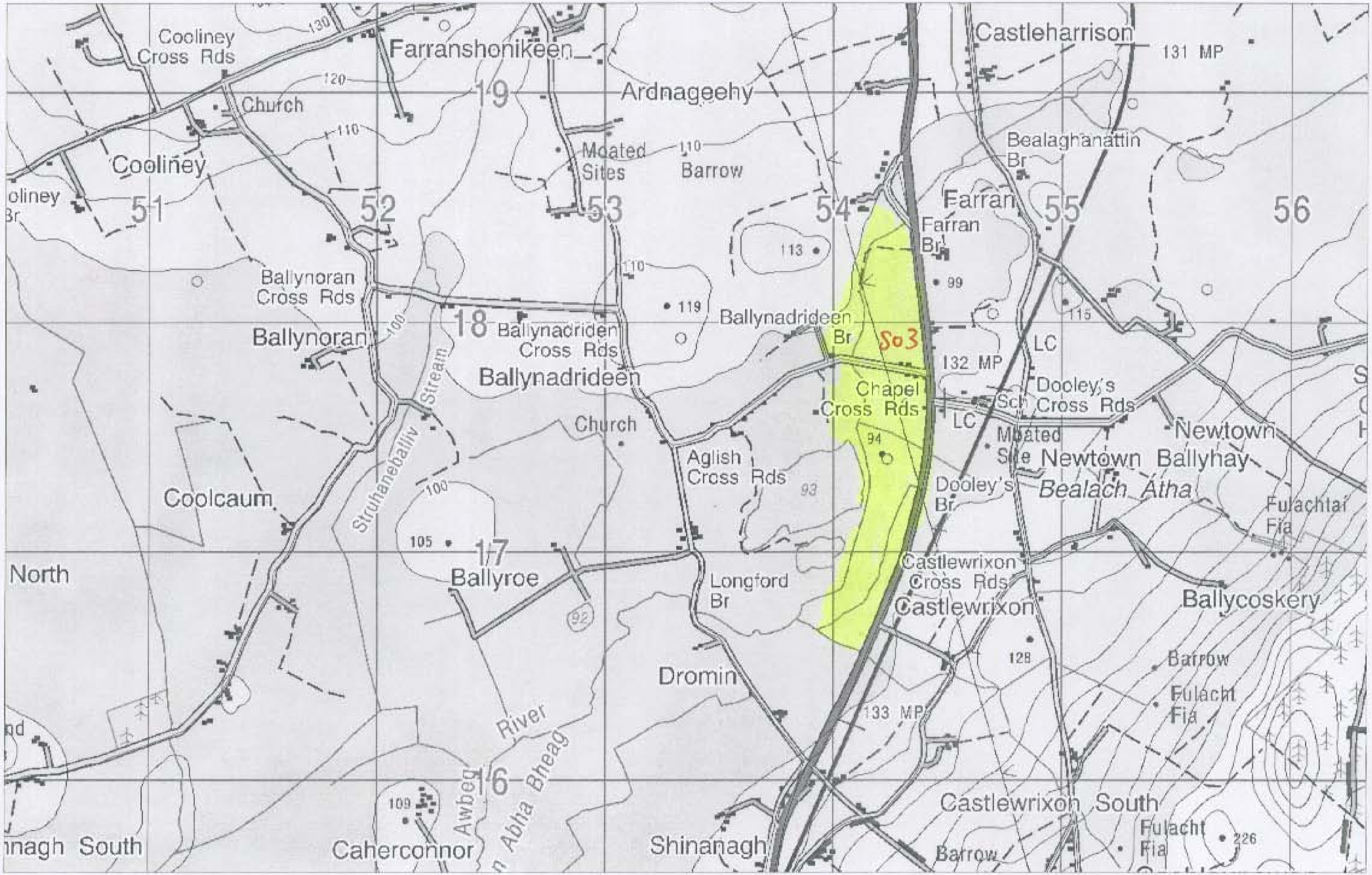
The Altitu... has been ...

502 - FLOOD ID 511

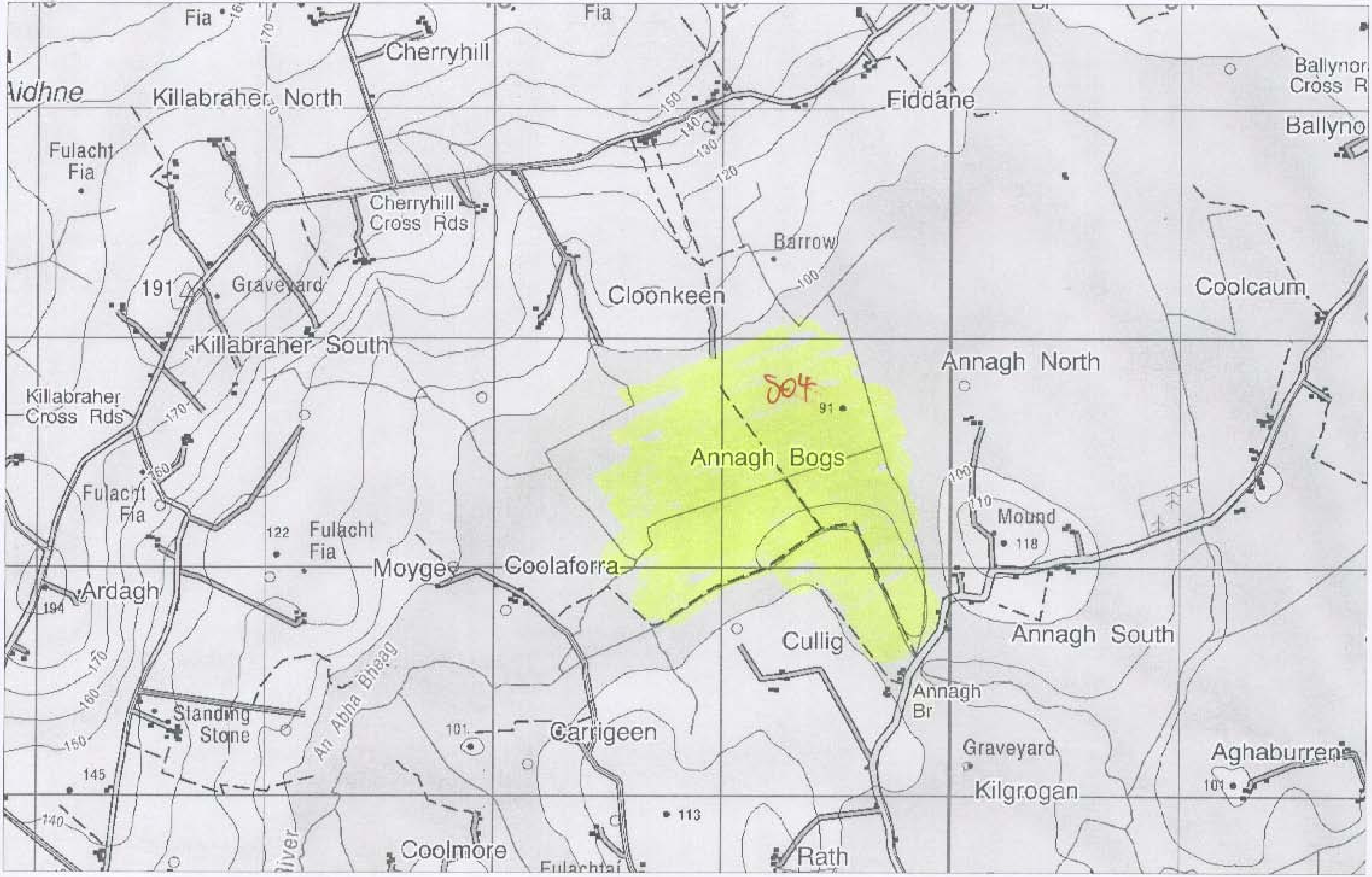
R578 – 303



503 - Flood in 2378 N20 Ballyhea – Buttevant

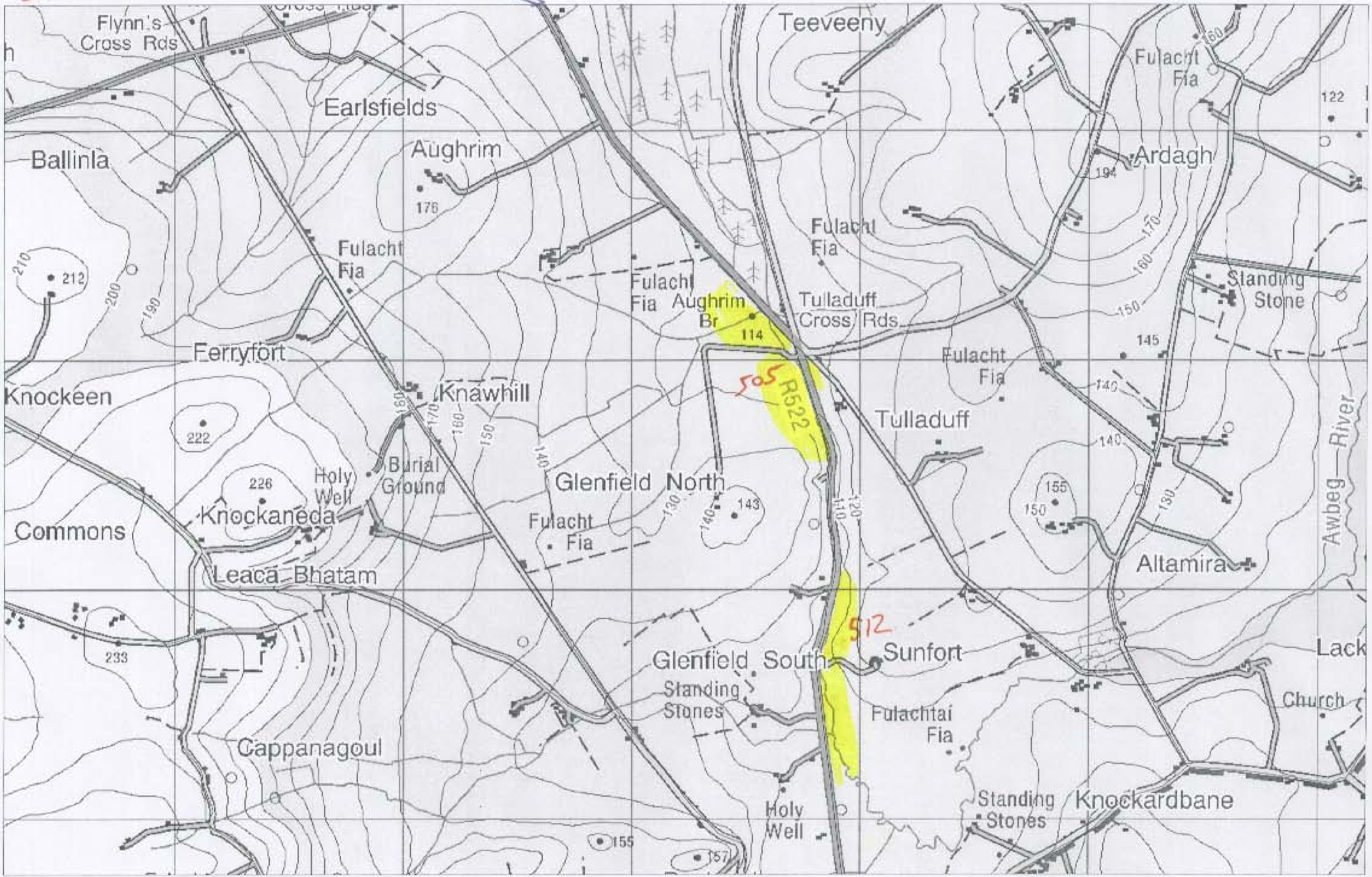


504 - F2000 ID 2381 Churchtown . Mallow.



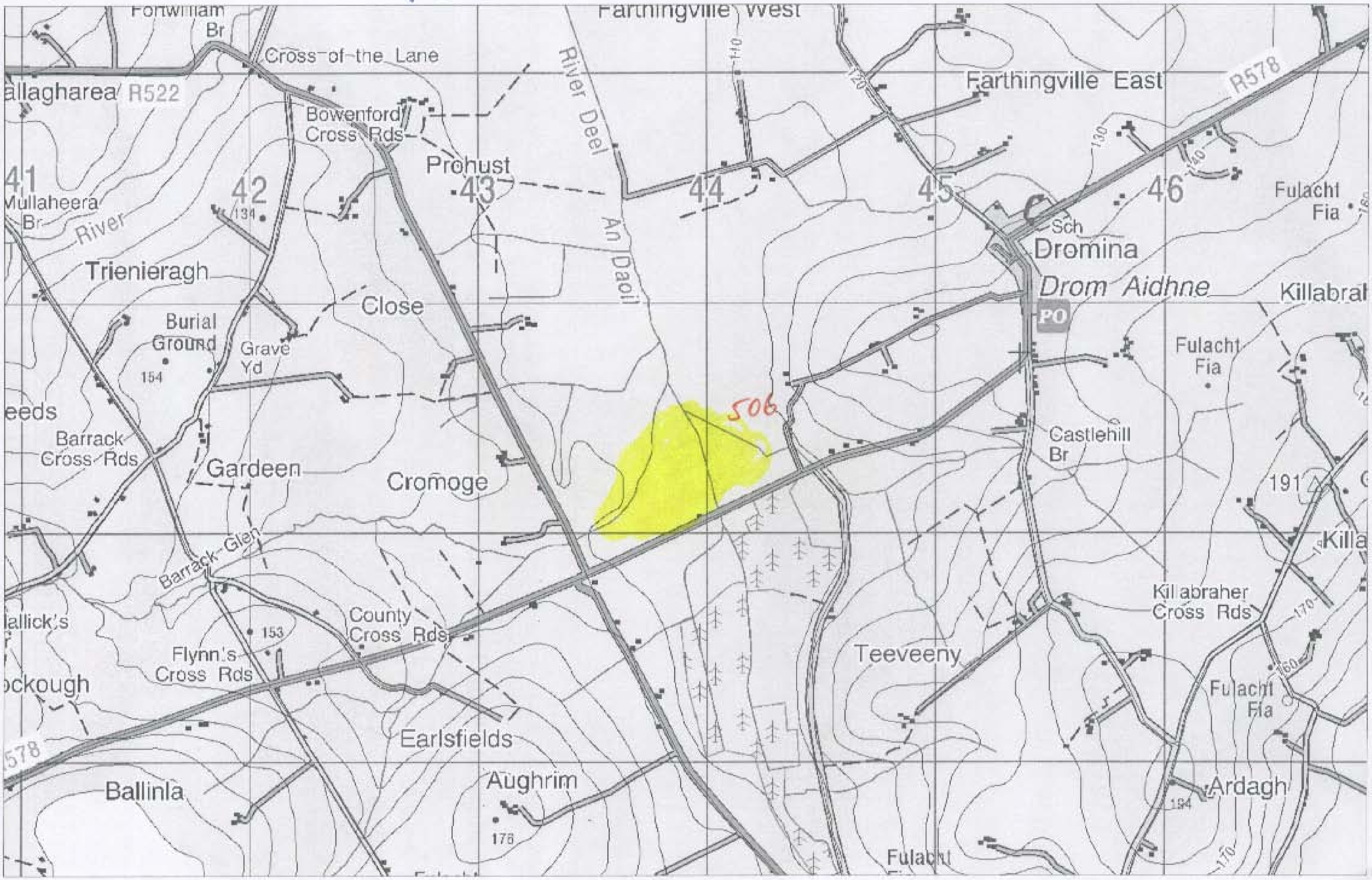
512 - 2331
505 - 2374

R 522-59

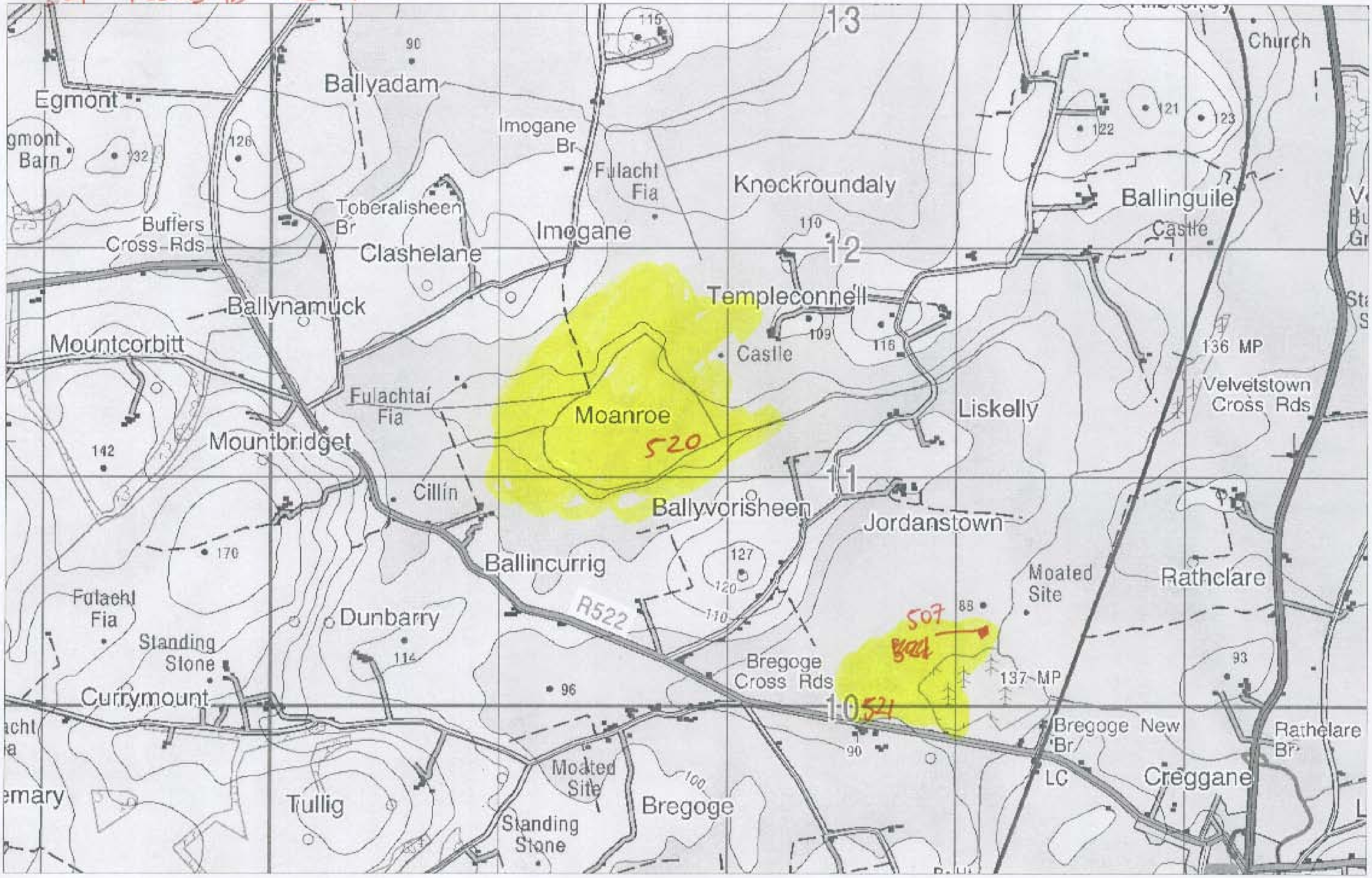


506- FLOOD IN 2330

R578-365.

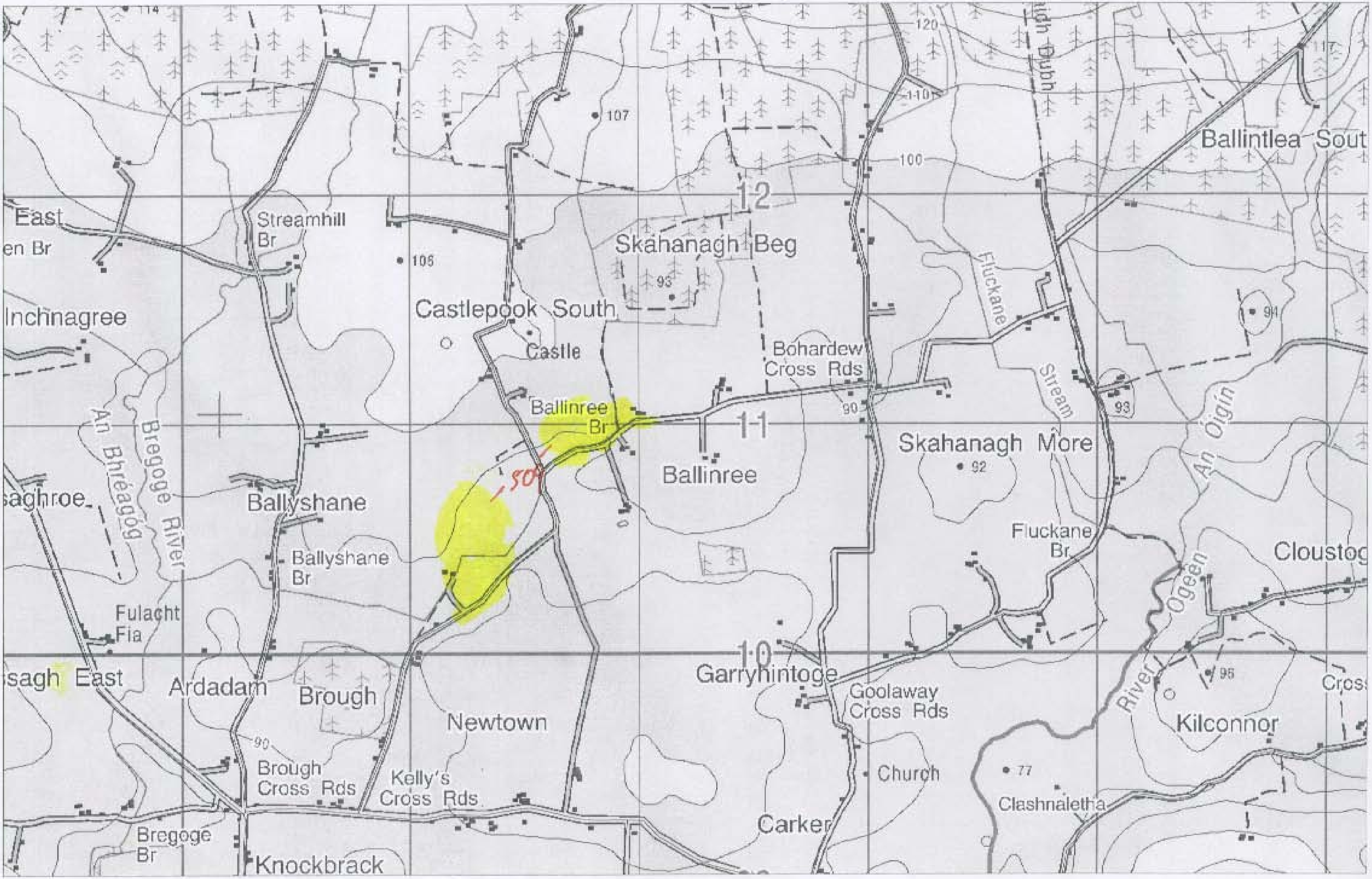


520 - FLOOD ID :-2376 507: R522-194 FLOOD REPORT 1975
521 - FLOOD ID :2377



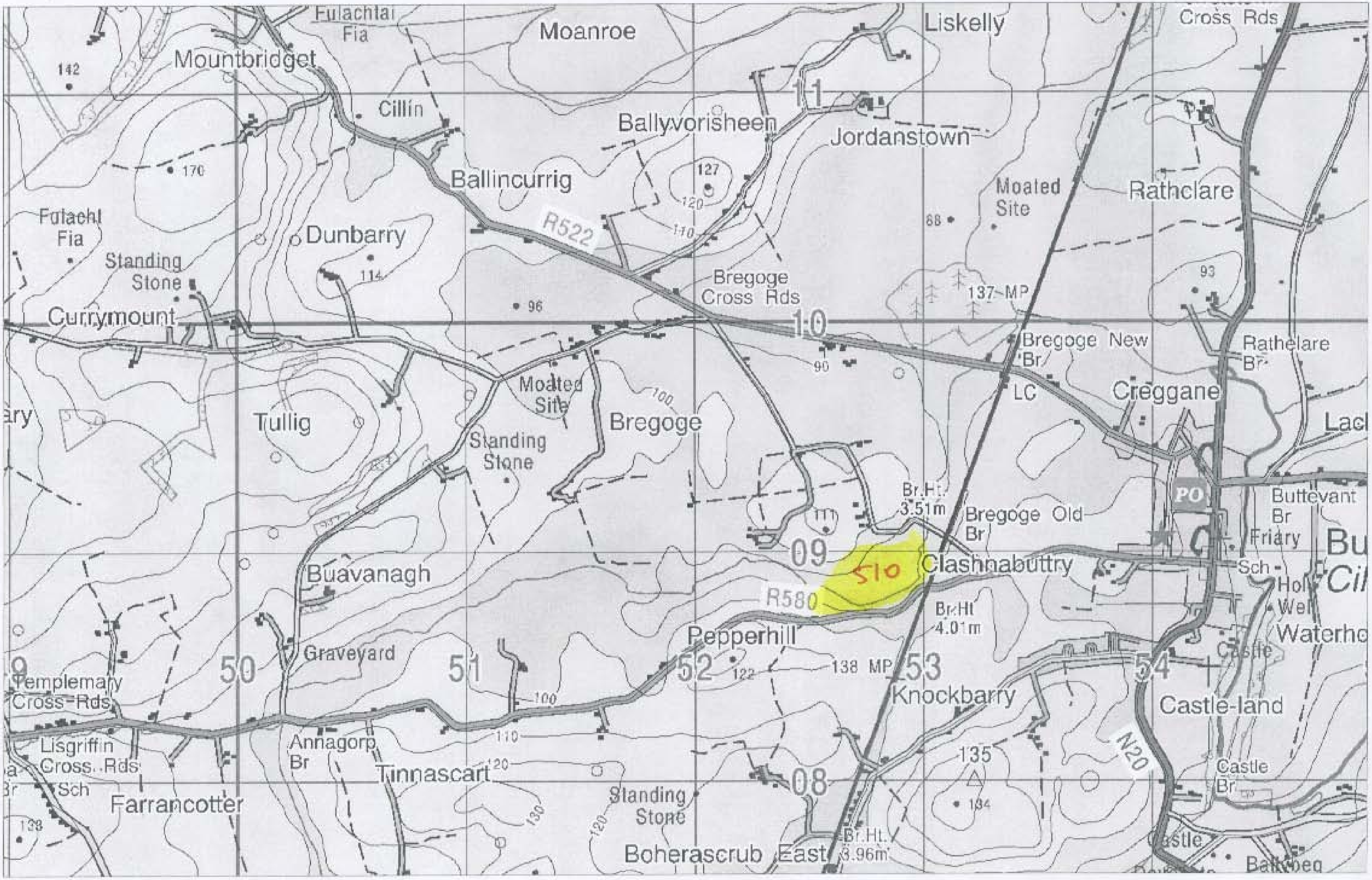
509- FLOOD ID's : 1206+403

L-5552-0



510 - Report in 2339

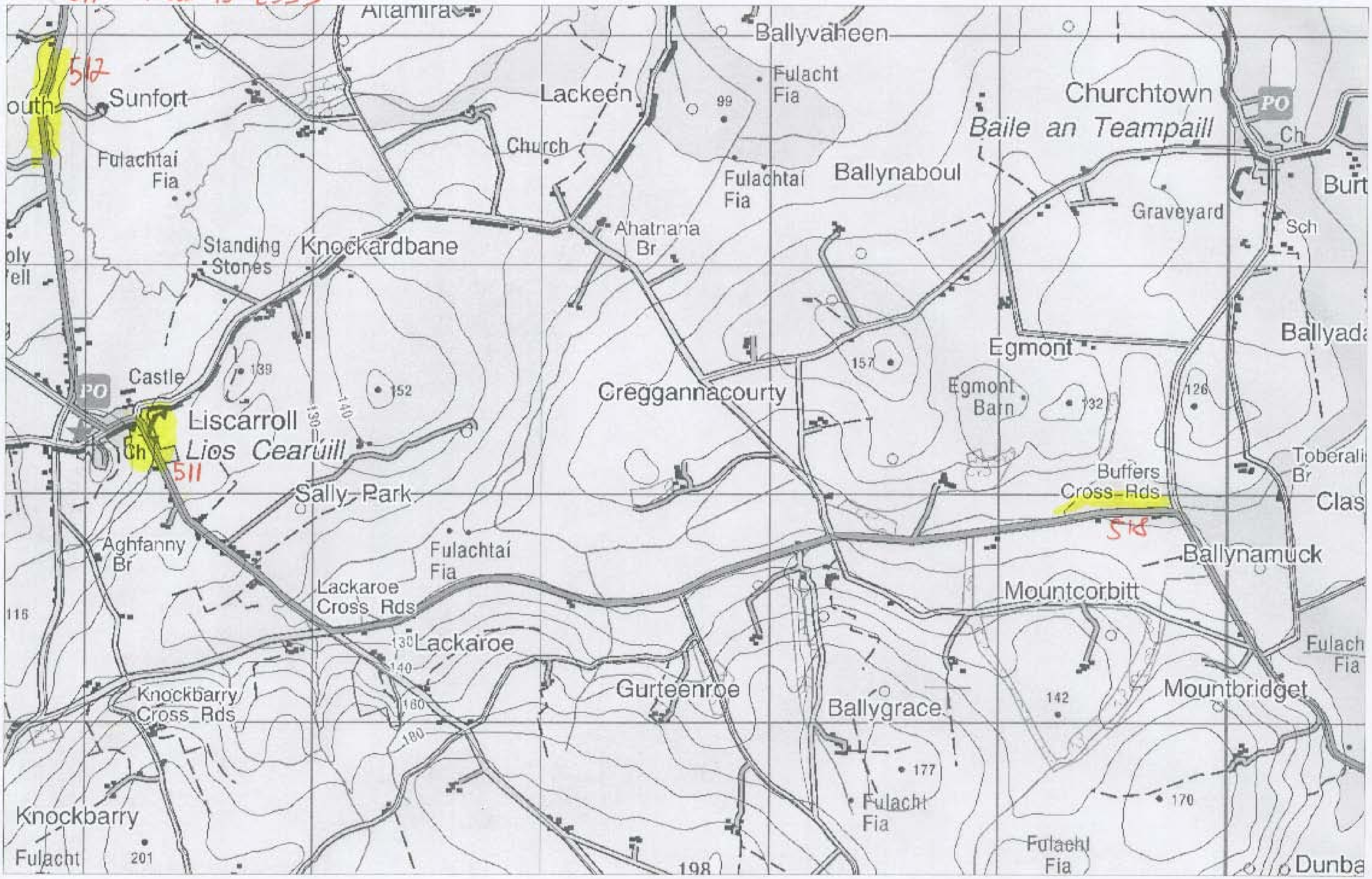
R580



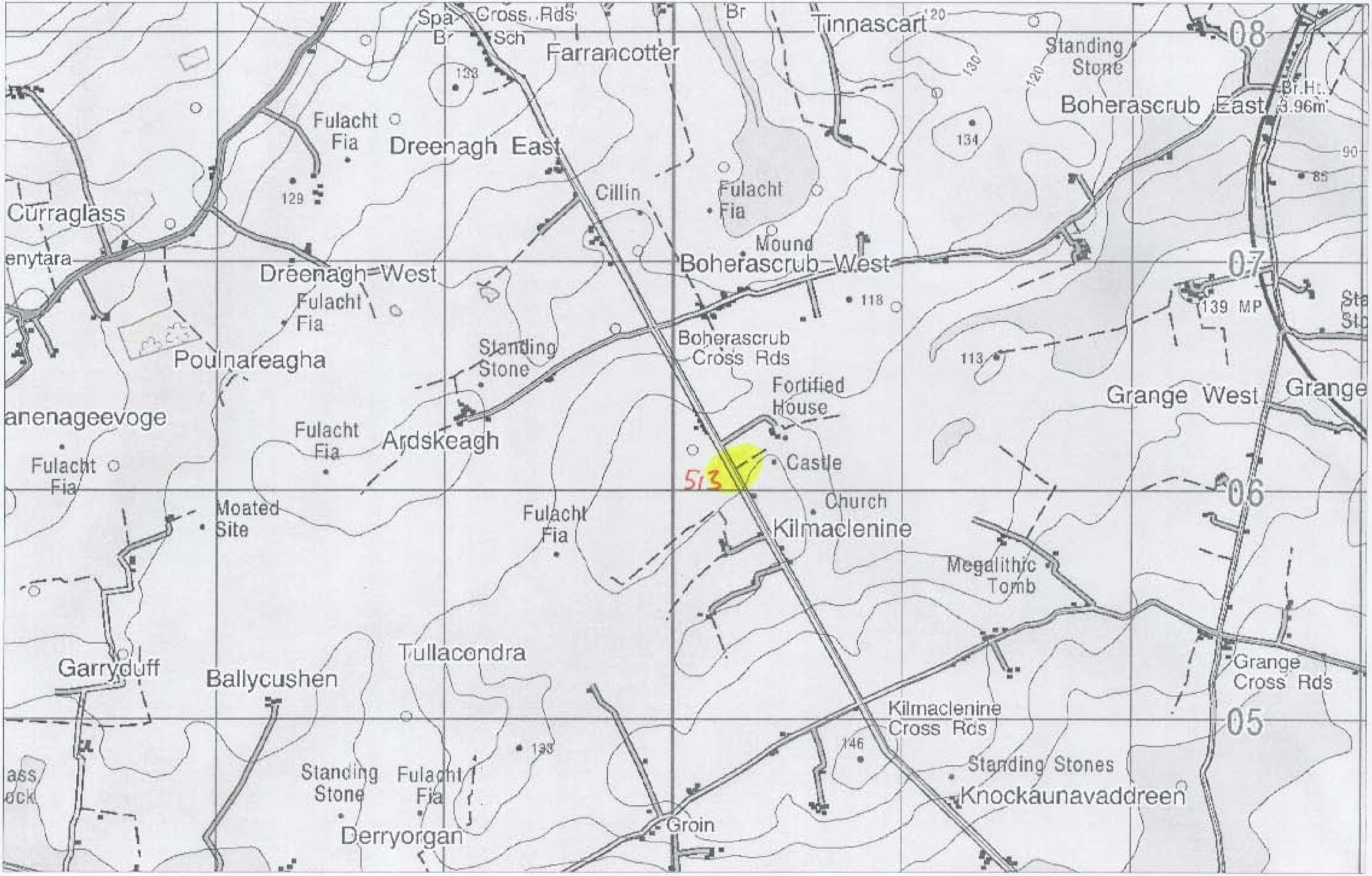
512 ⇒ FLOOD ID 2331
511 ⇒ FLOOD ID 2333

R522 - 80

518 ⇒ FLOOD ID 2338

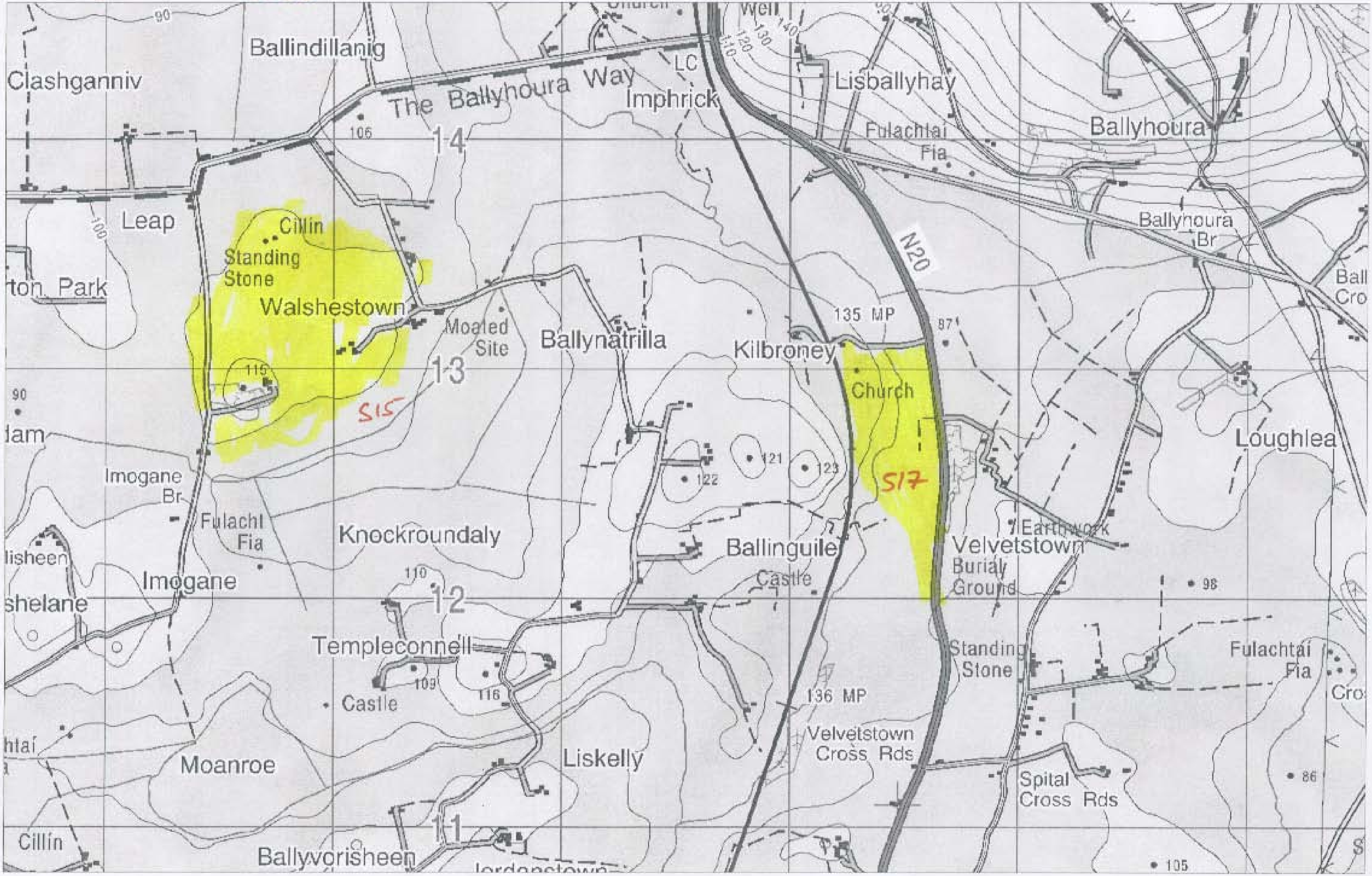


513 → FLOOD ID 2332 L-1319-64



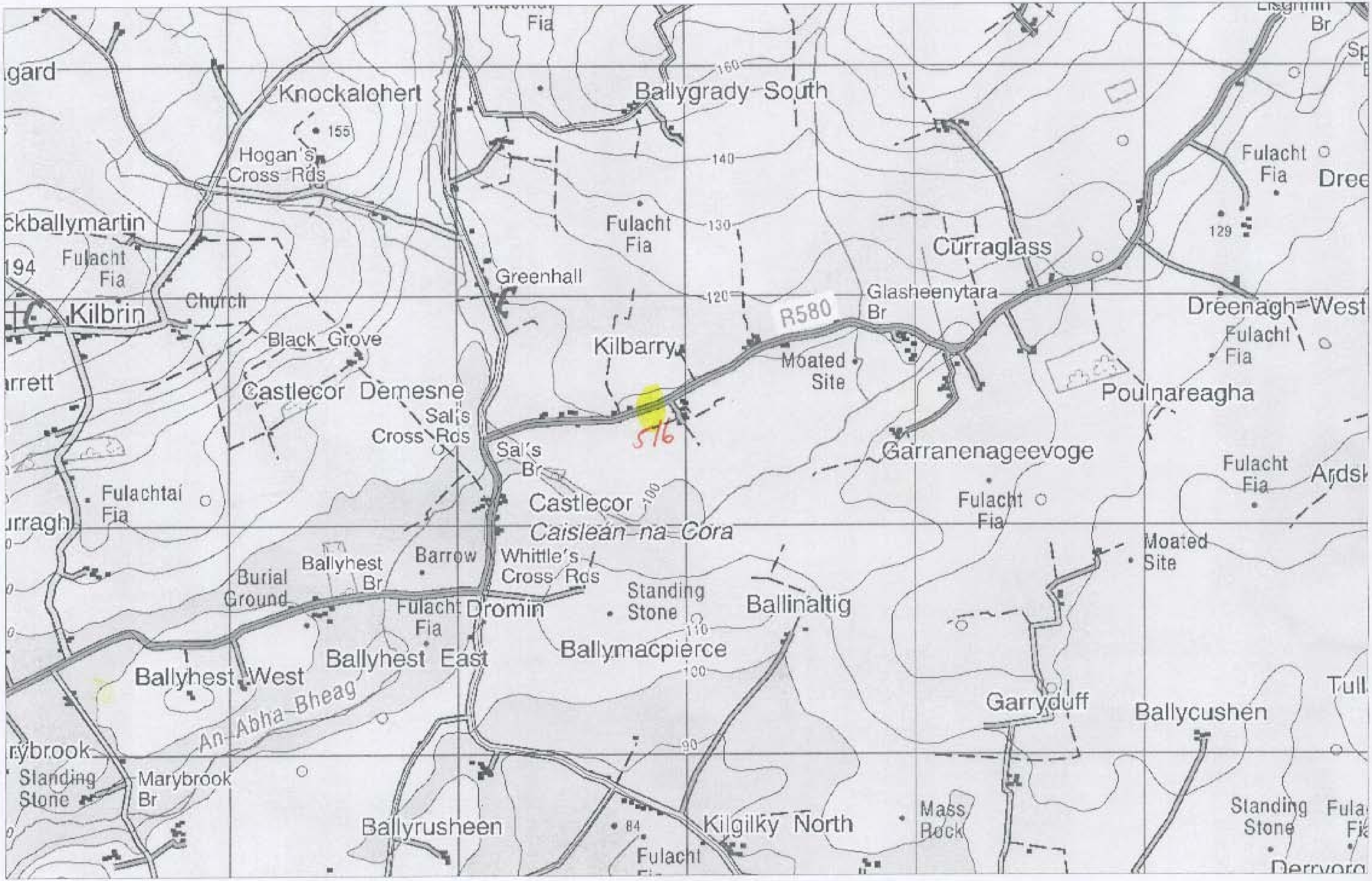
515 - FLOOD ID 2335
517 - FLOOD ID 2336

N20



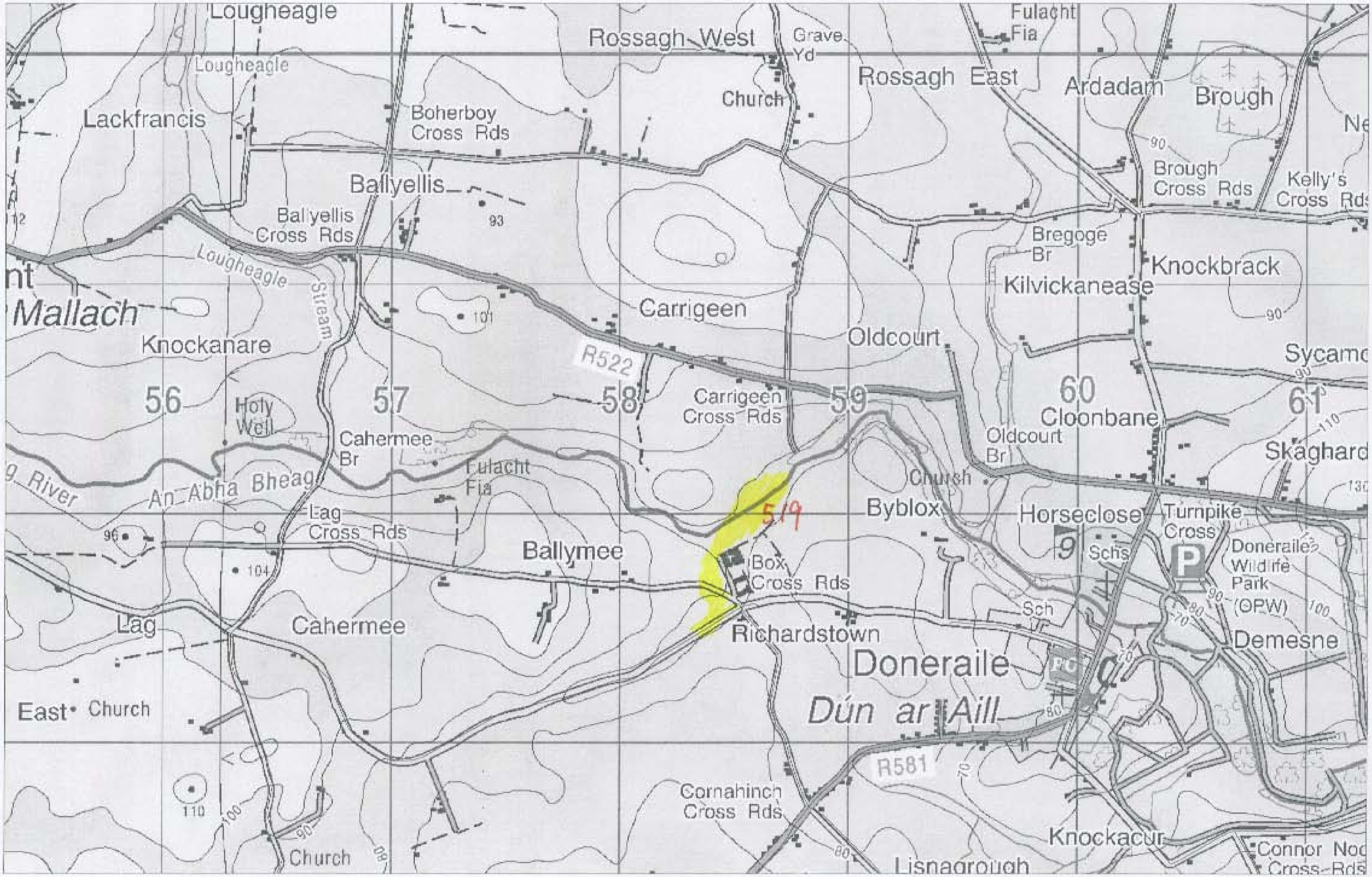
S16 → FLOOD ID 2334

R580–85.



519 - FLOOD ID: 2337

L-5572-0



Appendix B. XC219 Design Flow Estimation Report

Cork Line Level Crossing

Design Flow Estimation Report

32111000-JAC-ZZZ-XC219-RP-HY-0001 | 0

8 January 2020

Irish Rail

-

Cork Line Level Crossing

Project No:	3211100
Document Title:	Design Flow Estimation Report
Document No.:	32111000-JAC-ZZZ-XC219-RP-HY-0001
Revision:	0
Document Status:	Final
Date:	8 January 2020
Client Name:	Irish Rail
Client No:	-
Project Manager:	Pat Hall
Author:	Liam Meachen
File Name:	Hydrology Flow Estimation Report – Cork Line Level Crossing

Jacobs U.K. Limited

1180 Eskdale Road
Winnersh, Wokingham
Reading RG41 5TU
United Kingdom
T +44 (0)118 946 7000
F +44 (0)118 946 7001
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
0	08/01/2020	Final	LM	ET	KB	PH

Contents

1. Introduction

A range of design flow estimates were required for an unnamed watercourse, to provide inflows to a 1D hydraulic model of the watercourse. The result of the hydraulic model informs the design of a proposed overbridge for the R522 road where it crosses the Cork Railway Line near Buttevant in County Cork (see Figure 1.1). This railway crossing is currently a level road crossing with the unnamed watercourse crossing the road through two culverts. The hydraulic model will be used to estimate the design peak flow and water level through a new culvert under the proposed overbridge embankment.

Figure 1.1: Proposed level crossing location plan

Full hydrographs were required for the unnamed watercourse for the 20-year, 100-year and 1000-year (equivalent to the 5%, 1% and 0.1% annual exceedance probability respectively) design events. The FSU web portal (opw.hydronet.com) was used to produce the design flood hydrographs.

In addition, peak design flows were also required for the River Awbeg, to provide a downstream level boundary for the hydraulic model.

2. Catchment description

The catchment area draining to the unnamed watercourse at the R522 road crossing is 13.9km^2 in size. The unnamed watercourse flows into the River Awbeg (Major) approximately 300m downstream of the R522 crossing. The River Awbeg to this point has a catchment area of approximately 155km^2. A gauging station (Station 18004 – Ballynamona) is located on the River Awbeg downstream of Buttevant, with a catchment area of 310km^2. The River Awbeg flows to the River Blackwater. The area of interest is within OPW Unit of Management 18. Catchment descriptors referred to in this report are detailed in FSU (2014a).

The catchment of the unnamed watercourse to the R522 road crossing is moderately steep (S1085=12.9m/km) and relatively permeable (BFISOIL=0.64). There is no impact from reservoirs (FARL=1).

The River Awbeg catchment to the confluence with the unnamed tributary is much shallower (S1085=2.1m/km) and similarly permeable (BFISOIL=0.59). There is also no impact from reservoirs (FARL=1).

The catchment of the unnamed watercourse to the R522 road crossing is almost entirely given over to pasture (>99%). The catchment has not been subject to arterial drainage schemes (ARTDRAIN=0). There is very little urbanisation (URBEXT=0.0009).

The River Awbeg catchment to the confluence with the unnamed tributary is also largely pasture (90%), the remainder of the catchment is covered by forest (10%). The catchment has not been affected by arterial drainage schemes (ARTDRAIN=0). There is no significant urbanisation (URBEXT=0).

Both catchments have lower-than-average annual rainfall (SAAR=985mm for the unnamed watercourse and 986mm for the Awbeg), with SAAR varying from 710mm to 2465mm across the country.

The geology in the unnamed watercourse catchment to the R522 road crossing is similar in nature to that for the River Awbeg (GSI 2019). The bedrock geology consists largely of locally important and regionally important aquifers, a considerable part of which is karstified (diffuse) with extensive faulting. However, most of the bedrock in the catchment is overlain with superficial Till deposits (derived from sandstones and shales). Alluvium deposits are present in the watercourse valleys. Most subsoils are classed as having 'Medium' permeability.

3. Peak design flows

The subject site on the unnamed watercourse at the R522 road crossing is ungauged and too far upstream of the nearest gauging station in the same catchment (Station 18004 on the River Awbeg) to be able to use that station to inform the design flows. The Flood Studies Update (FSU) Qmed regression equation was therefore used to produce an unadjusted synthetic estimate of Qmed. Refer to Appendix A for more details on the FSU data, results and audit trail in Appendix A.

A review of the Catchment Flood Risk Assessment and Management (CFRAM) study report for Unit of Management 18 (Mott MacDonald 2016) confirmed that the CFRAM study area is too far downstream of the site to be of use.

A growth curve was determined using pooling group analysis with approximately 500 station-years of pooled data. Details on the choice of hydrologically similar sites are provided in the FSU data, results and audit trail pages in Appendix A.

The final growth curve based on a Generalised Extreme Value (GEV) distribution and the peak flows are shown in Table 3.1 below. The specific discharge refers to the flow per unit of catchment area in l/s/ha.

Table 3.1: Unnamed watercourse growth factors and peak design flows

Return period (year)	Growth factor	Peak flow (m^3/s)	Specific discharge (l/s/ha)
2	1.00	2.69	1.94
10	1.47	3.96	2.85
20	1.63	4.39	3.16
50	1.81	4.88	3.51
100	1.94	5.23	3.76
200	2.07	5.58	4.01
1000	2.32	6.25	4.50

The typical range for the 2-year specific discharge is between 1 and 10 l/s/ha from small catchments and can be considerably lower for large catchments. The specific discharge in Table 3.1 (1.94 l/s/ha) falls within that range.

The 100-year growth factor (1.94) is in the typical range for pooled growth curves in Unit of Management 18 as derived for the CFRAM study (Mott MacDonald 2016), between approximately 1.9 and 2.3.

The subject site on the River Awbeg was selected immediately upstream of the confluence of the unnamed tributary at Buttevant with the River Awbeg. The gauging station on the River Awbeg located downstream of the subject site (Station 18004 - Ballynamona) was adopted as a pivotal station for the estimation of Qmed. The Flood Studies Update (FSU) Qmed regression equation was used to produce a synthetic estimate of Qmed (21.51m^3/s), which was then adjusted using a Qmed adjustment factor obtained from Station 18004 (0.96).

A separate growth curve was determined for the River Awbeg subject site, also using pooling group analysis with approximately 500 station-years of pooled data, applying the GEV distribution. Refer to Appendix B for more details on the FSU data, results and audit trail.

Table 3.2: River Awbeg growth factors and peak design flows

Return period (year)	Growth factor	Peak flow (m^3/s)	Specific discharge (l/s/ha)
2	1.00	20.66	1.33
10	1.34	27.68	1.79
20	1.45	29.95	1.93
50	1.58	32.64	2.11
100	1.66	34.29	2.21
200	1.74	35.94	2.32
1000	1.89	39.04	2.52

For the River Awbeg (Table 3.2), the specific discharge for the 2-year peak flow (1.33) is lower than that for the unnamed watercourse (1.94), as expected for larger catchment with similar catchment characteristics. It is within the typical range (1-10l/s/ha).

The 100-year growth factor (1.66) for the River Awbeg is somewhat lower than the CFRAM range (1.9 to 2.3). It is noted that karstified geology is present in the River Awbeg catchment, as confirmed by Mott MacDonald (2016) and Geological Survey Ireland (GSI) online mapping (GSI 2019). In catchments with permeable subsoils this may create complex subsurface runoff routes. For comparison purposes, we produced a growth curve using at-site data for Station 18004 (Ballynamona). This is shown in Figure 3.1, together with a pooled growth curve and a weighted average between the single-site and pooled growth curves (both with EV1 distributions) as provided on the FSU web portal. Details of the pooling analysis at the gauging station are included in Appendix C. The station is graded A2 and the highest gauged flow as a fraction of Qmed (HGF/Qmed) is 1.12. Although the highest gauged flow is not much higher than Qmed, the station is incorporated in the FSU list of gauging stations considered for pooling (FSU 2014b).

The single site 100-year growth factor at the gauging station (1.55) is lower than that adopted in the CFRAM study, suggesting that geological conditions in the catchment contribute to the shallower (flatter) growth curve. (Adopting GEV distributions results in even shallower growth curves.) The average curve weighting was adjusted to 60%, i.e. a slight preference for the single site curve over the pooled curve. With this weighting the 20-year and 100-year growth factors at the gauging station (1.40 and 1.66 respectively) are similar to the pooled growth factors at the River Awbeg subject site.

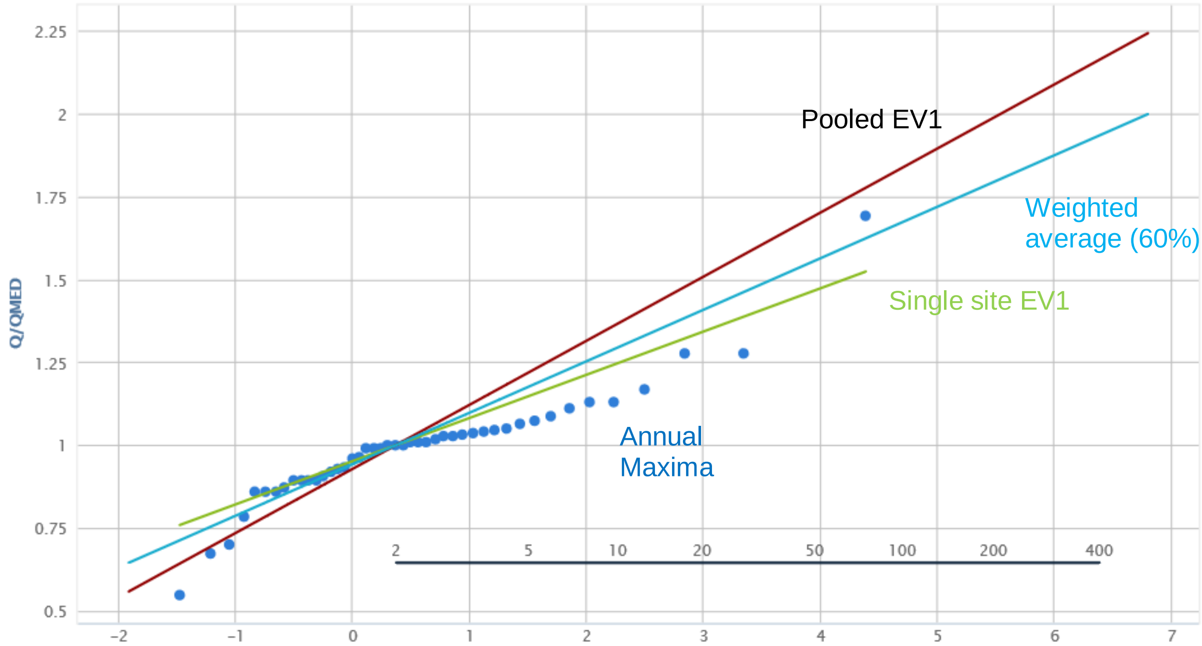


Figure 3.1: Single site, pooled and weighted-averaged growth curve River Awbeg at Ballynamona (No 18004)

For the subject sites on the River Awbeg and the unnamed tributary, the pooled growth curves were taken forward in favour of the at-site growth curve at Station 18004 (Ballynamona) for the following reasons:

1. The gauged record length (45 years) is too short to provide a reliable estimate of the 100-year target flood;
2. The highest gauged flow is only 12% higher than Qmed, making the highest AMAX flows uncertain.
3. GSI mapping (GSI 2019) suggests that the proportion of superficial Tills with shale (containing mud and thus reducing permeability) may be higher in the subject catchments than in the catchment to the gauging station. This in turn suggests that the permeable soil properties in the gauged catchment (BFISOIL = 0.685) may not be present as abundantly in the catchments to the subject sites.

A comparison of the specific discharges at the subject sites on the unnamed tributary and the River Awbeg with the CFRAM study for Unit of Management 18 (Mott MacDonald 2016) shows that the specific discharge at the subject sites for the 100-year flood (3.76l/s/ha and 2.21l/s/ha respectively) are much higher than that from the River Awbeg contribution to the Blackwater (0.5l/s/ha). This reflects that the rivers at the subject sites respond in a flashier manner to shorter duration storms, whilst the storms that are most likely to cause flooding on the River Blackwater have low intensities but long durations, of the order of days.

4. Hydrograph shape

A synthetic shape was produced for the subject site on the unnamed watercourse at the R522 road crossing using the FSU web portal, based on catchment descriptors (BFISOIL, FARL, ALLUV, ARTDRAIN and S1085). However, this appeared to have an unrealistically long duration for the size, slope and permeability of the catchment (blue line in Figure 4.1). A gauging station hydrologically similar to the subject site (Station 22009, AREA=35.4km^2) was used as a pivotal site to produce an adjustment to the parameter 'n' defining the 'width' of the hydrograph shape up to the inflection point shown in Figure 4.1. The adjustment was made by iteratively varying 'n' until the hydrograph shape fits best with observed events, and applying the 'n' thus obtained to the synthetic shape for the subject site. The other shape parameters (Tr and C) remained unaltered. The original and final shape parameters are summarised in Table 4.1. The application of the pivotal station resulted in the shorter hydrograph shown in black in Figure 4.1.

Table 4.1: Unnamed watercourse original and final hydrograph shape parameters

Parameter	Original values subject site	Original values pivotal station 22009	Final values pivotal station 22009	Final values subject site
n	5.4	7.1	40	40
Tr (hours)	34.8	33.2	33.2	34.8
C (hours)	26.3	20.6	32.9	26.3

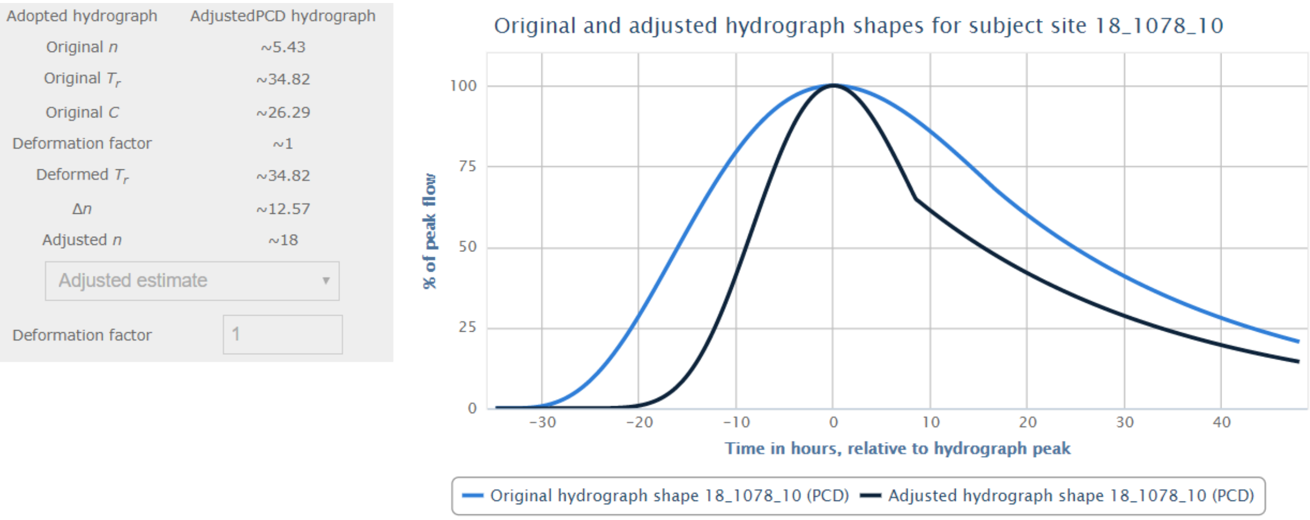


Figure 4.1: Synthetic and adjusted hydrograph shape at the subject site on the unnamed watercourse

The resulting hydrograph still appears to be relatively wide, which may be reflective of the relatively permeable nature of the catchment. It is noted in this regard that pivotal station 22009 has a BFISOIL of 0.58 (FSU Vol 4 p91), not too dissimilar to that for the subject. However, the long hydrograph could also reflect a limitation of the FSU technique for hydrograph shape estimation, e.g. differences in catchment characteristics other than BFISOIL could make it less appropriate to adopt this gauging station.

5. Uncertainty

Confidence intervals for the synthetic rural Qmed estimate to the R522 road crossing (2.69m^3/s) are provided on the FSU portal as shown in Table 5.1 below.

Table 5.1: Unnamed watercourse Qmed confidence intervals

Confidence interval	Lower limit (m^3/s)	Upper limit (m^3/s)
68%	1.96	3.69
95%	1.43	5.05

The uncertainty in hydrograph 'width' is considerable for this ungauged catchment. It is recommended that sensitivity testing of the hydraulic model is undertaken by varying the hydrograph width whilst retaining the flood peak.

Confidence intervals for the synthetic rural Qmed estimate to the River Awbeg at the confluence with the unnamed tributary at Buttevant (21.51m^3/s) are provided on the FSU portal as shown in Table 5.2 below.

Table 5.2: River Awbeg Qmed confidence intervals

Confidence interval	Lower limit (m^3/s)	Upper limit (m^3/s)
68%	15.70	29.47
95%	11.46	40.37

6. Climate change

Table 6.1 (reproduced from Table 12.1 of Mott MacDonald [2016]) shows recommended climate change allowances for Mid-Range Future Scenario (MRFS) and the High-End Future Scenario (HEFS, referred to in Mott MacDonald [2016] as HRFS). THE MRFS and HEFS represent different future greenhouse gas emission scenarios defined by the International Panel on Climate Change (IPCC).

Table 6.1: Climate change parameters (from Mott MacDonald 2016)

Catchment Parameter	MRFS	HRFS
Extreme Rainfall Depth	+20%	+30%
Flood Flows	+20%	+30%
Mean Sea Level Rise	+0.5m	+1.0m
Land Movement	-0.5mm/year i.e. +0.05m relative sea level rise over 100 years	-0.5mm/year i.e. +0.05m relative sea level rise over 100 years

Source: Reproduced from Appendix F of National Flood Risk Assessment and Management Programme, Catchment-Based Flood Risk Assessment and Management (CFRAM) Studies, Stage I Tender Documents: Project Brief.

A climate change factor of 20% has been applied to the inflows, representing the MRFS.

7. Results and recommendations

7.1 Results

Table 7.1 below reports the central estimates of the peak design flows and the peak design flows when the 68% and 95% upper limits are applied on the unnamed watercourse at the R522 road crossing. Peak design flows are obtained from the upper limit value of $Qmed_{rural}$ by applying an urban adjustment factor (1.0015) and the relevant growth factor. These confidence limits only consider the uncertainty in the estimation of Qmed, i.e. the 2-year design flood. For higher return periods the uncertainty may be expected to increase, but this has not been quantified. It is noted that statistical analysis in Section 9.6 of Flood Studies Update Volume II (FSU 2014b) found that: '… *the uncertainty in QT* [i.e. any higher return period peak flow] *is dominated by the uncertainty in QMED and is independent of return period* ...'.

Table 7.1: Unnamed watercourse upper limit peak design flows

Return period (years)	Central estimate of peak flow (m³/s)	68% upper limit (m³/s)	95% upper limit (m³/s)
2	2.69	3.69	5.05
10	3.96	5.43	7.43
20	4.39	6.02	8.24
50	4.88	6.69	9.15
100	5.23	7.17	9.81
200	5.58	7.65	10.47
1000	6.25	8.57	11.73

The culvert designer should check the operation of the culvert for the 68% or 95% upper limit flows, dependent on the level of flood risk that is acceptable.

Table 7.2 summarises the peak design flows (central estimate and upper limits of the confidence intervals) on the unnamed watercourse at the R522 road crossing, including a 20% allowance for climate change.

Table 7.2: Unnamed watercourse upper limit peak design flows with 20% climate change allowance

Return period (years)	Central estimate of peak flow plus climate change (m³/s)	68% upper limit plus climate change (m³/s)	95% upper limit plus climate change (m³/s)
2	3.23	4.43	6.06
10	4.75	6.52	8.92
20	5.27	7.23	9.89
50	5.86	8.03	10.99
100	6.28	8.60	11.77
200	6.70	9.18	12.56
1000	7.50	10.29	14.08

Tables 7.3 and 7.4 summarise the peak design flows on the River Awbeg at the confluence with the unnamed tributary, without and with climate change allowances, respectively.

Table 7.3 presents the central estimate and upper limits of the confidence intervals without climate change allowances.

Table 7.3: River Awbeg upper limit peak design flows

Return period (years)	Central estimate of peak flow (m^3/s)	68% upper limit (m^3/s)	95% upper limit (m^3/s)
2	20.66	29.47	40.37
10	27.68	39.49	54.10
20	29.95	42.73	58.54
50	32.64	46.56	63.78
100	34.29	48.92	67.01
200	35.94	51.28	70.24
1000	39.04	55.70	76.30

Table 7.4 presents the central estimate and upper limits of the confidence intervals including a 20% allowance for climate change.

Table 7.4: River Awbeg upper limit peak design flows with 20% climate change allowance

Return period (years)	Central estimate of peak flow plus climate change (m^3/s)	68% upper limit plus climate change (m^3/s)	95% upper limit plus climate change (m^3/s)
2	24.79	35.36	48.44
10	33.22	47.39	64.91
20	35.94	51.28	70.24
50	39.17	55.88	76.54
100	41.15	58.70	80.42
200	43.13	61.53	84.29
1000	46.85	66.84	91.56

7.2 Recommendations

Given the uncertainty in hydrograph width on the unnamed watercourse, it is recommended that sensitivity testing of the hydraulic model is undertaken by varying the hydrograph width whilst retaining the flood peak. The suggested sensitivity run hydrograph widths are:

- FSU recommended width (see Section 4) minus 50%; and
- FSU recommended width (see Section 4) plus 25%.

To demonstrate the impact of the proposed scheme on flood water levels, it is suggested that the hydraulic model be run with a range of design flood combinations on the unnamed tributary and the River Awbeg.

In the case that the water levels at the proposed scheme are affected by water levels on the River Awbeg, to identify the 20-year, 100-year and 1000-year peak flood flow and water levels at the proposed scheme, one would need to determine the combined (flow) probability distribution, which is a function of the individual probability distributions of the two watercourses and the dependency between flood peaks on the two watercourses. Without gauged data this dependency cannot be established. Given the difference in catchment size and peak flow between the two watercourses, it can be assumed that they respond to quite different storms. Therefore, the dependency between flood flows on the two watercourses can be expected to be low, although not nil.

In any case, the main purpose of the modelling is to show that the scheme does not negatively impact design flood levels for a wide range of floods. To this end, it is recommended that the modellers focus on the flood combinations provided in Table 7.5.

Table 7.5: Model run flood combinations

<table>
<tr><th>Overall return period (years)</th><th>Unnamed watercourse return period (years)</th><th>River Awbeg return period (years)</th><th>Code</th></tr>
<tr><td rowspan="2">20</td><td>2</td><td>20</td><td>U2-A20</td></tr>
<tr><td>20</td><td>2</td><td>U20-A2</td></tr>
<tr><td rowspan="3">100</td><td>2</td><td>100</td><td>U2-A100</td></tr>
<tr><td>20</td><td>20</td><td>U20-A20</td></tr>
<tr><td>100</td><td>2</td><td>U100-A2</td></tr>
<tr><td>100 + Climate Change</td><td colspan="3">Critical combination of 100-year overall return period runs (U2-A100 or U20-A20 or U100-A2, whichever gives the highest peak water level in the unnamed watercourse at the R522 road crossing), with climate change allowances added to both flows.</td></tr>
<tr><td rowspan="4">1000</td><td>2</td><td>1000</td><td>U2-A1000</td></tr>
<tr><td>20</td><td>100</td><td>U20-A100</td></tr>
<tr><td>100</td><td>20</td><td>U100-A20</td></tr>
<tr><td>1000</td><td>2</td><td>U1000-A2</td></tr>
</table>

If it is found that the water levels at the scheme are not sensitive to water levels in the River Awbeg, then the list of runs in Table 7.5 can be reduced as appropriate.

8. References

Flood Studies Update, 2009, Work Package 2.3 – Flood Estimation in Ungauged Catchments (Final Report), ICARUS, Dept of Geography, NIU Maynooth

Flood Studies Update, 2014a, Technical Research Report, Volume IV, Physical Catchment Descriptors

Flood Studies Update, 2014b, Technical Research Report, Volume II, Flood Frequency Estimation

Geological Survey Ireland, Spatial Resources Viewer, https://dcenr.maps.arcgis.com/apps/MapSeries/index.html?appid=a30af518e87a4c0ab2fbde2aaac3c228 (accessed December 2019)

Mott MacDonald, 2016, Final Hydrology Report Unit of Management 18, Rev D, South Western CFRAM Study, June 2016

Office of Public Works, FSU web portal, https://opw.hydronet.com/ (accessed December 2019)

Appendix A. FSU web portal: data, results and audit trail (unnamed watercourse)

Flood Estimation Report #9749 (Cork Line Level Crossing)

Generated 15-11-2019 14:45

Subject site

Attributes

Name	Unit	Value
Coordinate [X]		-966791.224438195
Coordinate [Y]		6843407.59607463
Distance	km	50.7245304036116
Station Number		18_1078_10
Location		
Water Body		
Catchment		
Hydrometric Area		
Organisation		
FSU Rating Classification		
Drainage works	year	
Contributing Catchment Area	km^2	13.909
Center Northing	m	108130
Center Easting	m	150510
Northing	m	109834
Easting	m	153266
A-Max series gap in years	year	
A-Max series number of years	year	
A-Max series number of usable years	year	
A-Max series end year	year	
A-Max series start year	year	
FARL		1
ALLUV		0.0278
PEAT		0
FOREST		0.0097
PASTURE		0.9991
S1085	m/km	12.89055
MSL	km	8.049
DRAIND	km/km^2	0.853
ALTBAR		124.1
NETLEN	km	11.863
T4		
T3		

SAAPE	mm	515.98
T2		
ARTDRAIN2		0
ARTDRAIN		0
TAYSLO		1.023242
STMFRQ		7
BFISOIL		0.6419587
SAAR	mm	980.8
RWSEG_CD		18_1078
TOP_RWSEG		
Bankfull		
HGF	m^3/s	
MAF	m^3/s	
FAI		0.0836
FLATWET		0.62
URBEXT		0.0009
HGF/QMED		
centroidx3857		-972184.777753009
centroidy3857		6840671.38436372
x3857		-966791.224438195
y3857		6843407.59607463

Pivotal site

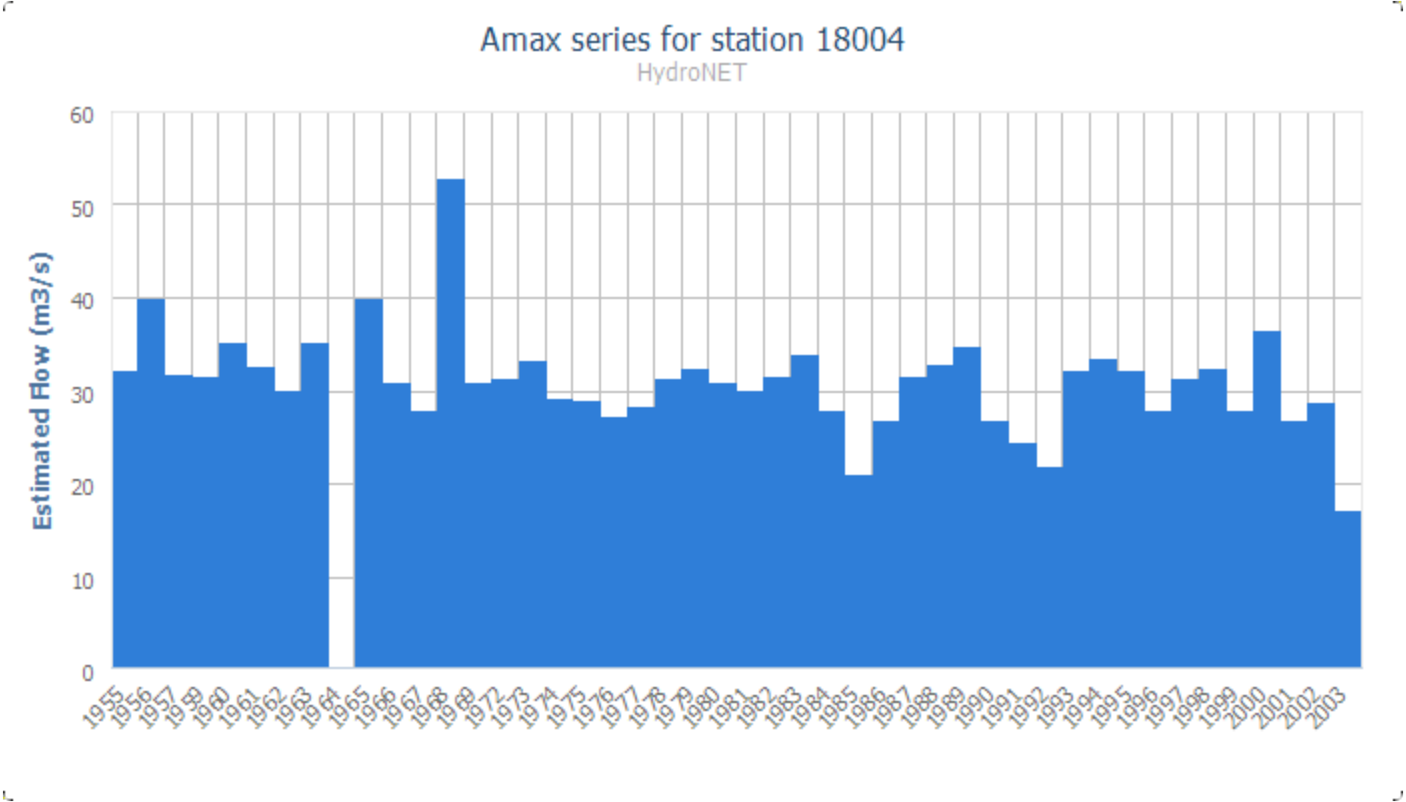
Attributes

Name	Unit	Value
Coordinate [X]		-946574.995822056
Coordinate [Y]		6839846.41016655
Station Number		18004
Location		BALLYNAMONA
Water Body		AWBEG
Catchment		Blackwater (Munster)
Hydrometric Area		18
Organisation		OPW
FSU Rating Classification		A2
Drainage works	year	No
Contributing Catchment Area	km^2	310.2956
Center Northing	m	113230
Center Easting	m	154460
Northing	m	107552
Easting	m	165657
A-Max series gap in years	year	0
A-Max series number of years	year	49
A-Max series number of usable years	year	45
A-Max series end year	year	2003
A-Max series start year	year	1955
FARL		0.999
ALLUV		0.0626
PEAT		0.0163
FOREST		0.205
PASTURE		0
S1085	m/km	1.48095
MSL	km	42.791
DRAIND	km/km^2	0.936
ALTBAR		0
NETLEN	km	290.542
T4		0.32926281711607
T3		0.051570062343489
SAAPE	mm	519.58
T2		0.087902542587319
ARTDRAIN2		0
ARTDRAIN		0
TAYSLO		0.306029
STMFRQ		209
BFISOIL		0.6847
SAAR	mm	985.41
RWSEG_CD		18_2677
TOP_RWSEG		18_941
Bankfull		1.41 from survey
HGF	m^3/s	35
MAF	m^3/s	30
FAI		0.2
FLATWET		0.61
URBEXT		0.0033
HGF/QMED		1.1225144323284
x3857		-946574.995822056
y3857		6839846.41016655

centroidx3857		-963081.251241695
centroidy3857		6848843.58002027
Distance	km	12.2335185777062

Map

Amax Series Chart



QMED Estimates

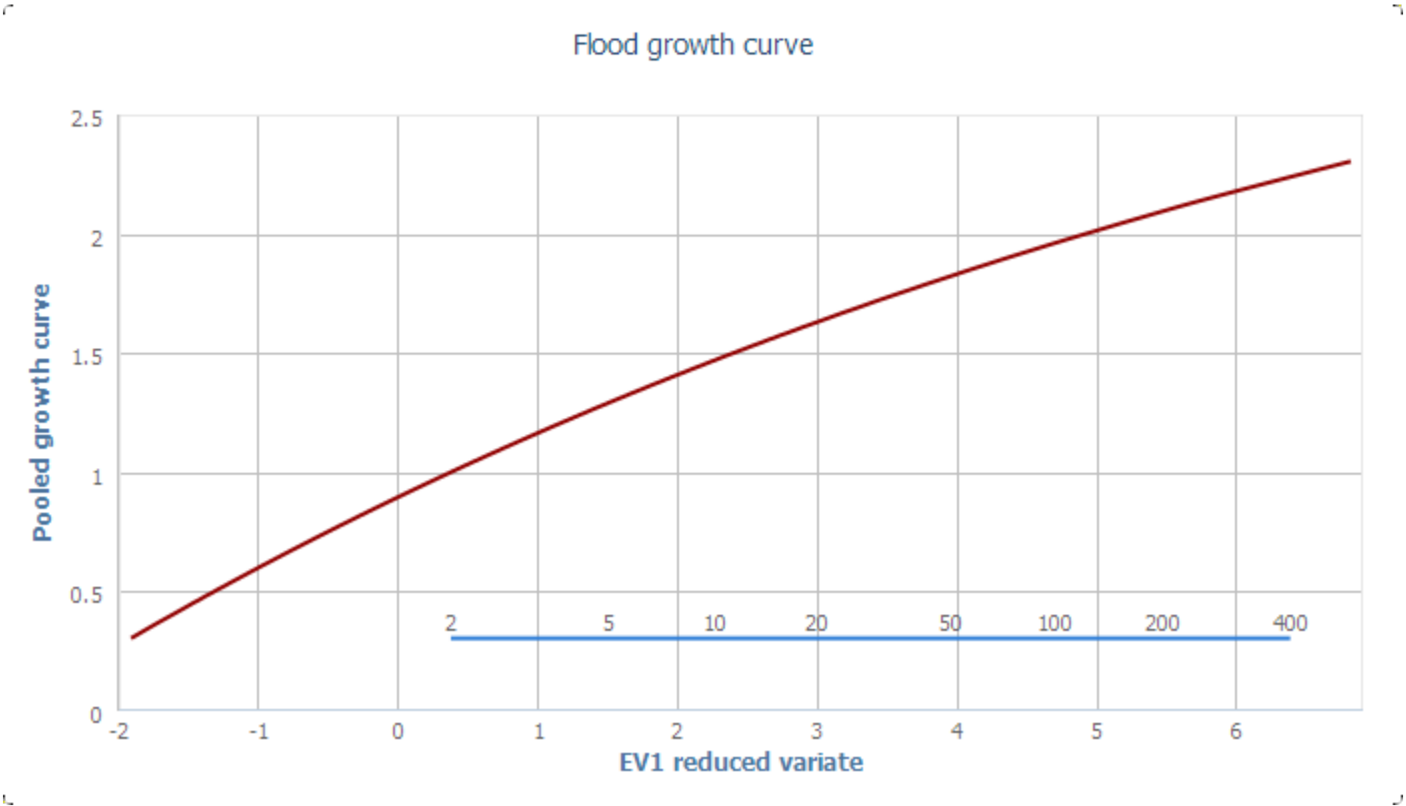
Subject rural QMED	2.69
Subject urban QMED	2.69
Pivotal gauged QMED	31.18
Pivotal adjustment factor QMED	0.96
Subject adjusted QMED	**2.59**

Pooling Group

Station	Amax years
25040 ROSCREA	19
25034 ROCHFORT	26
10022 CARRICKMINES	17
06031 CURRALHIR	18
22009 WHITE BRIDGE	24
26022 KILMORE	33
10021 COMMONS ROAD	24
13002 FOULKS MILL	19
08002 NAUL	21
08012 BALLYBOGHIL	19

16006 BALLINACLOGH	33
14009 CUSHINA	25
09010 WALDRONS BRIDGE	19
25023 MILLTOWN	33
19046 STATION ROAD	9
19020 BALLYEDMOND	28
25027 GOURDEEN BRIDGE	42
26009 BELLANTRA BR.	35
16005 AUGHNAGROSS	30
26020 ARGAR	33

Selected Flood Growth Curve



Pooled growth curve	EV1 reduced variate
0.3	-1.92
0.36	-1.76
0.39	-1.67
0.41	-1.6
0.43	-1.55
0.44	-1.51
0.45	-1.47
0.46	-1.44
0.47	-1.41
0.48	-1.38
0.49	-1.35
0.5	-1.33
0.51	-1.31
0.51	-1.29
0.52	-1.27
0.52	-1.25
0.53	-1.23
0.54	-1.21
0.54	-1.2
0.55	-1.18
0.55	-1.16
0.56	-1.15
0.56	-1.14
0.56	-1.12
0.57	-1.11
0.57	-1.09
0.58	-1.08
0.58	-1.07
0.59	-1.06

0.59	-1.04
0.59	-1.03
0.6	-1.02
0.6	-1.01
0.6	-1
0.61	-0.99
0.61	-0.98
0.61	-0.97
0.62	-0.96
0.62	-0.95
0.62	-0.94
0.63	-0.93
0.63	-0.92
0.63	-0.91
0.63	-0.9
0.64	-0.89
0.64	-0.88
0.64	-0.87
0.65	-0.86
0.65	-0.85
0.65	-0.84
0.65	-0.84
0.66	-0.83
0.66	-0.82
0.66	-0.81
0.66	-0.8
0.67	-0.79
0.67	-0.79
0.67	-0.78
0.67	-0.77
0.68	-0.76
0.68	-0.75
0.68	-0.75
0.68	-0.74
0.69	-0.73
0.69	-0.72
0.69	-0.72
0.69	-0.71
0.69	-0.7
0.7	-0.69
0.7	-0.69
0.7	-0.68
0.7	-0.67
0.7	-0.66
0.71	-0.66
0.71	-0.65
0.71	-0.64
0.71	-0.64
0.72	-0.63
0.72	-0.62
0.72	-0.62
0.72	-0.61
0.72	-0.6
0.73	-0.6
0.73	-0.59
0.73	-0.58
0.73	-0.58

0.73	-0.57
0.74	-0.56
0.74	-0.56
0.74	-0.55
0.74	-0.54
0.74	-0.54
0.74	-0.53
0.75	-0.52
0.75	-0.52
0.75	-0.51
0.75	-0.51
0.75	-0.5
0.76	-0.49
0.76	-0.49
0.76	-0.48
0.76	-0.48
0.76	-0.47
0.77	-0.46
0.77	-0.46
0.77	-0.45
0.77	-0.44
0.77	-0.44
0.77	-0.43
0.78	-0.43
0.78	-0.42
0.78	-0.41
0.78	-0.41
0.78	-0.4
0.78	-0.4
0.79	-0.39
0.79	-0.39
0.79	-0.38
0.79	-0.37
0.79	-0.37
0.79	-0.36
0.8	-0.36
0.8	-0.35
0.8	-0.35
0.8	-0.34
0.8	-0.33
0.8	-0.33
0.81	-0.32
0.81	-0.32
0.81	-0.31
0.81	-0.31
0.81	-0.3
0.81	-0.29
0.82	-0.29
0.82	-0.28
0.82	-0.28
0.82	-0.27
0.82	-0.27
0.82	-0.26
0.83	-0.25
0.83	-0.25
0.83	-0.24
0.83	-0.24

0.83	-0.23
0.83	-0.23
0.84	-0.22
0.84	-0.22
0.84	-0.21
0.84	-0.21
0.84	-0.2
0.84	-0.19
0.84	-0.19
0.85	-0.18
0.85	-0.18
0.85	-0.17
0.85	-0.17
0.85	-0.16
0.85	-0.16
0.86	-0.15
0.86	-0.15
0.86	-0.14
0.86	-0.13
0.86	-0.13
0.86	-0.12
0.87	-0.12
0.87	-0.11
0.87	-0.11
0.87	-0.1
0.87	-0.1
0.87	-0.09
0.87	-0.09
0.88	-0.08
0.88	-0.08
0.88	-0.07
0.88	-0.06
0.88	-0.06
0.88	-0.05
0.88	-0.05
0.89	-0.04
0.89	-0.04
0.89	-0.03
0.89	-0.03
0.89	-0.02
0.89	-0.02
0.9	-0.01
0.9	-0.01
0.9	0
0.9	0.01
0.9	0.01
0.9	0.02
0.9	0.02
0.91	0.03
0.91	0.03
0.91	0.04
0.91	0.04
0.91	0.05
0.91	0.05
0.92	0.06
0.92	0.06
0.92	0.07

0.92	0.08
0.92	0.08
0.92	0.09
0.92	0.09
0.93	0.1
0.93	0.1
0.93	0.11
0.93	0.11
0.93	0.12
0.93	0.12
0.93	0.13
0.94	0.13
0.94	0.14
0.94	0.15
0.94	0.15
0.94	0.16
0.94	0.16
0.95	0.17
0.95	0.17
0.95	0.18
0.95	0.18
0.95	0.19
0.95	0.19
0.95	0.2
0.96	0.21
0.96	0.21
0.96	0.22
0.96	0.22
0.96	0.23
0.96	0.23
0.96	0.24
0.97	0.24
0.97	0.25
0.97	0.25
0.97	0.26
0.97	0.27
0.97	0.27
0.98	0.28
0.98	0.28
0.98	0.29
0.98	0.29
0.98	0.3
0.98	0.3
0.98	0.31
0.99	0.32
0.99	0.32
0.99	0.33
0.99	0.33
0.99	0.34
0.99	0.34
1	0.35
1	0.36
1	0.36
1	0.37
1	0.37
1	0.38
1	0.38

1.01	0.39
1.01	0.4
1.01	0.4
1.01	0.41
1.01	0.41
1.01	0.42
1.02	0.42
1.02	0.43
1.02	0.44
1.02	0.44
1.02	0.45
1.02	0.45
1.03	0.46
1.03	0.46
1.03	0.47
1.03	0.48
1.03	0.48
1.03	0.49
1.03	0.49
1.04	0.5
1.04	0.51
1.04	0.51
1.04	0.52
1.04	0.52
1.04	0.53
1.05	0.54
1.05	0.54
1.05	0.55
1.05	0.55
1.05	0.56
1.05	0.57
1.06	0.57
1.06	0.58
1.06	0.59
1.06	0.59
1.06	0.6
1.06	0.6
1.07	0.61
1.07	0.62
1.07	0.62
1.07	0.63
1.07	0.64
1.07	0.64
1.08	0.65
1.08	0.65
1.08	0.66
1.08	0.67
1.08	0.67
1.08	0.68
1.09	0.69
1.09	0.69
1.09	0.7
1.09	0.71
1.09	0.71
1.09	0.72
1.1	0.73
1.1	0.73

1.1	0.74
1.1	0.75
1.1	0.75
1.1	0.76
1.11	0.77
1.11	0.77
1.11	0.78
1.11	0.79
1.11	0.79
1.12	0.8
1.12	0.81
1.12	0.81
1.12	0.82
1.12	0.83
1.12	0.83
1.13	0.84
1.13	0.85
1.13	0.86
1.13	0.86
1.13	0.87
1.14	0.88
1.14	0.88
1.14	0.89
1.14	0.9
1.14	0.91
1.14	0.91
1.15	0.92
1.15	0.93
1.15	0.94
1.15	0.94
1.15	0.95
1.16	0.96
1.16	0.97
1.16	0.97
1.16	0.98
1.16	0.99
1.17	1
1.17	1
1.17	1.01
1.17	1.02
1.17	1.03
1.18	1.04
1.18	1.04
1.18	1.05
1.18	1.06
1.18	1.07
1.19	1.08
1.19	1.08
1.19	1.09
1.19	1.1
1.19	1.11
1.2	1.12
1.2	1.13
1.2	1.13
1.2	1.14
1.21	1.15
1.21	1.16

1.21	1.17
1.21	1.18
1.21	1.19
1.22	1.19
1.22	1.2
1.22	1.21
1.22	1.22
1.23	1.23
1.23	1.24
1.23	1.25
1.23	1.26
1.23	1.27
1.24	1.28
1.24	1.29
1.24	1.29
1.24	1.3
1.25	1.31
1.25	1.32
1.25	1.33
1.25	1.34
1.26	1.35
1.26	1.36
1.26	1.37
1.26	1.38
1.27	1.39
1.27	1.4
1.27	1.41
1.27	1.42
1.28	1.43
1.28	1.44
1.28	1.46
1.28	1.47
1.29	1.48
1.29	1.49
1.29	1.5
1.29	1.51
1.3	1.52
1.3	1.53
1.3	1.54
1.31	1.55
1.31	1.57
1.31	1.58
1.31	1.59
1.32	1.6
1.32	1.61
1.32	1.63
1.33	1.64
1.33	1.65
1.33	1.66
1.33	1.68
1.34	1.69
1.34	1.7
1.34	1.71
1.35	1.73
1.35	1.74
1.35	1.75
1.36	1.77

1.36	1.78
1.36	1.8
1.37	1.81
1.37	1.82
1.37	1.84
1.38	1.85
1.38	1.87
1.38	1.88
1.39	1.9
1.39	1.91
1.39	1.93
1.4	1.95
1.4	1.96
1.41	1.98
1.41	1.99
1.41	2.01
1.42	2.03
1.42	2.04
1.43	2.06
1.43	2.08
1.43	2.1
1.44	2.12
1.44	2.13
1.45	2.15
1.45	2.17
1.46	2.19
1.46	2.21
1.46	2.23
1.47	2.25
1.47	2.27
1.48	2.3
1.48	2.32
1.49	2.34
1.49	2.36
1.5	2.39
1.5	2.41
1.51	2.43
1.52	2.46
1.52	2.48
1.53	2.51
1.53	2.54
1.54	2.56
1.54	2.59
1.55	2.62
1.56	2.65
1.56	2.68
1.57	2.71
1.58	2.74
1.59	2.78
1.59	2.81
1.6	2.85
1.61	2.88
1.62	2.92
1.62	2.96
1.63	3
1.64	3.05
1.65	3.09

1.66	3.14
1.67	3.18
1.68	3.24
1.69	3.29
1.7	3.35
1.72	3.41
1.73	3.47
1.74	3.54
1.76	3.61
1.77	3.69
1.79	3.77
1.81	3.86
1.83	3.96
1.85	4.07
1.87	4.2
1.9	4.34
1.93	4.51
1.96	4.71
2.01	4.96
2.06	5.29
2.15	5.78
2.3	6.81

Adopted Growth Factors

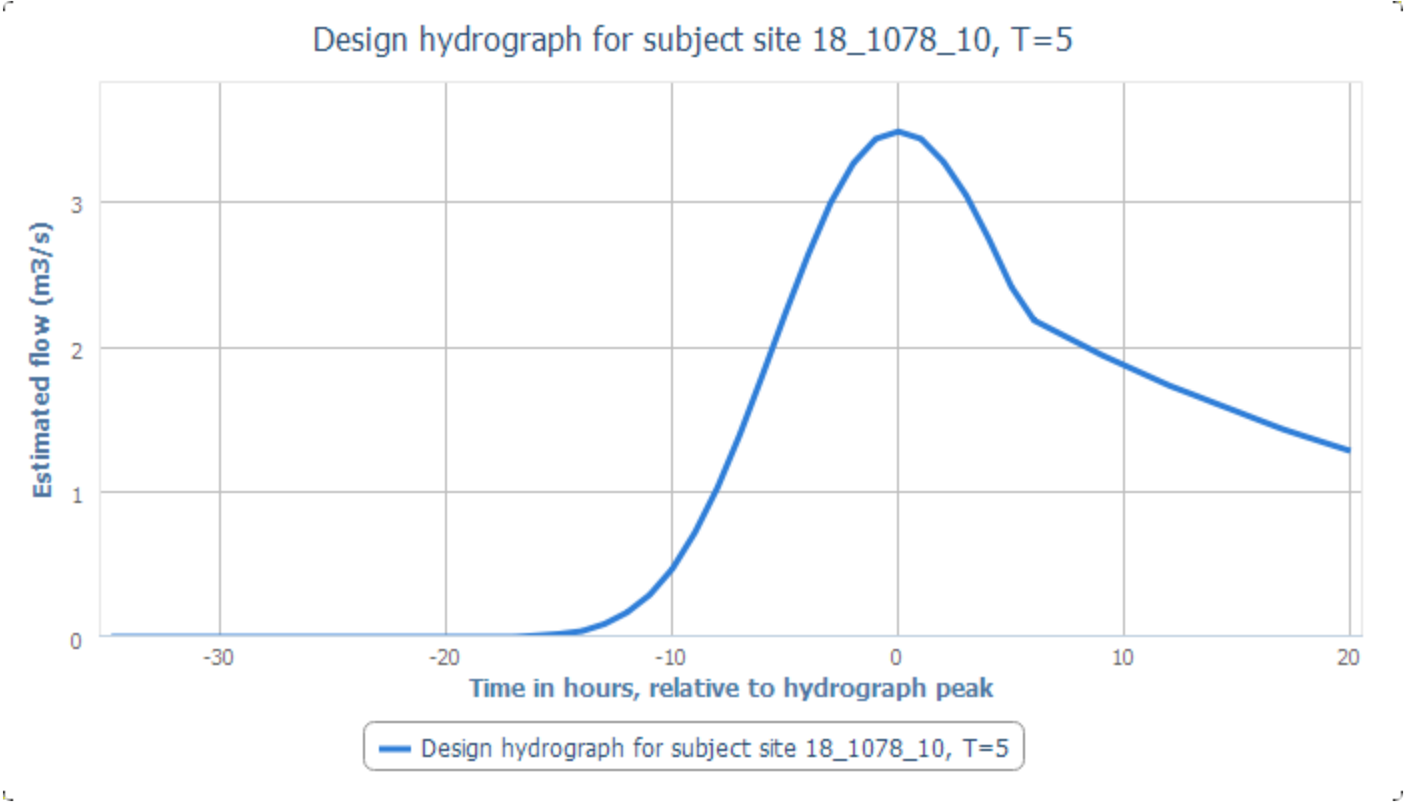
Return Period	Growth Factor	Design Peak Flow (m^3/s)
1.3	0.79	2.13
2	1	2.69
5	1.29	3.48
10	1.47	3.96
20	1.63	4.39
30	1.71	4.61
50	1.81	4.88
100	1.94	5.23
200	2.07	5.58
500	2.21	5.96
1000	2.32	6.25

Hydrograph Width Estimation Summary

Name	Value
Pivotal site	22009 "WHITE BRIDGE"
Adjustment type	The user adopted the latest HWA hydrograph
Transfer type	The user adjusted the subject site estimate with the pivotal site deformation factor
Deformation factor	1
Custom deformation factor	1
Accepted n	40
Accepted Tr	34.8235723330599
Accepted C	26.2948046027457

Hydrograph Plots

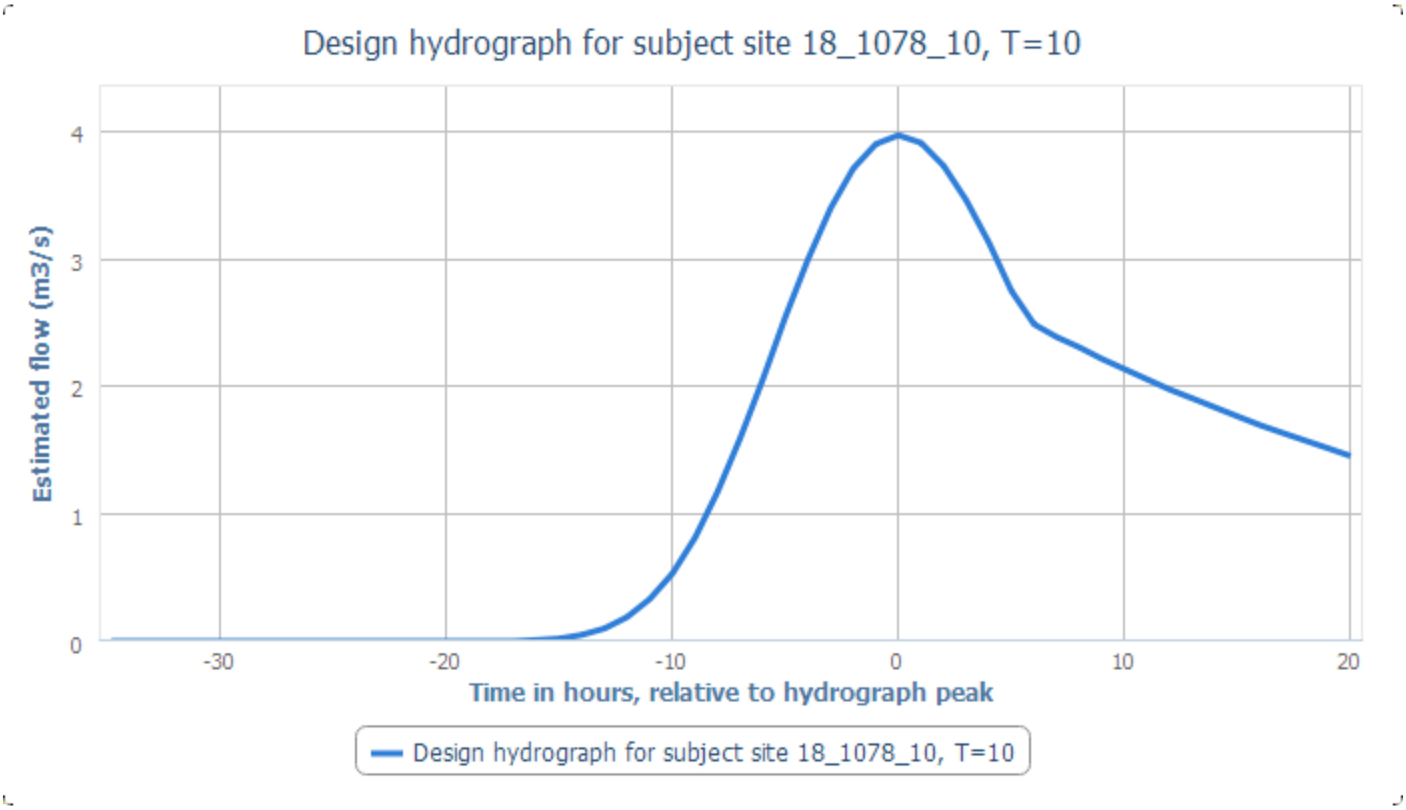
Return Period: 5



Hours relative to hydrograph peak	Estimated flow (m3/s)
-34.82	0
-34	0
-33	0
-32	0
-31	0
-30	0
-29	0
-28	0
-27	0
-26	0
-25	0
-24	0
-23	0
-22	0
-21	0
-20	0
-19	0
-18	0
-17	0
-16	0.01
-15	0.02
-14	0.04
-13	0.09
-12	0.17
-11	0.29
-10	0.47
-9	0.72
-8	1.03
-7	1.4

-6	1.81
-5	2.23
-4	2.63
-3	2.99
-2	3.26
-1	3.43
0	3.48
1	3.43
2	3.27
3	3.04
4	2.74
5	2.41
6	2.18
7	2.1
8	2.02
9	1.94
10	1.87
11	1.8
12	1.73
13	1.67
14	1.61
15	1.55
16	1.49
17	1.43
18	1.38
19	1.33
20	1.28

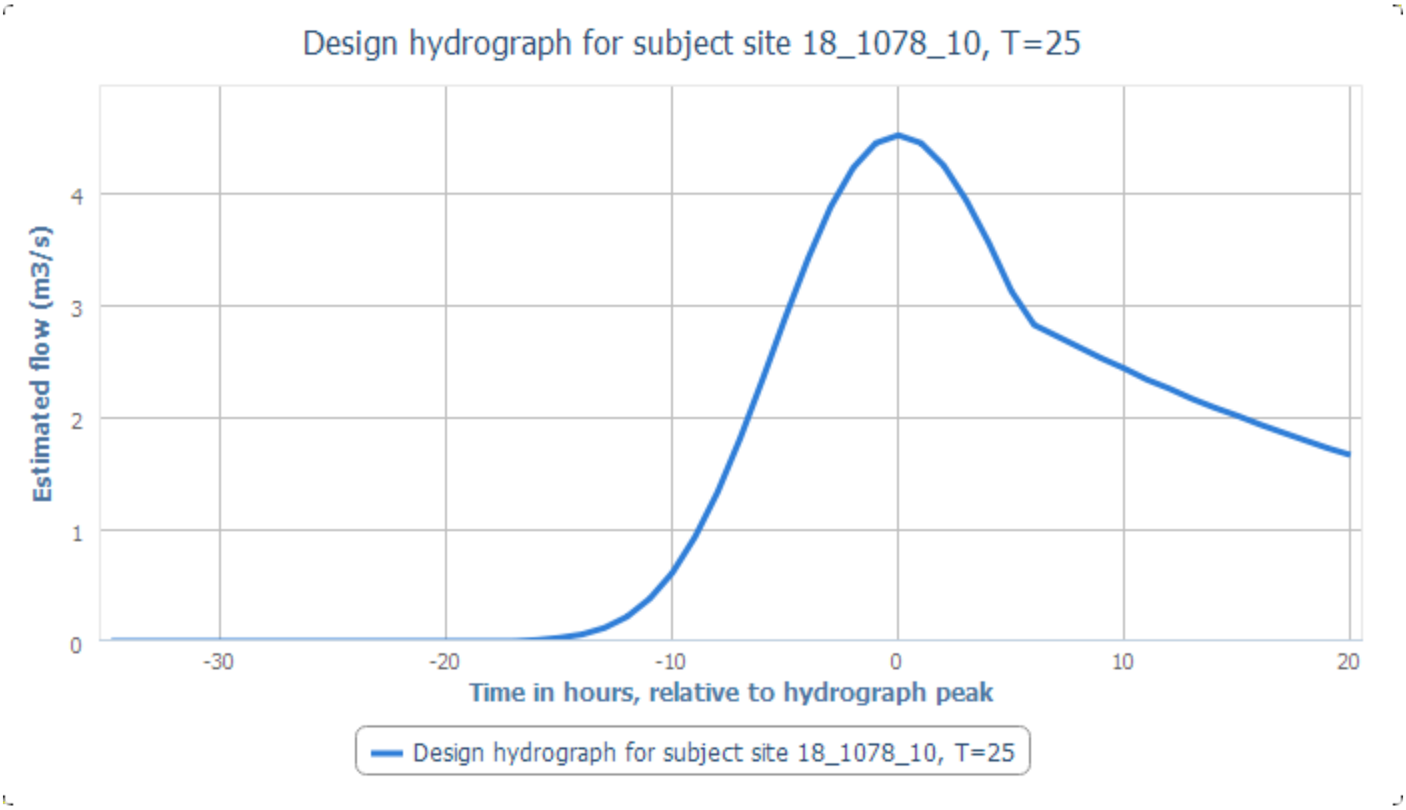
Return Period: 10



Hours relative to hydrograph peak	Estimated flow (m3/s)
-34.82	0
-34	0
-33	0
-32	0
-31	0
-30	0
-29	0
-28	0
-27	0
-26	0
-25	0
-24	0
-23	0
-22	0
-21	0
-20	0
-19	0
-18	0
-17	0
-16	0.01
-15	0.02
-14	0.05
-13	0.1
-12	0.19
-11	0.33
-10	0.53
-9	0.81
-8	1.17
-7	1.59
-6	2.05
-5	2.54

-4	2.99
-3	3.39
-2	3.7
-1	3.89
0	3.96
1	3.9
2	3.72
3	3.45
4	3.12
5	2.74
6	2.48
7	2.38
8	2.3
9	2.21
10	2.13
11	2.05
12	1.97
13	1.9
14	1.83
15	1.76
16	1.69
17	1.63
18	1.57
19	1.51
20	1.45

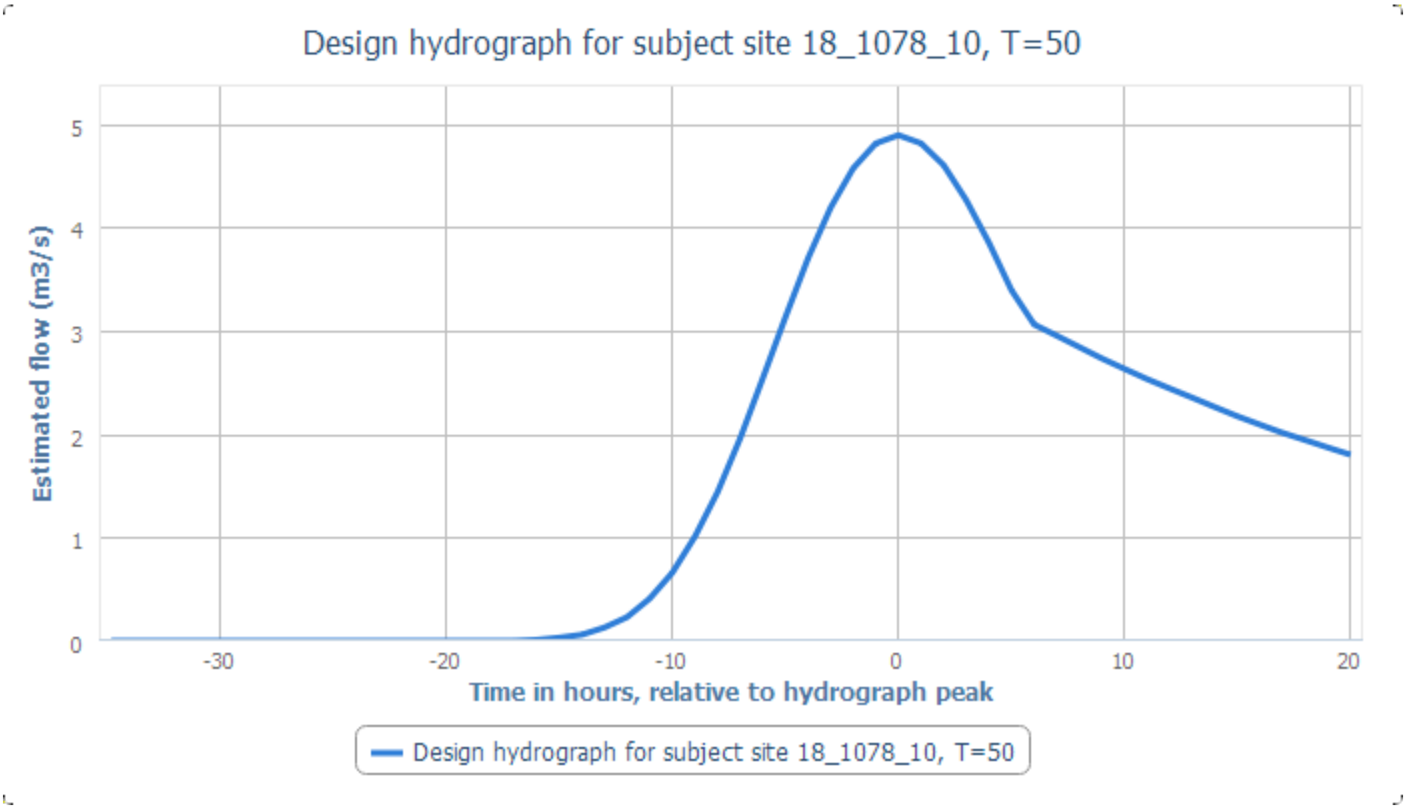
Return Period: 25



Hours relative to hydrograph peak	Estimated flow (m3/s)
-34.82	0
-34	0
-33	0
-32	0
-31	0
-30	0
-29	0
-28	0
-27	0
-26	0
-25	0
-24	0
-23	0
-22	0
-21	0
-20	0
-19	0
-18	0
-17	0
-16	0.01
-15	0.03
-14	0.06
-13	0.12
-12	0.22
-11	0.38
-10	0.61
-9	0.93
-8	1.33
-7	1.81
-6	2.34
-5	2.89

-4	3.41
-3	3.87
-2	4.22
-1	4.44
0	4.51
1	4.44
2	4.24
3	3.93
4	3.55
5	3.12
6	2.82
7	2.72
8	2.62
9	2.52
10	2.43
11	2.33
12	2.25
13	2.16
14	2.08
15	2.01
16	1.93
17	1.86
18	1.79
19	1.72
20	1.66

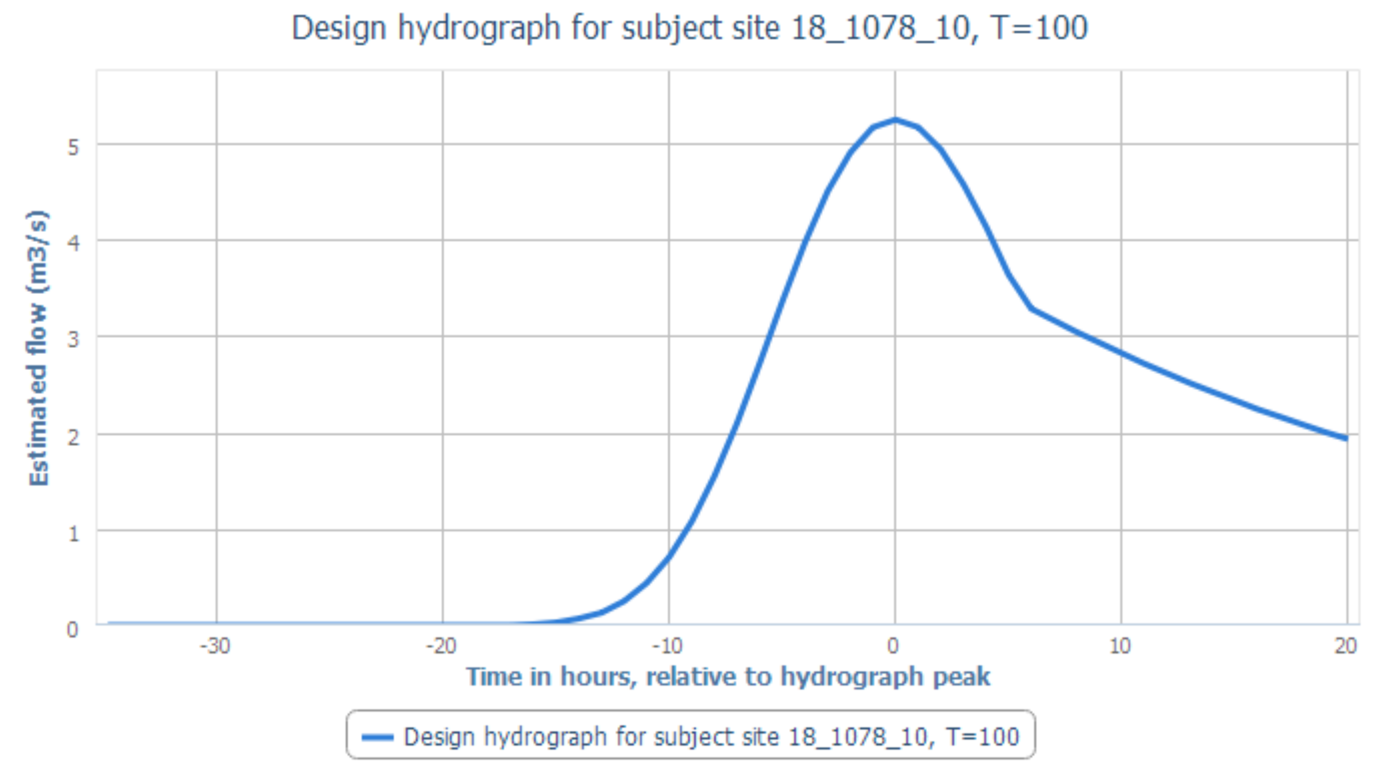
Return Period: 50



Hours relative to hydrograph peak	Estimated flow (m3/s)
-34.82	0
-34	0
-33	0
-32	0
-31	0
-30	0
-29	0
-28	0
-27	0
-26	0
-25	0
-24	0
-23	0
-22	0
-21	0
-20	0
-19	0
-18	0
-17	0
-16	0.01
-15	0.03
-14	0.06
-13	0.13
-12	0.23
-11	0.41
-10	0.66
-9	1.01
-8	1.44
-7	1.96
-6	2.54
-5	3.13

-4	3.7
-3	4.19
-2	4.57
-1	4.81
0	4.89
1	4.81
2	4.6
3	4.26
4	3.85
5	3.39
6	3.06
7	2.95
8	2.84
9	2.73
10	2.63
11	2.53
12	2.44
13	2.35
14	2.26
15	2.17
16	2.09
17	2.01
18	1.94
19	1.87
20	1.8

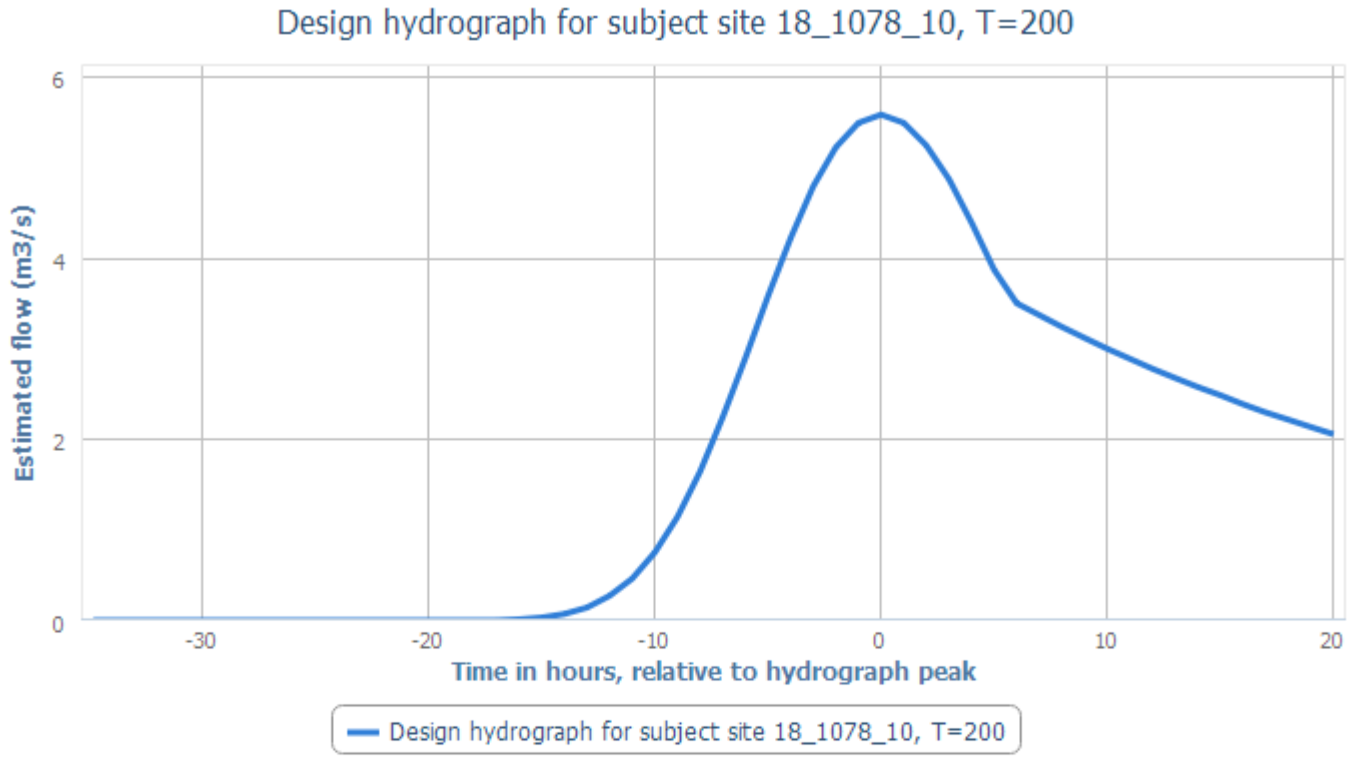
Return Period: 100



Hours relative to hydrograph peak	Estimated flow (m3/s)
-34.82	0
-34	0
-33	0
-32	0
-31	0
-30	0
-29	0
-28	0
-27	0
-26	0
-25	0
-24	0
-23	0
-22	0
-21	0
-20	0
-19	0
-18	0
-17	0
-16	0.01
-15	0.03
-14	0.07
-13	0.13
-12	0.25
-11	0.44
-10	0.71
-9	1.08
-8	1.55
-7	2.1
-6	2.72
-5	3.36

-4	3.97
-3	4.5
-2	4.9
-1	5.16
0	5.24
1	5.16
2	4.93
3	4.57
4	4.13
5	3.63
6	3.28
7	3.16
8	3.04
9	2.93
10	2.82
11	2.71
12	2.61
13	2.51
14	2.42
15	2.33
16	2.24
17	2.16
18	2.08
19	2
20	1.93

Return Period: 200



Hours relative to hydrograph peak	Estimated flow (m3/s)
-34.82	0
-34	0
-33	0
-32	0
-31	0
-30	0
-29	0
-28	0
-27	0
-26	0
-25	0
-24	0
-23	0
-22	0
-21	0
-20	0
-19	0
-18	0
-17	0
-16	0.01
-15	0.03
-14	0.07
-13	0.14
-12	0.27
-11	0.46
-10	0.75
-9	1.14
-8	1.64
-7	2.24
-6	2.89
-5	3.57

-4	4.21
-3	4.78
-2	5.21
-1	5.48
0	5.57
1	5.48
2	5.23
3	4.86
4	4.38
5	3.86
6	3.49
7	3.36
8	3.23
9	3.11
10	2.99
11	2.88
12	2.77
13	2.67
14	2.57
15	2.48
16	2.38
17	2.29
18	2.21
19	2.13
20	2.05

IBIDEM Plots and Tables

No IBIDEM plots were saved by the user.

Audit Trail Report #9749 (Cork Line Level Crossing)

User ID:	liam.meachen@jacobs.com
Name:	Meachen, Liam
Company:	
Address:	
Report date & time:	15-11-2019 14:46
Start of Calculation:	13-11-2019 11:58

Decisions made by the user:

Decision	**User comment**	**System information**	**Date**
2.1 Subject site accepted	N/A	Location 18_1078_10	13-11-2019 12:03
2.2 Subject site with area < 25km2 accepted	N/A		13-11-2019 12:05
2.4 Pivotal site accepted	Reason for accepting: We will select this as the pivtoal site now but reject it at a later stage because its catchment is 22 times larger Reason for ignoring warnings:	Station: 18004 BALLYNAMONA The user has been notified that 80 candidates where either hydrologically or geographically closer to the subject site than the chosen pivotal site. The user has accepted to reject these sites in preference of the chosen pivotal site.	13-11-2019 12:31

2.8 QMED data transfer performed	Catchment is 22 times larger than subject site. It is not justified to reduce Qmed based on this pivotal site	Warning: you are disallowing the pivotal site from playing a part in QMED estimation at the subject site. Please provide a reason for this choice.	13-11-2019 12:43
2.10 Pooling stations excluded	N/A	The following stations were excluded: Station: 30020, Atribute: draind, Reason: DrainD is much larger than the sibject site, Station: 09011, Atribute: s1085, Reason: S1085 is much greater than at subject site and Urbext is also much greater than at subject site, Station: 16051, Atribute: s1085, Reason: S1085 is much more shallow than subject site, Station: 26058, Atribute: artdrain2, Reason: Artdrain2 is much greater than subject site, Station: 24022, Atribute: artdrain2, Reason: Artdrain2 is much larger than subject site, Station: 09035, Atribute: urbext, Reason: Urbext is much greater than at subject site, Station: 09002, Atribute: saar, Reason: SAAR is much less than at subject site, Station: 06033, Atribute: bfisoil, Reason: BFI is much lower than at subject site. Also Ardrain2 is much greater than at subject site, Station: 26010, Atribute: s1085, Reason: S1085 is much more shallow than at subject site, Station: 26018, Atribute: farl, Reason: FARL is much lower than at subject site	15-11-2019 15:06

2.11 Pooling group accepted	N/A	Pooled group accepted with the following stations: [25040, 25034, 10022, 06031, 22009, 26022, 10021, 13002, 08002, 08012, 16006, 14009, 09010, 25023, 19046, 19020, 25027, 26009, 16005, 26020] and distribution: GEV	15-11-2019 15:06
2.13 Module 2 finalized	N/A	Finished pooled analysis with the following distribution selected: GEV.	15-11-2019 15:09
3.2 Hydrograph pivotal site accepted	Poor fit with historic hydrograph data at 19020	Station: 19020 BALLYEDMOND	15-11-2019 15:32
3.2 Hydrograph pivotal site accepted	Catchment area is too large compared to subject site	Station: 25022 SYNGEFIELD	15-11-2019 15:34
3.1 Hydrograph pivotal site rejected	Hydrologically similar with similar catchment area	Station: 22009 WHITE BRIDGE	15-11-2019 15:36
3.3 Proceeded from hydrograph display	N/A		15-11-2019 15:39
3.3 Proceeded from hydrograph display	N/A		15-11-2019 15:39
3.4 Hydrograph inspected and adjusted	N/A	The user adopted the latest HWA hydrograph	15-11-2019 15:41
3.5 Hydrograph transferred to subject site	N/A	The user adjusted the subject site estimate with n = 40, Tr = 34.8235723330599, C = 26.2948046027457	15-11-2019 15:43

Appendix B. FSU web portal: data, results and audit trail (River Awbeg)

Flood Estimation Report #9923 (Cork Line - Awbeg)

Generated 20-12-2019 15:21

Subject site

Attributes

Name	Unit	Value
Coordinate [X]		-966556.407341953
Coordinate [Y]		6843736.5591325
Distance	km	66.7945746639853
Station Number		18_534_4
Location		
Water Body		
Catchment		
Hydrometric Area		
Organisation		
FSU Rating Classification		
Drainage works	year	
Contributing Catchment Area	km^2	154.941
Center Northing	m	116050
Center Easting	m	152640
Northing	m	110034
Easting	m	153412
A-Max series gap in years	year	
A-Max series number of years	year	
A-Max series number of usable years	year	
A-Max series end year	year	
A-Max series start year	year	
FARL		1
ALLUV		0.1093
PEAT		0.0178
FOREST		0.1137
PASTURE		0.8983
S1085	m/km	2.08861
MSL	km	25.405
DRAIND	km/km^2	1.073
ALTBAR		137.8
NETLEN	km	166.19
T4		
T3		

SAAPE	mm	518.54
T2		
ARTDRAIN2		0
ARTDRAIN		0
TAYSLO		0.377601
STMFRQ		141
BFISOIL		0.594428074
SAAR	mm	986.25
RWSEG_CD		18_534
TOP_RWSEG		
Bankfull		
HGF	m^3/s	
MAF	m^3/s	
FAI		0.2058
FLATWET		0.61
URBEXT		0
HGF/QMED		
centroidx3857		-968344.606385277
centroidy3857		6853414.88798649
x3857		-966556.407341953
y3857		6843736.5591325

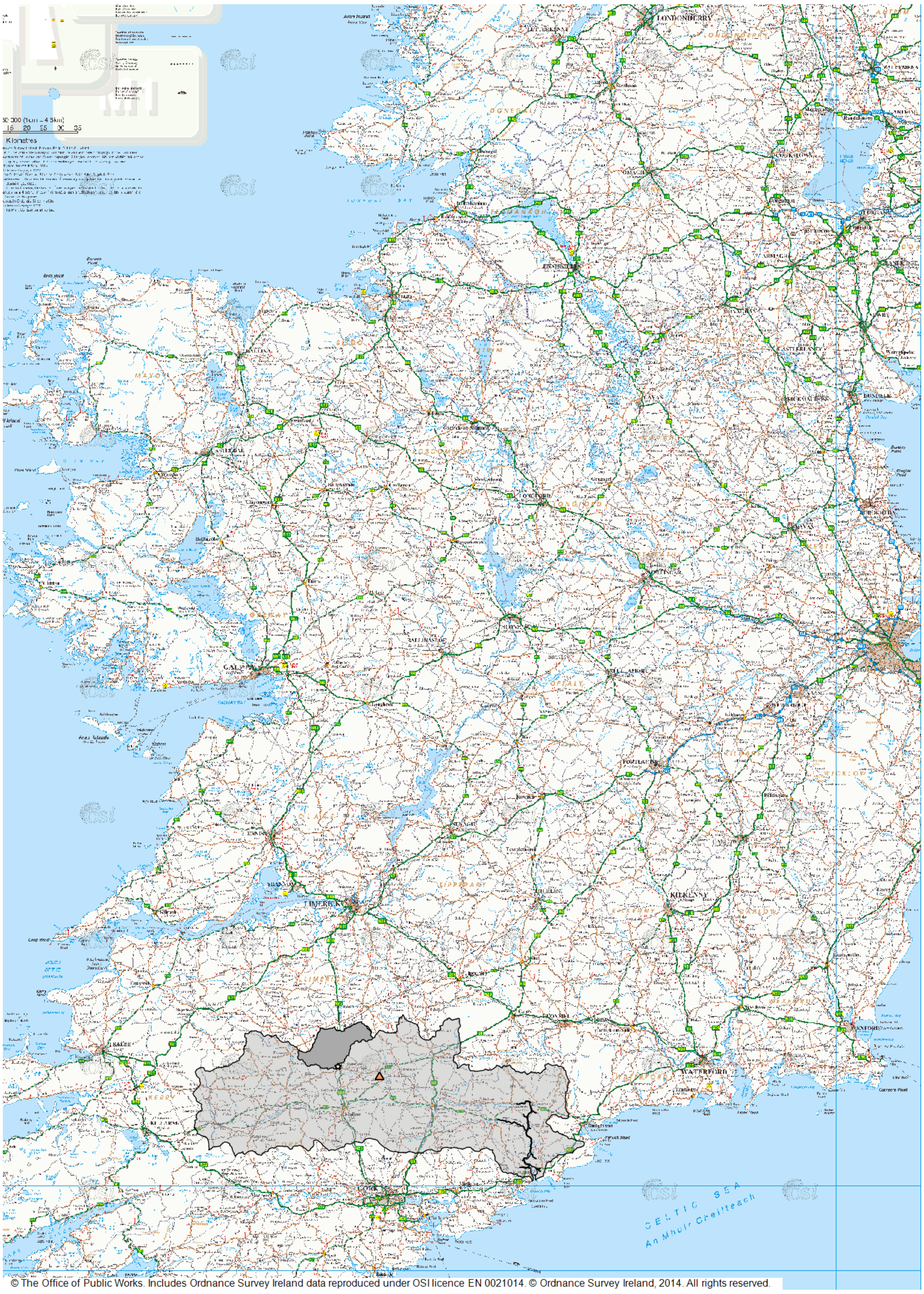
Pivotal site

Attributes

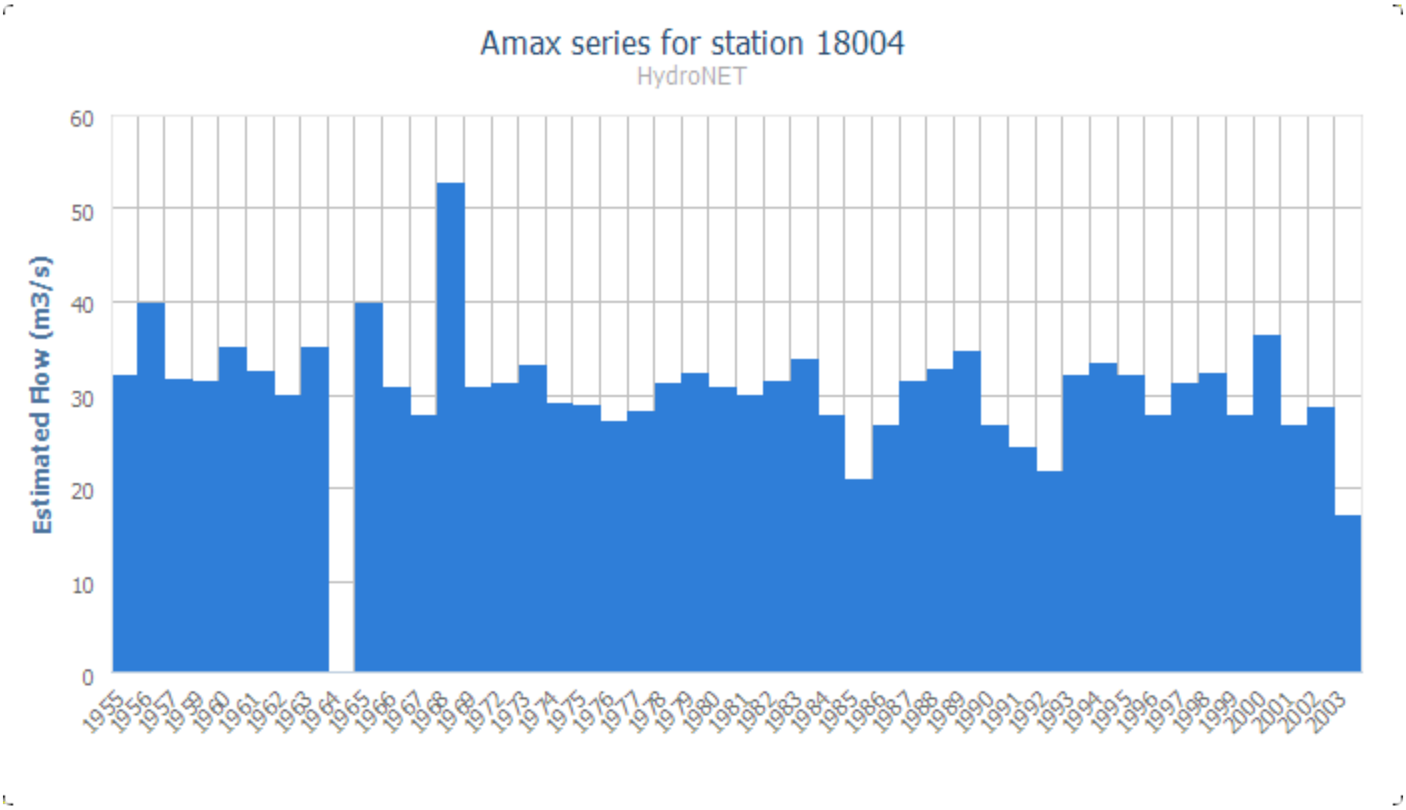
Name	Unit	Value
Coordinate [X]		-946574.995822056
Coordinate [Y]		6839846.41016655
Station Number		18004
Location		BALLYNAMONA
Water Body		AWBEG
Catchment		Blackwater (Munster)
Hydrometric Area		18
Organisation		OPW
FSU Rating Classification		A2
Drainage works	year	No
Contributing Catchment Area	km^2	310.2956
Center Northing	m	113230
Center Easting	m	154460
Northing	m	107552
Easting	m	165657
A-Max series gap in years	year	0
A-Max series number of years	year	49
A-Max series number of usable years	year	45
A-Max series end year	year	2003
A-Max series start year	year	1955
FARL		0.999
ALLUV		0.0626
PEAT		0.0163
FOREST		0.205
PASTURE		0
S1085	m/km	1.48095
MSL	km	42.791
DRAIND	km/km^2	0.936
ALTBAR		0
NETLEN	km	290.542
T4		0.32926281711607
T3		0.051570062343489
SAAPE	mm	519.58
T2		0.087902542587319
ARTDRAIN2		0
ARTDRAIN		0
TAYSLO		0.306029
STMFRQ		209
BFISOIL		0.6847
SAAR	mm	985.41
RWSEG_CD		18_2677
TOP_RWSEG		18_941
Bankfull		1.41 from survey
HGF	m^3/s	35
MAF	m^3/s	30
FAI		0.2
FLATWET		0.61
URBEXT		0.0033
HGF/QMED		1.1225144323284
x3857		-946574.995822056
y3857		6839846.41016655

centroidx3857		-963081.251241695
centroidy3857		6848843.58002027
Distance	km	6.97135308885369

Map



Amax Series Chart



QMED Estimates

Subject rural QMED	21.51
Subject urban QMED	21.51
Pivotal gauged QMED	31.18
Pivotal adjustment factor QMED	0.96
Subject adjusted QMED	**20.66**

Pooling Group

Station	**Amax years**
25022 SYNGEFIELD	22
16004 THURLES	48
16001 ATHLUMMON	33
07006 FYANSTOWN	19
25027 GOURDEEN BRIDGE	42
25016 RAHAN	48
24002 GRAYS BR.	32
25014 MILLBROOK	54
26010 RIVERSTOWN	35
26019 MULLAGH	51

26009 BELLANTRA BR.	35
29001 RATHGORGIN	40
25023 MILLTOWN	33

Selected Flood Growth Curve

Growth Curve is not available for this report because Flood Frequencies was not finished.

Adopted Growth Factors

Return Period	Growth Factor	Design Peak Flow (m^3/s)
1.3	0.84	17.35
2	1	20.66
5	1.22	25.2
10	1.34	27.68
20	1.45	29.95
30	1.51	31.19
50	1.58	32.64
100	1.66	34.29
200	1.74	35.94
500	1.83	37.8
1000	1.89	39.04

Hydrograph Width Estimation Summary

Hydrograph summary is not available for this report because the hydrograph was not transferred to the subject site.

Hydrograph Plots

Hydrographs are not available for this report because module 3 was not finished.

IBIDEM Plots and Tables

No IBIDEM plots were saved by the user.

Audit Trail Report #9923 (Cork Line - Awbeg)

The Office of Public Works
Oifig na nOibreacha Poiblí

User ID:	elmar.torenga@jacobs.com
Name:	Torenga, Elmar
Company:	Jacobs
Address:	
Report date & time:	20-12-2019 15:21
Start of Calculation:	18-12-2019 11:50

Decisions made by the user:

Decision	User comment	System information	Date
2.1 Subject site accepted	N/A	Location 18_534_4	18-12-2019 11:56
2.4 Pivotal site accepted	Reason for accepting: nearest gauging station d/s of subject site (area is twice the subject site area). Reason for ignoring warnings:	Station: 18004 BALLYNAMONA The user has been notified that 25 candidates where either hydrologically or geographically closer to the subject site than the chosen pivotal site. The user has accepted to reject these sites in preference of the chosen pivotal site.	18-12-2019 11:57
2.8 QMED data transfer performed	N/A		18-12-2019 12:08
2.8 QMED data transfer performed	N/A		20-12-2019 16:06

2.10 Pooling stations excluded	N/A	The following stations were excluded: Station: 07004, Atribute: farl, Reason: farl too low, Station: 26008, Atribute: farl, Reason: farl too low, Station: 26020, Atribute: draind, Reason: DrainD too low, Station: 09010, Atribute: s1085, Reason: S1085 too high, Station: 06025, Atribute: artdrain2, Reason: ARTDRAIN2 too high, Station: 25020, Atribute: artdrain2, Reason: ARTDRAIN2 too high, Station: 06026, Atribute: artdrain2, Reason: ARTDRAIN2 too high	20-12-2019 16:18
2.11 Pooling group accepted	N/A	Pooled group accepted with the following stations: [25022, 16004, 16001, 07006, 25027, 25016, 24002, 25014, 26010, 26019, 26009, 29001, 25023] and distribution: GEV	20-12-2019 16:18
2.13 Module 2 finalized	N/A	Finished pooled analysis with the following distribution selected: GEV. The user was notified of the following: Pooled growth curve: Warning: the GEV model fitted by L-moments implies an upper bound of 46.73m3/s. This is only 35.1% greater than the largest observation. Do you wish to consider a different model such as the 2-parameter EV1 distribution?	20-12-2019 16:19

Appendix C. FSU web portal: data, results and audit trail (Station 18004 – River Awbeg at Ballynamona)

Flood Estimation Report #9975 (18004)

Generated 07-01-2020 15:40

Subject site

Attributes

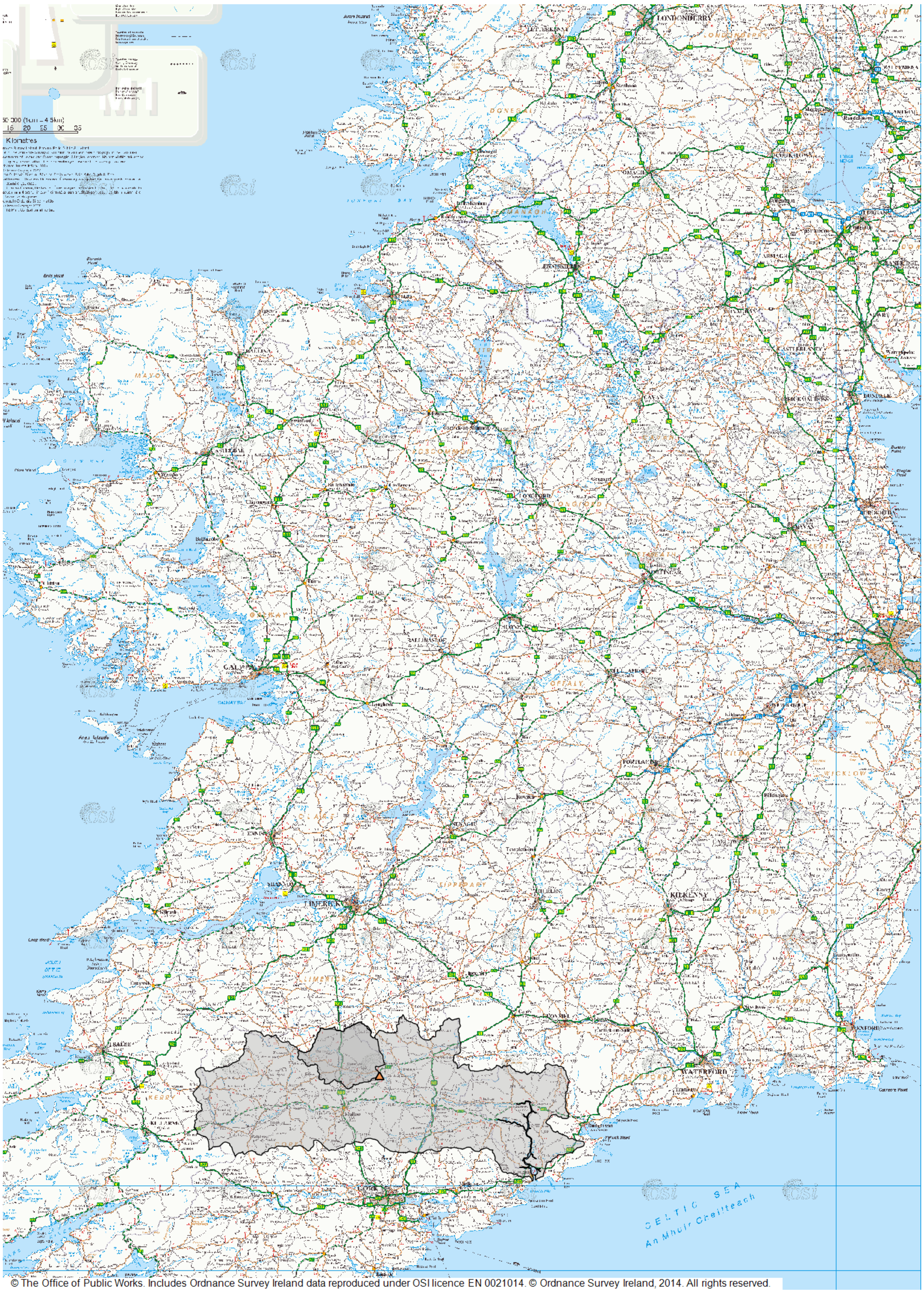
Name	Unit	Value
Coordinate [X]		-946574.995822056
Coordinate [Y]		6839846.41016655
Station Number		18004
Location		BALLYNAMONA
Water Body		AWBEG
Catchment		Blackwater (Munster)
Hydrometric Area		18
Organisation		OPW
FSU Rating Classification		A2
Drainage works	year	No
Contributing Catchment Area	km^2	310.2956
Center Northing	m	113230
Center Easting	m	154460
Northing	m	107552
Easting	m	165657
A-Max series gap in years	year	0
A-Max series number of years	year	49
A-Max series number of usable years	year	45
A-Max series end year	year	2003
A-Max series start year	year	1955
FARL		0.999
ALLUV		0.0626
PEAT		0.0163
FOREST		0.205
PASTURE		0
S1085	m/km	1.48095
MSL	km	42.791
DRAIND	km/km^2	0.936
ALTBAR		0
NETLEN	km	290.542
T4		0.32926281711607
T3		0.051570062343489
SAAPE	mm	519.58

T2		0.087902542587319
ARTDRAIN2		0
ARTDRAIN		0
TAYSLO		0.306029
STMFRQ		209
BFISOIL		0.6847
SAAR	mm	985.41
RWSEG_CD		18_2677
TOP_RWSEG		18_941
Bankfull		1.41 from survey
HGF	m^3/s	35
MAF	m^3/s	30
FAI		0.2
FLATWET		0.61
URBEXT		0.0033
HGF/QMED		1.1225144323284
centroidx3857		-963081.251241695
centroidy3857		6848843.58002027
x3857		-946574.995822056
y3857		6839846.41016655
Distance	km	0

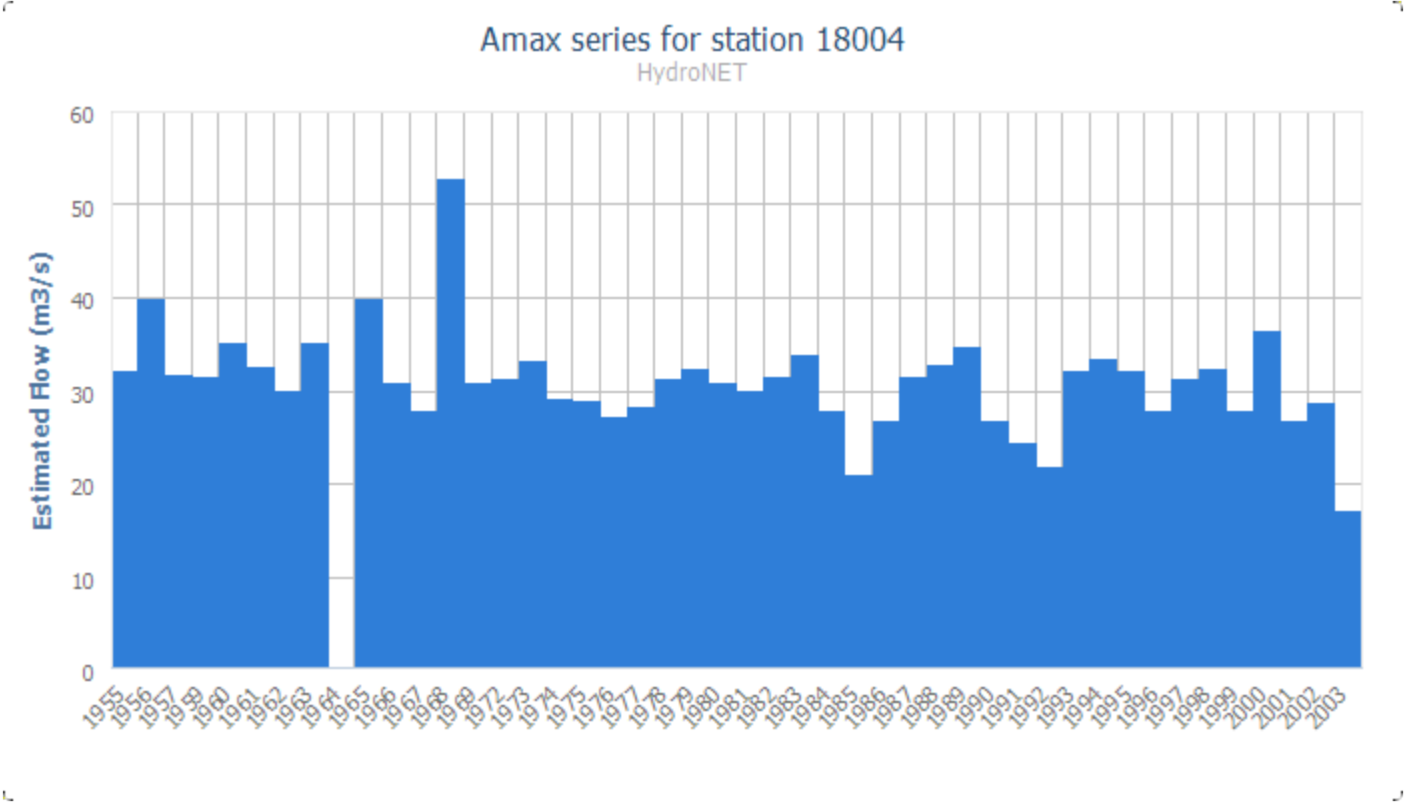
Pivotal site

The subject site is gauged, so the subject site is the pivotal site.

Map



Amax Series Chart



QMED Estimates

Subject rural QMED	32.31
Subject urban QMED	32.46
Pivotal gauged QMED	31.18
Pivotal adjustment factor QMED	1
Subject adjusted QMED	**31.18**

Selected Flood Growth Curve

Growth Curve is not available for this report because Flood Frequencies was not finished.

Adopted Growth Factors

Return Period	Growth Factor	Design Peak Flow (m^3/s)
1.3	0.88	27.44
2	1	31.18
5	1.18	36.79
10	1.29	40.22
20	1.4	43.65
30	1.47	45.83
50	1.55	48.33
100	1.66	51.76
200	1.77	55.19
500	1.91	59.55
1000	2.02	62.98

Hydrograph Width Estimation Summary

Hydrograph summary is not available for this report because the hydrograph was not transferred to the subject site.

Hydrograph Plots

Hydrographs are not available for this report because module 3 was not finished.

IBIDEM Plots and Tables

No IBIDEM plots were saved by the user.

Audit Trail Report #9975 (18004)

The Office of Public Works
Oifig na nOibreacha Poiblí

User ID:	liam.meachen@jacobs.com
Name:	Meachen, Liam
Company:	
Address:	
Report date & time:	07-01-2020 15:41
Start of Calculation:	07-01-2020 14:43

Decisions made by the user:

Decision	**User comment**	**System information**	**Date**
2.1 Subject site accepted	N/A	Location 18004	07-01-2020 14:45
2.9 Single site analysis accepted	N/A		07-01-2020 14:49
2.10 Pooling stations excluded	N/A	The following stations were excluded: Station: 25020, Atribute: artdrain2, Reason: Artdrain2 is much larger than at subject site, Station: 06014, Atribute: artdrain2, Reason: Artdrain2 is much larger than at subject site, Station: 25016, Atribute: artdrain2, Reason: Artdrain2 is much larger than at subject site	07-01-2020 16:30

2.11 Pooling group accepted	N/A	Pooled group accepted with the following stations: [07011, 36018, 06011, 36016, 07004, 25014, 36012, 16002, 26008, 06012, 36011, 29011] and distribution: GEV	07-01-2020 16:30
2.13 Module 2 finalized	N/A	Finished combined analysis using distribution: EV1 and weight: 0.6.	07-01-2020 16:40

Appendix C. XC219 Hydraulic Modelling Report

Cork Line Level Crossings

XC219 Hydraulic Modelling Report

October 2020

Irish Rail

Cork Line Level Crossings

Project No: 32111001
Document Title: XC219 Hydraulic Modelling Report
Document No.: --
Revision: P01

Date: October 2020
Client Name: Irish Rail
Client No:
Project Manager: Alex Bradley
Author: Ana Santos Silva

Jacobs Engineering Ireland Limited

Merrion House
4 Merrion Road
Dublin D04 R2C5
Ireland
+353 (0)1 269 5666
+353 (0)1 269 5497
www.jacobs.com

Document history and status

Revision	Date	Description	Author	Checked	Reviewed	Approved
P01	01/10/2020	For Issue	Ana Silva	Ross Holman	Pat Hall	

Contents

Page intentionally left blank.

1. Introduction

1.1 Background

The Dublin to Cork rail line has 7 no. manned public road level crossings in operation between Limerick Junction and Mallow stations. These crossings are located within a 15 mile/24 km section of the line (between chainages 122 miles 808 yards and 137 miles 315 yards), which straddles the Cork/Limerick county boundary.

Irish Rail have proposed to de-man the level crossing located in Buttevant, XC219, and replacing the level crossing with a new overbridge. A Site-specific Flood Risk Assessment was undertaken and concluded that that the fluvial flood risk to and arising from the proposed works at this site is high. In this regard, Jacobs UK Limited has been appointed by Rail Ireland to complete a Stage 3 Detailed Flood Risk Assessment (including a site specific hydraulic assessment).

To support the Stage 3 Detailed Flood Risk Assessment the hydraulic assessment should identify the following information:

- Confirm the 5% (20-year), 1% (100-year) and 1% (plus 20% allowance for Climate Change) and 0.1% (1000-year) Annual Exceedance Probability (AEP) flood level at the culvert;
- Confirm the size of box culvert required to safely pass flood flows associated with the 1% AEP (plus 20% allowance for Climate Change);
- Verify if the proposed work results in any increase to flood water level.

The new overpass bridge is potentially impacted by two watercourses: Pepperhill stream and River Awbeg. Figure 1 shows the location of the Pepperhill stream, River Awbeg and the proposed overbridge.

Figure 1. Study Area and modelled watercourses

The hydraulic modelling undertaken for both watercourses has been documented in this report using surveyed cross-sections, extended cross-sections from 5m Digital Terran model (DTM) data and information gathered during a site visit.

1.2 Aim and Objectives

The aim of this study is to undertake a hydraulic assessment of the proposed overpass at XC219 in Buttevant. A one-dimensional (1D) model for the area of interest was created to provide the required information (see Section 1.1) for:

- the existing (baseline) conditions;
- the post-development conditions, and
- the design of the new structure for the preferred design option.

1.3 Methodology

The hydraulic model was built using a 1D schematisation, where the watercourse channels and adjacent floodplain are represented as a 1D component. The model was built using the river modelling package Flood Modeller Pro (version 4.6.7). Survey information was used to represent the cross sections entered in the software whilst a site visit and map observations aided in selecting roughness Manning's 'n' coefficient applied to the watercourse cross-sections.

2. Input Data

The data used to construct the hydraulic model for the Pepperhill stream and River Awbeg are summarised in Table 1.

Table 1: Data Used to Build the Hydraulic Model

Data	Description	Source
Hydrological Flow Estimates	Model inflows obtained through the FEH Web Service and WINFAP-FEH Version 4.0 (2016).	Jacobs January 2020
Channel survey	In-channel cross sections and hydraulic structures dated 2020.	Jacobs July 2020
5m DTM	Topographical levels from LiDAR data.	LiDAR Data
Watercourse photographs	Survey – road, existing bride (rough) photographs.	Jacobs Site visit January 2020

3. Hydrology

The subject site on the Pepperhill stream, immediately upstream of the R522 road crossing near Buttevant is ungauged and too far upstream of the nearest gauging station in the same catchment (Station 18004 on the River Awbeg) to be able to use that station to inform the design flows. The Flood Studies Update (FSU) Qmed regression equation was therefore used to produce an unadjusted synthetic estimate of Qmed.

A growth curve was determined using pooling group analysis with approximately 500 station-years of pooled data. The derived growth curve was then applied to the Qmed estimate, resulting in peak flow estimates for a number of design flood events with varying annual exceedance probabilities.

This section documents the discretisation of the hydrological flood estimation inputs to provide hydrological inflows to the Pepperhill stream and River Awbeg hydraulic model.

3.1 Methodology

As discussed, the FSU methodology was used to derive the design peak flows.

Climate Change scenarios have been considering by the application of the Mid-Range Future Scenario (MRFS), specifically a 20% uplift on the estimated 1% AEP peak fluvial flow.

Final design peak flows for both the Pepperhill stream and River Awbeg are detailed in Table 2 below.

Table 2: Design Peak Flows.

Annual Exceedance Probability (AEP)	Peak Flow (m^3/s)	
	Pepperhill stream	River Awbeg
50%	2.69	20.66
10%	3.96	27.68
5%	4.39	29.95
2%	4.88	32.64
1%	5.23	34.29
1% (MRFS scenario)	6.28	41.15
0.5%	5.58	35.94
0.1%	6.25	39.04

4. Hydraulic Modelling

4.1 Model Build

Model extent

Model cross-section locations are shown in Figure 2 for the baseline model. The model extent ensures the area of interest (the new culvert box structure) is covered with sufficient upstream and downstream reach length to determine impact on flood water levels. The Pepperhill reach of the model extends from model node Pep01_11.4 upstream to node Pep01_713itp at its confluence with the River Awbeg. The River Awbeg reach extends from node Awb01_6.64 upstream of the confluence with the Pepperhill Tributary at Awb01_154.59 to node Awb01_364.55.

The numbering of the model nodes is based on the surveyed chainage of the respective watercourses (Ch 11.4m to Ch 713m for the Pepperhill and Ch. 6.64m to 364.55m for the River Awbeg).

In-Channel Geometry

Surveyed river cross-sections have been used to inform the in-channel geometry of the modelled watercourses. A review of the received cross section survey was undertaken; it was found that all received cross-sections were provided in the correct format and orientation (i.e. looking downstream) and as such there was no requirement to make any modifications to the received data (i.e. flipping the sections).

Limited survey data was available at the confluence of the Pepperhill stream and River Awbeg. To represent the confluence an upstream cross-section of the tributary was added to ensure the bed level of the Pepperhill and the River Awbeg were the same. Where dense vegetation resulted in limited access to the Pepperhill tributary vicinities the cross-sections obtained from the survey were extended using the available 5m DTM available.

In-Channel hydraulic friction

The hydraulic roughness (Manning's 'n' coefficient) values were determined from survey photographs and standard guidance (Chow, 1959). Table 3 shows the roughness used in the Pepperhill stream and the River Awbeg.

Table 3: Manning's 'n' Coefficients

Reach	Nodes	In channel (Manning's n)	Bankside (Manning's n)
Pepperhill Tributary	Pep01_11.4 to Pep01_713itp	0.07	0.04/0.05
River Awbeg	Awb01_6.64 to Awb01_364.55	0.07	0.04/0.08

Baseline In-Channel hydraulic structures

The in-channel hydraulic structure included in the baseline hydraulic model is the existing conduit sprung arch at the Station Road on R522.

Table 4 presents the model nodes associated with the key structures and features of the hydraulic models for baseline and design options. The nodes included within the baseline model are shown in Figure 2.

Table 4: Key structures and features in the baseline hydraulic model

Model Node	Key Structure/Feature
Pep01_11.4	Upstream extent of the Pepperhill Stream
Pep01_425CU	Upstream inlet of existing culvert at Station Road
Pep01_425C	Upstream of existing conduit
Pep01_434C	Downstream of existing conduit
Pep01_434CU	Downstream outlet of existing culvert at Station Road
Pep01_434.82	Cross-section directly downstream of existing culvert at Station Road
Awb01_6.64	Upstream extent of River Awbeg reach
Awb01_154.59	River Awbeg confluence with Pepperhill Stream
Awb01_364.55	Downstream extent of River Awbeg reach

Boundary Conditions

The upstream and downstream boundary conditions applied to the model are described in Table 5.

Table 5: Boundary Conditions

Type of Boundary	Flood Modeller Node	Description
Flow-Time Boundary	Pep01_11.4	Flow-Time inflow boundary was applied at the upstream end of the Pepperhill Tributary at node Pep01_11.4
Flow-Time Boundary	Awb01_6.64	Flow-Time inflow boundary was applied at the upstream end of River Awbeg at node Awb01_6.64
Normal Depth Boundary	Awb01_364.55	Normal Depth boundary condition applied to the downstream end of River Awbeg at cross section Awb01_364.55

Floodplain

Along the length of the Pepperhill stream and the River Awbeg cross-sections have been extended using LiDAR data as the surveyed cross-sections only extended a few meters either side of the channel bank top.

Two reservoir units were used to represent the left bank floodplain along the Pepperhill Stream upstream and downstream of the existing culvert as the topography slopes away from the Pepperhill Stream.

The downstream reservoir representing the left bank floodplain of the Pepperhill Stream and right bank floodplain of the River Awbeg was unable to be extended due to limited upstream extent of the surveyed River Awbeg. As such, the reservoir representing the downstream floodplain is slightly smaller than would be liked.

2D schematisation of the floodplain has not been carried out.

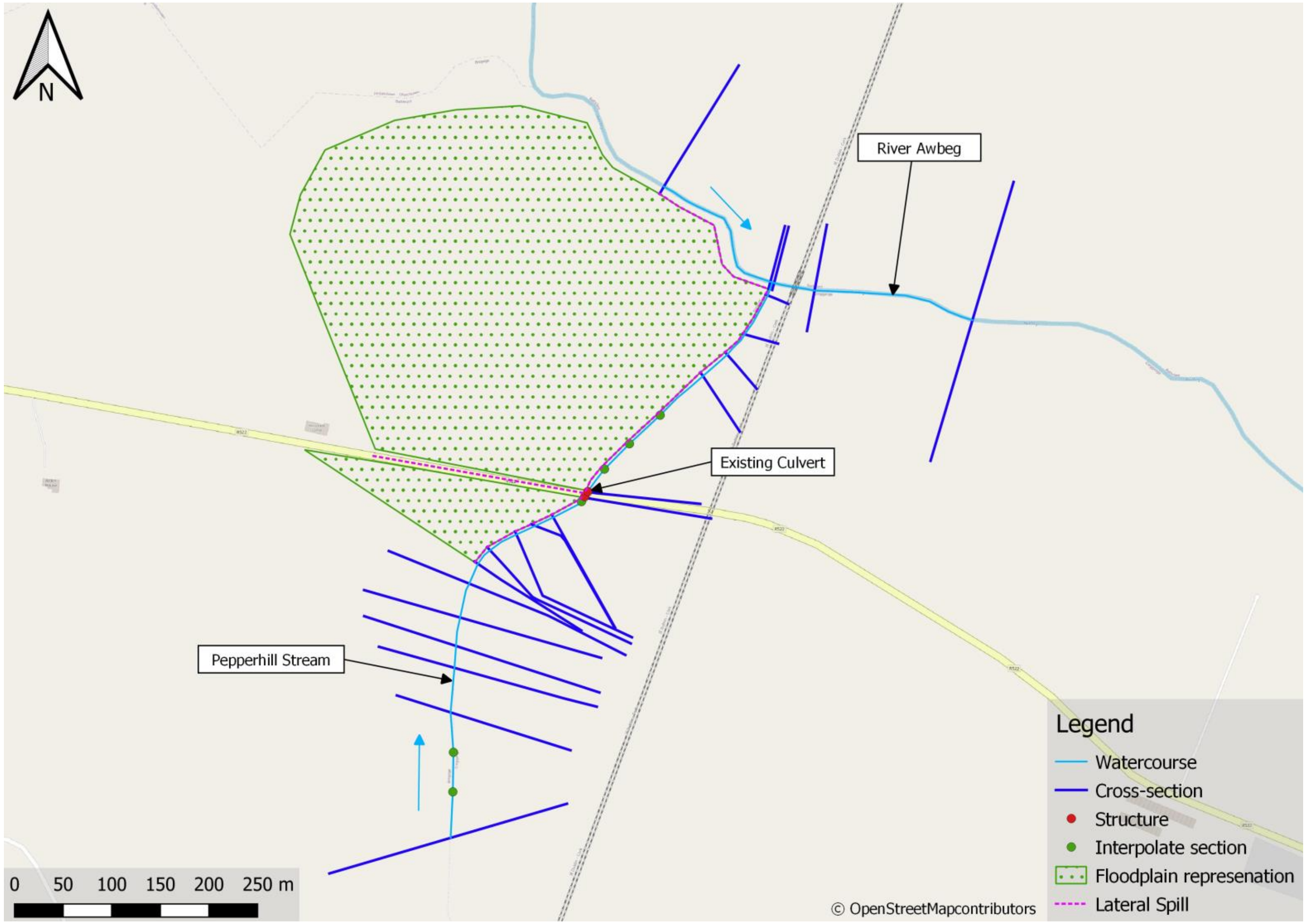


Figure 2. Model schematisation (baseline scenario)

4.2 Simulated Scenarios

Baseline runs were carried out for 5% (20-year), 1% (100-year) and 0.1% AEP (1000-year) as well as 1% plus the MRFS allowance for Climate Change (CC) flood events. In addition to the baseline model, simulations were run for the scheme scenario (i.e. preferred design option) for the same flood events.

Scheme scenario (Including Realigned Channel)

The design option consists of building a new bridge with a 29.5m long, 3m high and 6m wide box culvert 6m south of the existing structure. It would include an embedment of 500mm of riverine material. A cross-section of the proposed river box culvert is shown in Figure 3 below.

The bed levels of the upstream and downstream cross sections will be tied into the new structure at an invert level of 81.8m and widened to the same extent.

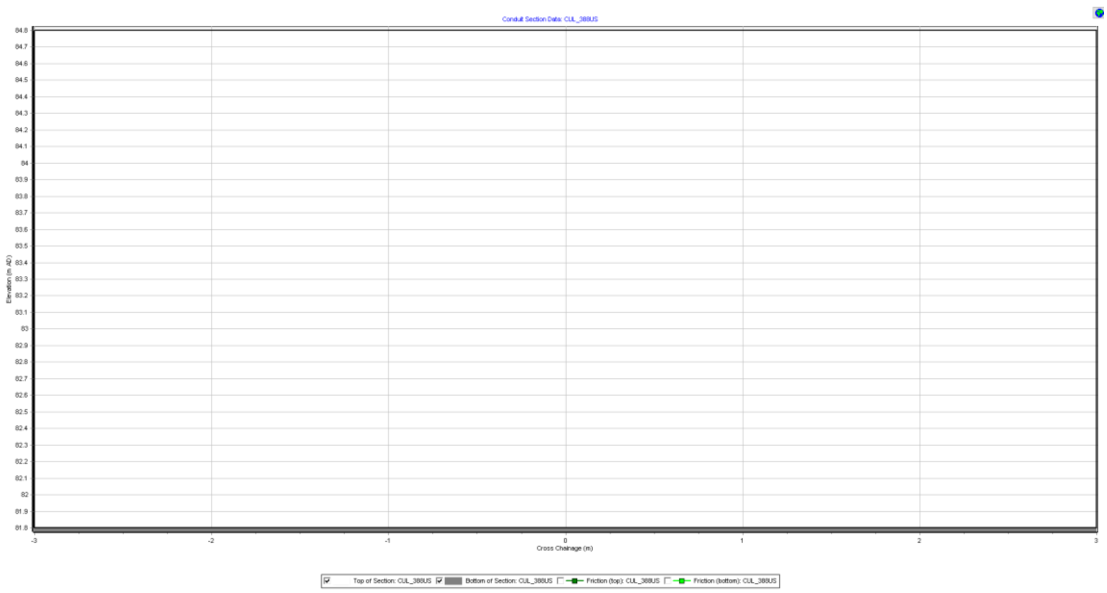


Figure 3: Proposed river box culvert

The embankment of the new bridge encroaches into the functional floodplain, as such, the area of the reservoir used in the baseline model was reduced in size and the area/elevation updated accordingly. The schematisation of the design option in Flood Modeller Pro is shown in Figure 4.

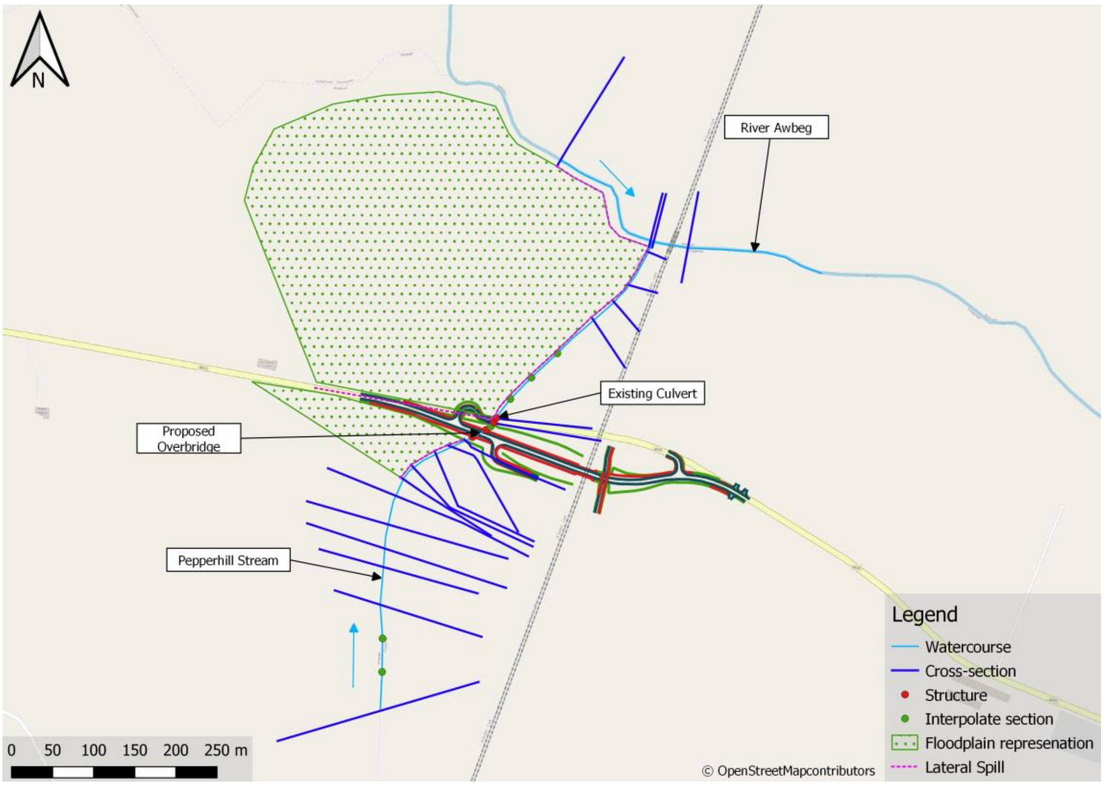


Figure 4: Scheme Scenario (new bridge with box culvert)

Table 6 shows the key model nodes in the Scheme model.

Table 6: Key structures and features in the Scheme hydraulic model

Model Node	Key Structure/Feature
Pep01_388.94	Cross-section directly upstream of proposed overbridge
Pep01_388CU	Upstream inlet of the proposed overbridge (represented as a box culvert)
CUL_388US	Upstream conduit of the proposed overbridge
CUL_418DS	Downstream conduit of the proposed overbridge
Pep01_418DS (culvert)	Downstream outlet of the proposed overbridge
Pep01_418.44	Cross-section directly downstream of proposed overbridge
Awb01_6.64	Upstream extent of River Awbeg reach
Awb01_154.59	River Awbeg confluence with Pepperhill Stream
Awb01_364.55	Downstream extent of River Awbeg reach

5. Model Proving

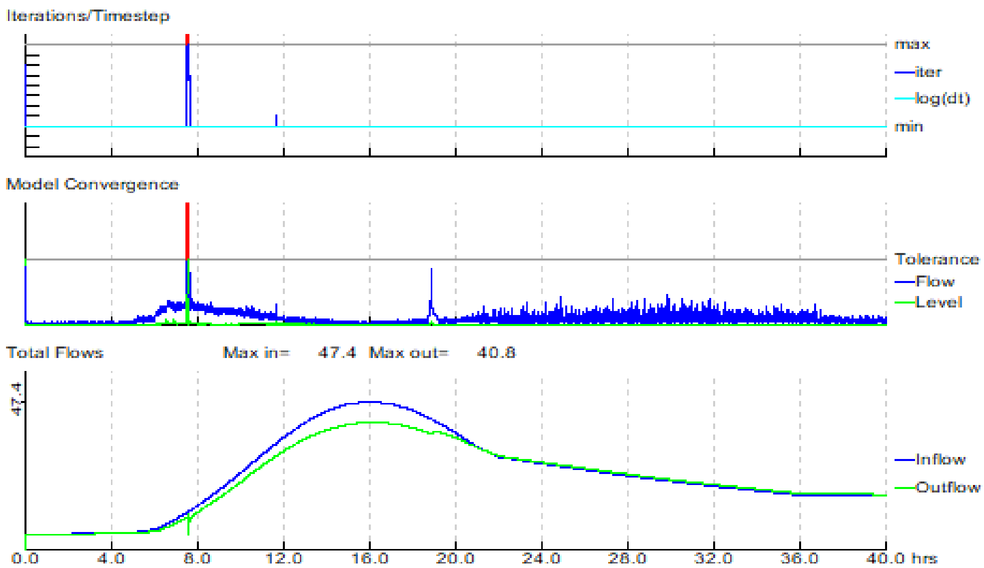
5.1 Introduction

The following sections discuss the model performance and the verification process.

5.2 Model Performance

Un-steady state run performance has been monitored throughout the model build process to ensure model convergence was achieved. Convergence refers to the ability of the modelling software to arrive at a solution for which the variation of the found solution between successive iterations is either zero or negligibly small and lies within a pre-specified tolerance limit.

As shown in 5 and 6 below, 1D Flood Modeller Pro convergence for the 1% AEP plus Climate Change event simulation is good. During the baseline model simulations, non-convergence occurs on the rising limb of the hydrograph approximately 8 hours before the peak of the simulation at the time in which water spills from the Pepperhill Stream into the floodplain. This convergence plot is generally typical for all the modelled events in the baseline scenarios. Non-convergence is not observed for the design simulations.



Datafile: ...\FM\BASELINE\DAT\2_PEPPERHILL_BSL_006_V2.DAT
Results: ...\RESULTS\2_PEPPERHILL_BSL_006_100YRCC_V2.zzl
Ran at 16:42:17 on 30/09/2020
Ended at 16:50:33 on 30/09/2020
Start Time: 0.000 hrs
End Time: 40.000 hrs
Timestep: 20.0 secs

Current Model Time: 40.00 hrs
Percent Complete: 100 %

Figure 5: 1D Model Convergence – 1 % AEP Event plus Climate Change (Baseline)

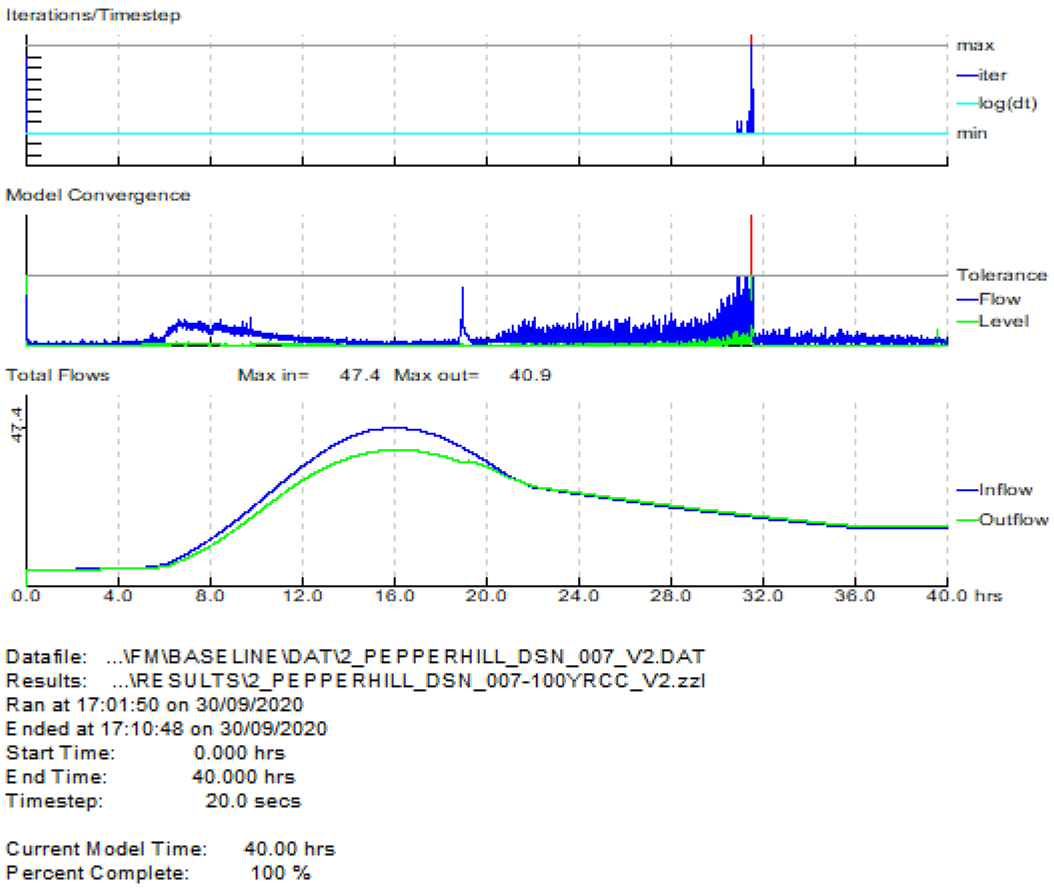


Figure 6: 1D Model Convergence – 1 % AEP Event plus Climate Change (Scheme)

5.3 Verification

As the Pepperhill Stream is ungauged and no gauging stations are located on the River Awbeg in the vicinity of the modelled reach, it has not been possible to acquire any hydrometric data for calibration/validation purposes. Cork County Council provided a historical flood map for the Buttevant area. This historic flood data was compared to verify the results of the baseline 1% AEP flood event and can be seen below in Figure 7.

It can be seen on Figure 7 that in the study area the observed flood extents compare relatively well with the maximum extent of inundation for the 1% AEP flood event.

Figure 7: Comparison of observed flood extents from Cork County Council (left) and modelled flood extents (right)

Model boundaries in Figure 7 are illustrated in dashed black lines, flood extents illustrated in blue, red shading on right hand side shows higher ground based on LiDAR

6. Model Results

6.1 Baseline Scenario

In the baseline scenario, the hydraulic model predicts a peak water level (PWL) on the upstream extent of both the Pepperhill stream and River Awbeg, of 83.647mAOD and 83.627mAOD for the 1% AEP MRFS flood event, respectively. A long section of the peak water level profile in both watercourses can be found in Figure 8 and Figure 9. It can be seen in Figure 8, that the existing structure at the R522 is not surcharged but only provides 61mm of freeboard as the peak water level is 83.629mAOD. The peak water level for the same flood event scenario downstream of the confluence is 83.532mAOD. The long section also illustrates that the River Awbeg has a significant effect on the peak water levels along the Pepperhill Stream. Tabulated peak water levels, flows and velocities for the baseline scenario are presented in Appendix A.

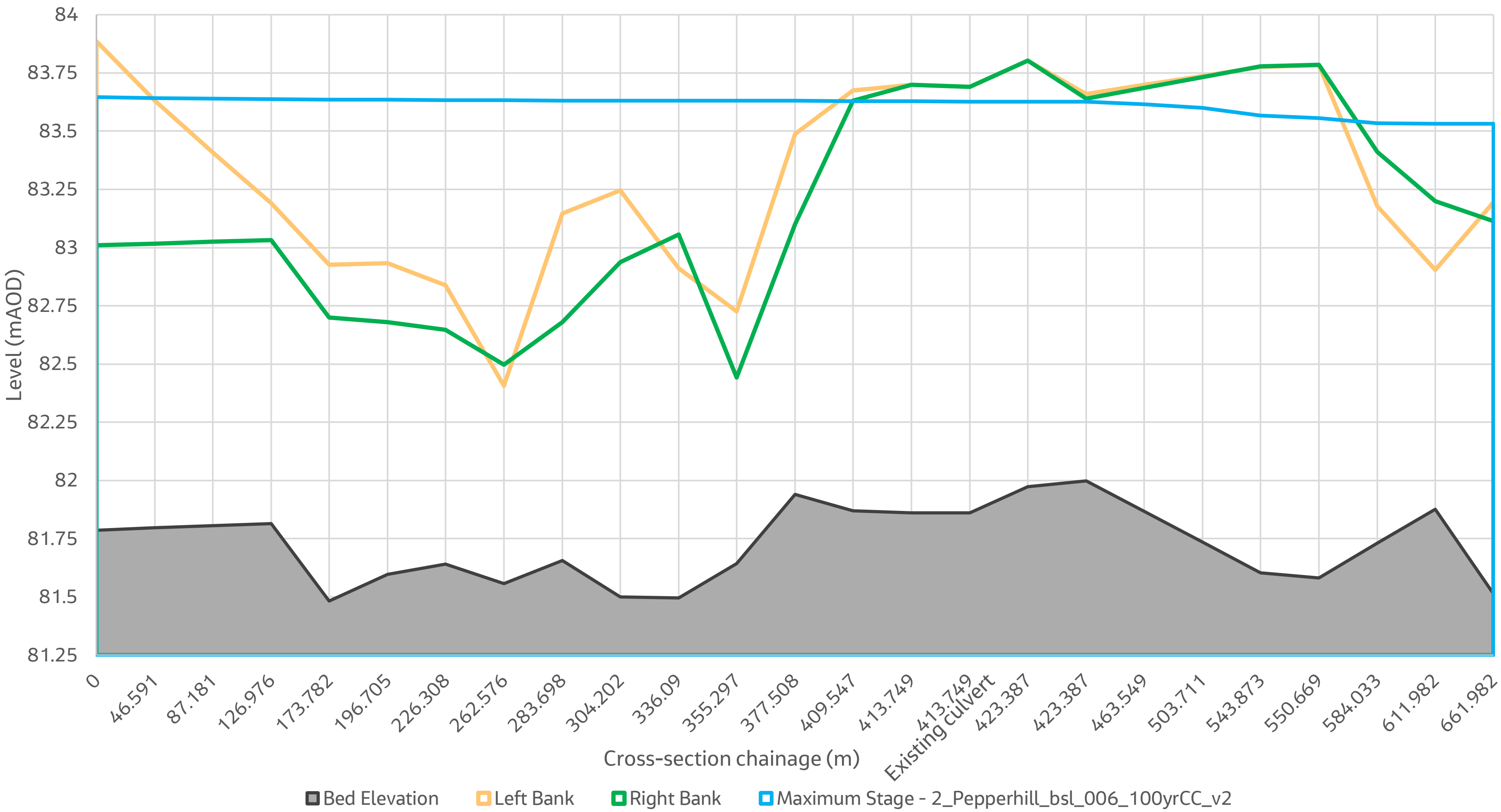


Figure 8: Maximum Water Level profile predicted for a 1 % AEP Event plus Climate Change for the baseline scenario on the Pepperhill Tributary

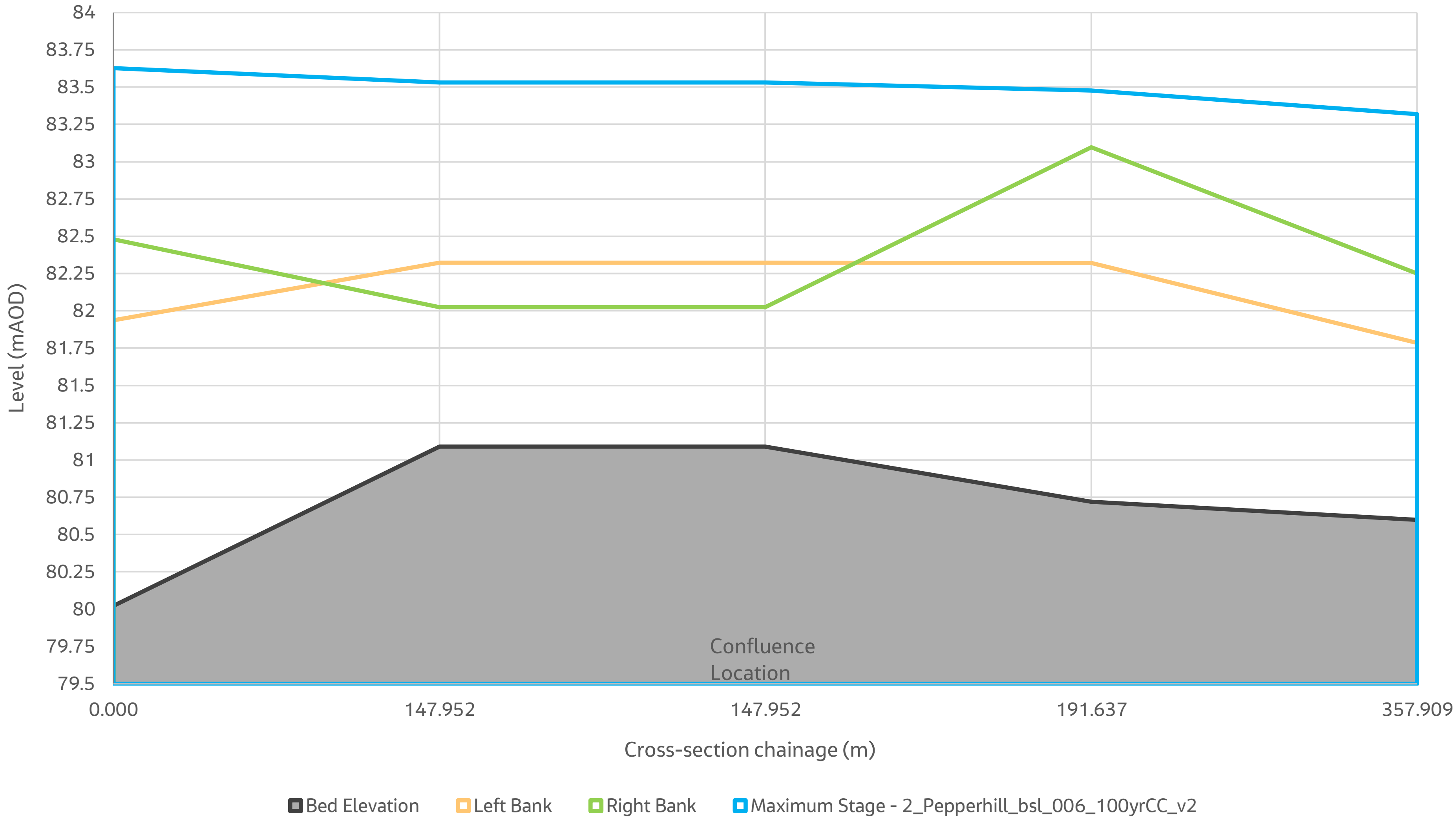


Figure 9: Maximum Water Level profile predicted for a 1 % AEP Event plus Climate Change for the baseline scenario on the River Awbeg

6.2 Scheme Scenario

The hydraulic model predicts a peak water level on the upstream extent of both the Pepperhill stream and River Awbeg of 83.645mAOD and 83.627mAOD for the 1% AEP MRFS flood event in the Pepperhill and River Awbeg, respectively. Figure 10 illustrates the maximum water level through the proposed culvert for the 1% AEP MRFS flood event. Figure 8 shows that that both the existing structure and the proposed overbridge are not surcharged or overtopped for the 1% AEP MRFS flood event. The existing culvert has 63mm freeboard whilst the proposed overbridge has a freeboard of 1171mm for the peak water levels of 83.629mAOD and 83.627mAOD, respectively. The peak water level for the same flood event scenario downstream of the confluence is 83.532mAOD. Tabulated peak water levels, flows and velocities for the scheme scenario are presented in Appendix B.

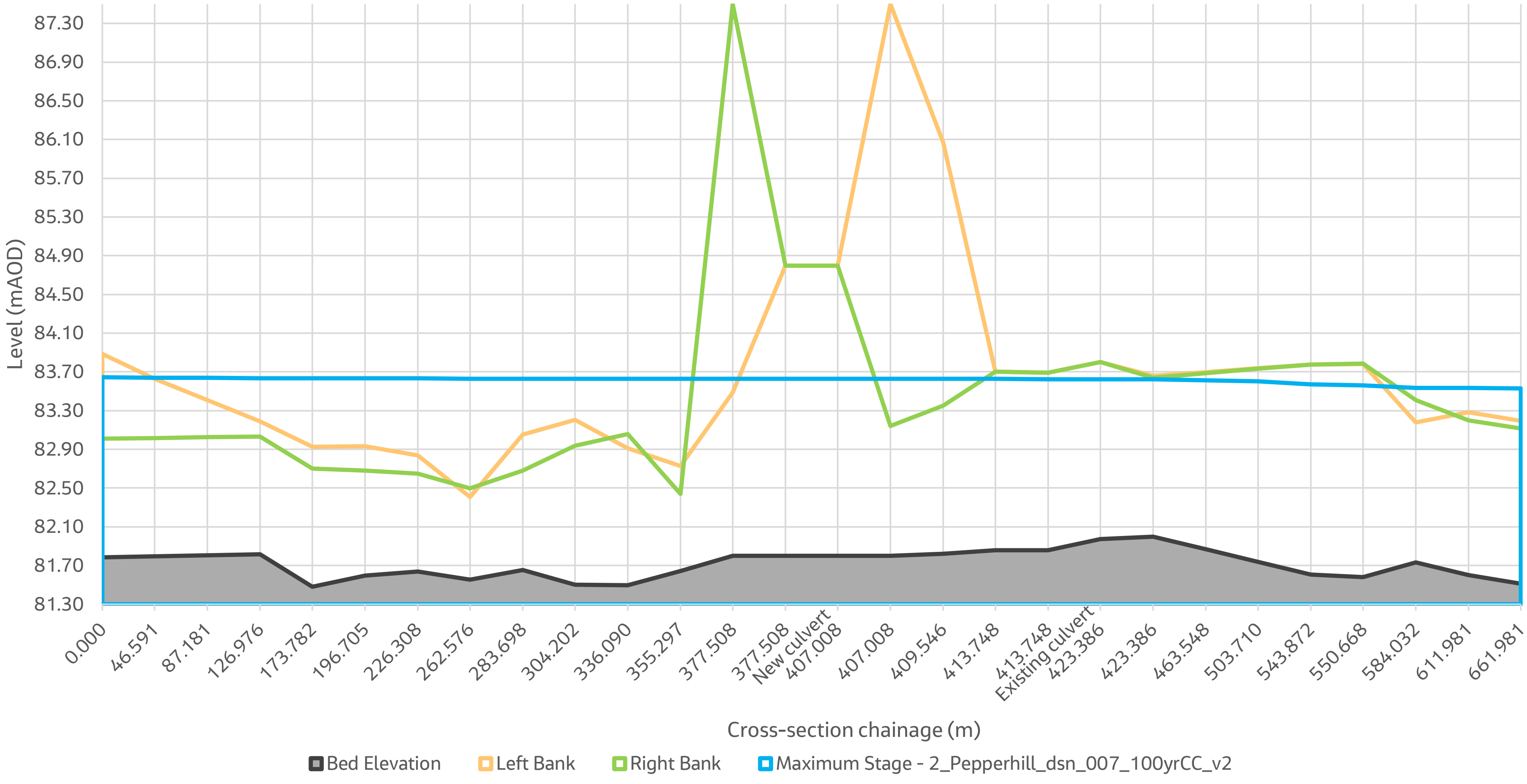


Figure 10: Maximum Water Level profile predicted for a 1 % AEP Event plus Climate Change for the scheme scenario on the Pepperhill Tributary

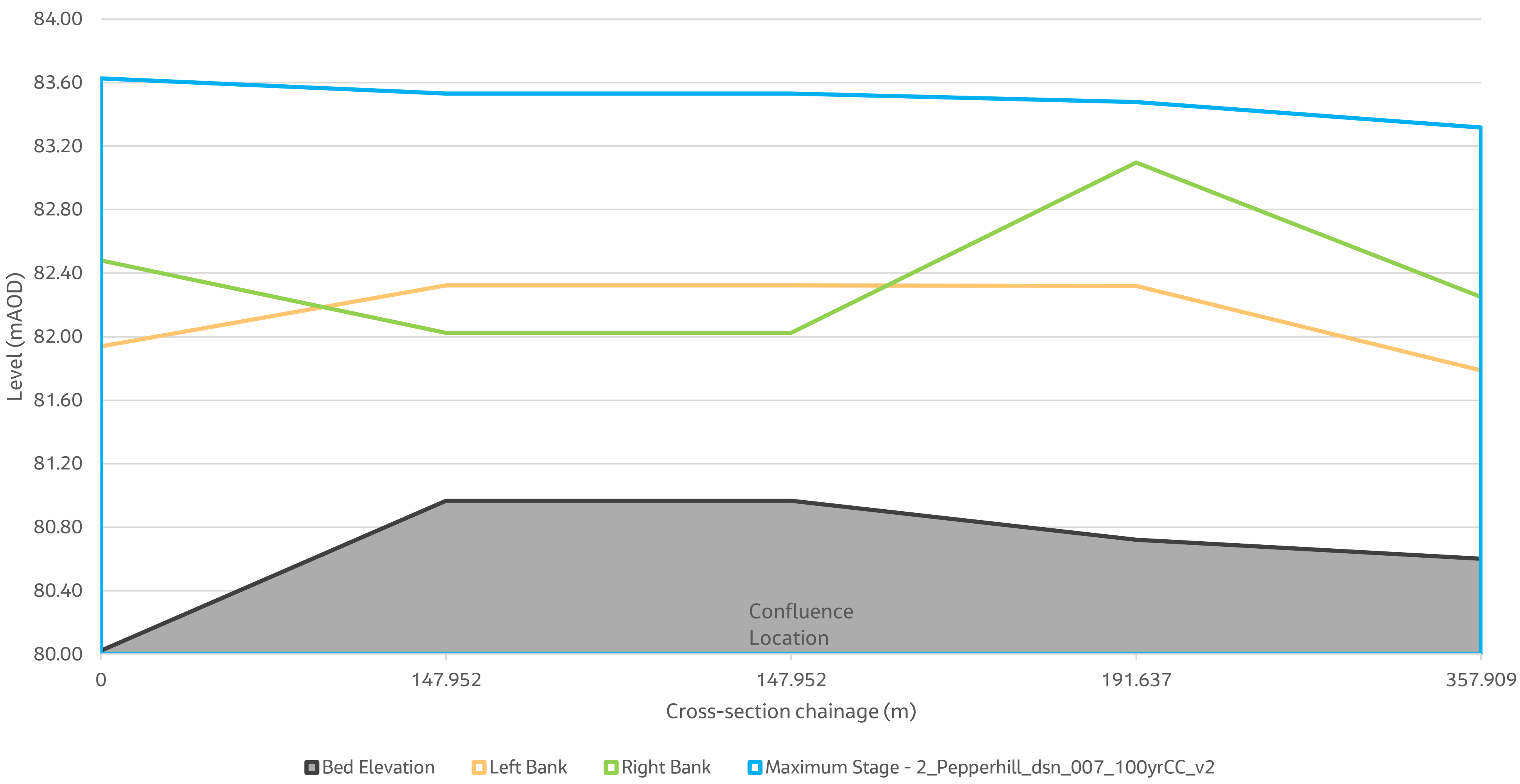


Figure 11: Maximum Water Level profile predicted for a 1 % AEP Event plus Climate Change for the scheme scenario on the River Awbeg

6.3 Discussion

For the proposed scheme scenario, the hydraulic model predicts a peak water level of 83.629mAOD for the 1% AEP MRFS flood event at the entrance of the proposed overbridge culvert. The proposed culvert is 3m high and 6m wide (including a 500mm embedment) with a soffit level of 84.8mAOD at the entrance. The resulting freeboard to the soffit is therefore 1171mm which complies with OPW Section 50 requirements.

There is a minor increase in the scheme model compared to the baseline model with respect to the peak water level downstream of the Pepperhill Stream for the 1% AEP MRFS flood event. Whilst the peak water level for the modelled baseline at cross-section Pep01_602.27 is 83.556mAOD, in the scheme model it has increased slightly to 83.559mAOD. This 3mm difference in peak water level is well within model tolerance and shows that the proposed overbridge will have negligible impact on flood risk in the area.

A summary of the scheme modelled peak water levels at the model structures for the 1% AEP MRFS flood event is tabulated in Table 7 below.

Table 7: Summary of peak modelled water levels at crossing

Scenario	Annual Exceedance Probability (AEP)	Inlet Soffit Level (mAOD)	Peak Modelled Water Level (mAOD)	Freeboard at inlet (mm)
Proposed Box Culvert 6m x 3m (including a 500mm embedment)	1% MRFS	84.800	83.629	1171
Existing Sprung Arch Culvert	1% MRFS	83.690	83.627	63

7. Model Assumptions and Limitations

7.1 Introduction

The accuracy and validity of the hydraulic model results are heavily dependent on the accuracy of the hydrological and topographic data included in the model. While the most appropriate available information has been used to construct the model to represent fluvial flooding mechanisms, there are uncertainties and limitations associated with the model. These include assumptions made as part of the model build process.

The sections below summarise the key sources of uncertainty in addition to the limitations associated with the modelling undertaken for the Pepperhill Stream and River Awbeg watercourses.

7.2 Limitations

Channel Cross Sections

The model of the Pepperhill Stream and River Awbeg was built using the topographical survey collected in July 2020. This has been reviewed and cross sections were extended, as necessary, using the available 5m DTM data. A comparison of ground levels between the two datasets was undertaken and showed differences of up to 200mm. However, the use of the DTM data was deemed appropriate as it prevented glass-walling of the short channel sections.

Limited topographical survey was undertaken on the existing sprung arch culvert due to significant overgrowth of vegetation in the Pepperhill channel causing very difficult (and dangerous) access issues. However, site observations and interpretation of topographic survey data available enabled a robust representation of this structure in the hydraulic model.

Channel Roughness

The values used for channel roughness were confirmed via a site visit and also satellite imaging (see Table 3).

Hydraulic coefficients for structures have been applied using available guidance within the Flood Modeller software. These have been applied to the structures.

Model Verification

The flood extent derived through the hydraulic model was compared against Cork County Council's historical flood map for the Buttevant area. The 100-year return flood + CC flood extent shows an acceptable matched with this historical data.

8. Conclusions

This report has detailed the modelling carried out to assess peak water levels for the Pepperhill Stream and the River Awbeg. The assessment considered baseline and scheme (the proposed overpass bridge) scenarios. A 662m reach of the Pepperhill Stream watercourse and 358m reach of River Awbeg have been modelled using a 1D hydraulic model to simulate the 5% AEP, 1% AEP, and 0.1% AEP as well as 1% AEP MRFS flood events. A topographical survey has been used to build the 1D model. Cross sections were extended where necessary using available 5m DTM data and where required floodplain was represented using a reservoir unit.

The proposed culvert is 3m high and 6m wide with a soffit level of 84.8mAOD at the entrance. A minimum depth of 500mm of natural bed material will be reinstated through the proposed river box culvert structure to provide a natural bed and match the existing bed levels.

With the above dimensions, the hydraulic model predicts a peak water level at the proposed river box culvert entrance of 83.629mAOD for the 1% AEP plus Climate Change flood event. This results in a freeboard to the soffit of 1171mm which complies with OPW Section 50 requirements and confirms the size of the proposed box culvert is adequate to safely pass flood flows under such event.

Modelling results have shown that the proposed overbridge has a negligible flood risk impact to the area of interest.

9. References

Chow V T (1959). Open Channel Hydraulics.

Appendix A. Baseline model results

Water course	Model Node	Description	Maximum Stage (mAOD)				Maximum Flow (m3/s)				Maximum Velocity (m/s)			
			5% AEP	1% AEP	1% AEP MRFS	0.1% AEP	5% AEP	1% AEP	1% AEP MRFS	5% AEP	1% AEP	1% AEP MRFS	0.1% AEP	5% AEP
Pepperhill Tributary	Pep01_11.4	U/S model	83.588	83.614	83.646	83.643	4.390	5.240	6.288	6.250	0.345	0.347	0.351	0.352
	Itp_1_58		83.585	83.611	83.642	83.639	4.388	5.239	6.286	6.248	0.209	0.213	0.215	0.215
	Itp_1_98		83.583	83.609	83.640	83.637	4.386	5.237	6.284	6.246	0.172	0.176	0.179	0.178
	Pep01_138.4		83.582	83.607	83.637	83.634	4.384	5.235	6.282	6.245	0.171	0.172	0.176	0.176
	Pep01_185.22		83.580	83.605	83.635	83.632	4.381	5.232	6.280	6.241	0.112	0.115	0.117	0.116
	Pep01_208.14		83.580	83.605	83.634	83.631	4.380	5.231	6.279	6.239	0.152	0.153	0.156	0.155
	Pep01_237.74		83.579	83.604	83.634	83.631	4.379	5.231	6.278	6.237	0.096	0.097	0.097	0.097
	Pep01_274.01		83.578	83.603	83.632	83.629	4.378	5.229	6.277	6.236	0.074	0.080	0.091	0.091
	Pep01_295.13		83.578	83.602	83.631	83.628	4.378	5.226	6.277	6.236	0.103	0.104	0.105	0.105
	Pep01_315.64		83.577	83.602	83.631	83.628	3.696	4.362	5.170	5.153	0.097	0.097	0.097	0.097
	Pep01_347.52		83.577	83.602	83.631	83.628	2.754	3.148	3.593	3.615	0.115	0.115	0.115	0.116
	Pep01_366.73		83.577	83.601	83.631	83.627	2.020	2.200	2.369	2.421	0.159	0.160	0.160	0.160
	Pep01_388.94		83.576	83.601	83.630	83.627	1.578	1.551	1.591	1.604	0.270	0.271	0.271	0.271
	Pep01_420itp		83.574	83.599	83.629	83.626	1.579	1.556	1.621	1.633	0.161	0.158	0.154	0.155
	Pep01_425.18		83.573	83.598	83.629	83.625	1.579	1.556	1.621	1.633	0.176	0.174	0.172	0.173
	Pep01_425CU	U/S existing culvert inlet	83.573	83.598	83.629	83.625	1.579	1.556	1.621	1.633	0.024	0.024	0.024	0.024
	Pep01_425C	U/S face of existing conduit	83.571	83.597	83.627	83.624	1.579	1.556	1.621	1.633	0.297	0.293	0.298	0.300
	Pep01_434C	D/S extent of existing conduit	83.569	83.595	83.626	83.622	1.579	1.556	1.621	1.633	0.311	0.307	0.309	0.312
	Pep01_434CD	D/S extent of existing culvert	83.569	83.595	83.626	83.622	1.579	1.556	1.621	1.633	0.020	0.020	0.020	0.020
	Pep01_434.82		83.569	83.595	83.626	83.622	1.579	1.556	1.621	1.633	0.335	0.330	0.321	0.324
	Itp_3		83.548	83.578	83.615	83.609	1.579	1.556	1.622	1.634	0.380	0.374	0.365	0.368
	Itp_4		83.519	83.555	83.601	83.591	1.580	1.557	1.623	1.634	0.475	0.463	0.441	0.447
	Itp_5		83.446	83.499	83.568	83.550	1.580	1.558	1.624	1.635	0.781	0.744	0.696	0.710
	Pep01_602.27		83.421	83.480	83.556	83.536	1.580	1.558	1.624	1.635	0.916	0.859	0.789	0.809

Water course	Model Node	Description	Maximum Stage (mAOD)				Maximum Flow (m3/s)				Maximum Velocity (m/s)			
			5% AEP	1% AEP	1% AEP MRFS	0.1% AEP	5% AEP	1% AEP	1% AEP MRFS	5% AEP	1% AEP	1% AEP MRFS	0.1% AEP	5% AEP
	Pep01_635.63		83.371	83.441	83.534	83.508	1.581	1.559	1.625	1.636	0.524	0.463	0.455	0.463
	Pep01_663.58		83.364	83.437	83.532	83.506	1.582	1.564	1.628	1.638	0.456	0.405	0.418	0.373
	Pep01_713itp	Confluence with River Awbeg	83.357	83.434	83.532	83.505	1.591	2.395	3.834	3.603	0.457	0.595	0.608	0.631
River Awbeg	Awb01_6.64	U/S extent of River Awbeg	83.439	83.522	83.628	83.598	29.950	34.290	41.150	39.040	0.458	0.465	0.480	0.474
	Awb01_154.59	Upstream of confluence	83.357	83.434	83.532	83.505	29.926	34.266	40.972	38.937	0.434	0.468	0.580	0.504
	AwbDS_154.59DS	Downstream of confluence	83.357	83.434	83.532	83.505	31.135	35.051	40.801	39.114	0.452	0.479	0.617	0.507
	Awb01_198.28		83.314	83.387	83.479	83.454	31.131	35.048	40.796	39.111	0.598	0.634	0.682	0.669
	Awb01_364.55	D/S extent of River Awbeg	83.168	83.234	83.318	83.295	31.119	35.037	40.783	39.097	0.543	0.440	0.608	0.443

Appendix B. Scheme Results

Water course	Model Node	Description	Maximum Stage (mAOD)				Maximum Flow (m3/s)				Maximum Velocity (m/s)			
			5% AEP	1% AEP	1% AEP MRFS	0.1% AEP	5% AEP	1% AEP	1% AEP MRFS	0.1% AEP	5% AEP	1% AEP	1% AEP MRFS	0.1% AEP
Pepperhill Tributary	Pep01_11.4		83.585	83.612	83.645	83.642	4.390	5.240	6.288	6.25	0.354	0.358	0.36	0.361
	Itp_1_58		83.582	83.609	83.641	83.638	4.388	5.238	6.286	6.249	0.217	0.221	0.223	0.224
	Itp_1_98		83.581	83.607	83.638	83.635	4.386	5.236	6.284	6.248	0.185	0.188	0.191	0.19
	Pep01_138.4		83.579	83.605	83.636	83.633	4.384	5.234	6.282	6.245	0.181	0.184	0.186	0.186
	Pep01_185.22		83.578	83.603	83.634	83.631	4.382	5.233	6.281	6.243	0.123	0.125	0.127	0.126
	Pep01_208.14		83.577	83.602	83.633	83.63	4.380	5.231	6.279	6.242	0.165	0.166	0.169	0.168
	Pep01_237.74		83.576	83.602	83.632	83.629	4.379	5.230	6.277	6.239	0.108	0.110	0.109	0.108
	Pep01_274.01		83.576	83.601	83.631	83.628	4.380	5.227	6.275	6.238	0.082	0.083	0.092	0.091
	Pep01_295.13		83.575	83.600	83.63	83.627	4.379	5.227	6.274	6.238	0.113	0.114	0.114	0.114
	Pep01_315.64		83.575	83.600	83.63	83.626	3.642	4.285	5.055	5.047	0.106	0.106	0.107	0.107
	Pep01_347.52		83.575	83.600	83.629	83.626	2.740	3.100	3.481	3.515	0.123	0.123	0.124	0.124
	Pep01_366.73		83.574	83.599	83.629	83.626	2.033	2.171	2.254	2.322	0.178	0.180	0.179	0.179
	Pep01_388.94		83.574	83.599	83.629	83.626	1.685	1.669	1.72	1.735	0.124	0.123	0.122	0.123
	Pep01_388CU	U/S face of the proposed river box culvert	83.574	83.599	83.629	83.626	1.685	1.669	1.72	1.735	0.000	0.000	0	0
	CUL_388US	U/S face of the proposed river box conduit	83.573	83.598	83.628	83.625	1.685	1.669	1.72	1.735	0.164	0.162	0.163	0.165
	CUL_418DS	D/S extent of the proposed river box conduit	83.571	83.597	83.628	83.624	1.672	1.669	1.72	1.735	0.345	0.345	0.345	0.345
	Pep01_418DS	D/S extent of the proposed river box culvert	83.571	83.597	83.627	83.624	1.672	1.669	1.72	1.735	0.324	0.324	0.324	0.324
	Pep01_418.44		83.571	83.597	83.627	83.624	1.672	1.669	1.72	1.735	0.000	0.000	0	0
	Pep01_420itp		83.571	83.596	83.627	83.624	1.672	1.669	1.721	1.735	0.310	0.310	0.31	0.31
	Pep01_425.18		83.570	83.595	83.627	83.623	1.672	1.669	1.721	1.735	0.318	0.318	0.318	0.318
	Pep01_425CU	U/S culvert inlet Station Road	83.570	83.595	83.627	83.623	1.672	1.669	1.721	1.735	0.024	0.024	0.024	0.024
	Pep01_425C	U/S face of existing conduit	83.568	83.594	83.625	83.621	1.672	1.669	1.721	1.735	0.363	0.363	0.363	0.363

Water course	Model Node	Description	Maximum Stage (mAOD)				Maximum Flow (m3/s)				Maximum Velocity (m/s)			
			5% AEP	1% AEP	1% AEP MRFS	0.1% AEP	5% AEP	1% AEP	1% AEP MRFS	0.1% AEP	5% AEP	1% AEP	1% AEP MRFS	0.1% AEP
	Pep01_434C	D/S extent of existing conduit	83.565	83.592	83.624	83.62	1.672	1.669	1.721	1.735	0.329	0.325	0.33	0.333
	Pep01_434CD	D/S extent of existing culvert at Station Road	83.564	83.590	83.623	83.618	1.672	1.669	1.721	1.735	0.020	0.020	0.02	0.02
	Pep01_434.82		83.564	83.590	83.623	83.618	1.672	1.669	1.721	1.735	0.549	0.549	0.549	0.549
	Itp_3		83.546	83.576	83.614	83.607	1.674	1.670	1.722	1.746	0.319	0.315	0.314	0.317
	Itp_4		83.523	83.558	83.603	83.594	1.675	1.670	1.731	1.776	0.398	0.385	0.374	0.377
	Itp_5		83.453	83.506	83.572	83.556	1.677	1.671	1.75	1.764	0.771	0.735	0.687	0.7
	Pep01_602.27		83.425	83.484	83.559	83.54	1.677	1.671	1.725	1.741	0.945	0.895	0.83	0.847
	Pep01_635.63		83.368	83.441	83.535	83.509	1.679	1.671	1.726	1.739	0.551	0.492	0.459	0.467
	Pep01_663.58		83.361	83.436	83.532	83.506	1.682	1.675	1.728	1.741	0.483	0.432	0.369	0.377
	Pep01_713itp	Confluence with River Awbeg	83.354	83.433	83.532	83.505	1.694	2.347	3.822	3.604	0.491	0.606	0.614	0.645
River Awbeg	Awb01_6.64	U/S extent of River Awbeg	83.436	83.521	83.627	83.598	29.950	34.290	41.15	39.04	0.464	0.467	0.48	0.474
	Awb01_154.59	Upstream of confluence	83.354	83.433	83.532	83.505	29.926	34.266	40.973	38.94	0.435	0.469	0.519	0.504
	AwbDS_154.59DS	Downstream of confluence	83.354	83.433	83.532	83.505	31.232	35.141	40.872	39.194	0.454	0.481	0.518	0.508
	Awb01_198.28		83.310	83.385	83.479	83.453	31.229	35.138	40.868	39.19	0.602	0.637	0.684	0.671
	Awb01_364.55	D/S extent of River Awbeg	83.163	83.231	83.317	83.294	31.216	35.126	40.853	39.178	0.442	0.442	0.447	0.444