Sure Partners Limited

ARKLOW BANK WIND PARK PHASE 2
ONSHORE GRID INFRASTRUCTURE

VOLUME III
Chapter 10 APPENDICES

Appendix 10.1 Flood Risk Assessment

ARUP

sse Renewables

Appendix 10.1

Substation Flood Risk Assessment

220kV Substation Flood Risk Assessment

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Quality information

Prepared by	Checked by	Approved by
Morag Hutton	Sally Homoncik	Dylan Huws
Senior Hydrologist	Senior Geomorphologist	Associate Director

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Prepared for:

Sure Partner's Limited (SPL)

Prepared by:

AECOM
E: morag.hutton@aecom.com

AECOM Limited
1 Tanfield
Edinburgh
EH3 5DA
UK

T: +44 131 301 8600
aecom.com

Executive summary

Introduction

AECOM have been commissioned by Sure Partner's Limited (SPL) to carry out a Flood Risk Assessment (FRA) for a proposed substation at Avoca River Park, Arklow Co Wicklow. This FRA will assess flooding from all sources and will be used to inform design and support the planning application for the development.

Project background

The proposed substation site sits within the Avoca River Park industrial area, approximately 2km northwest of Arklow, Co Wicklow. The wider industrial estate is a combination of brownfield and manufacturing, contained on the west and south by the Avoca River and to the north and east by open grassland and capped landfill. An embankment extends around much of the western, southern and eastern edges of the Avoca River Park, providing protection from the Avoca River. A pond and pump arrangement provides drainage to the site as natural routes have been cut off by the embankment.

Arklow and Environs Local Area 2018 Plan: Strategic Flood Risk Assessment Guidelines sets out Flood Zones in relation to land use planning and development suitability. Very minor flooding on the substation site is shown in the mapping, and based on a precautionary approach, the site sits within Zone A. Given the site is considered essential infrastructure, and therefore highly vulnerable, a justification test is required to assess the appropriateness of the development in that location.

Assessment of flood risk

Flood risk from all sources was considered in this FRA. The initial high level assessment confirmed that fluvial, tidal, pluvial and residual were likely to pose a flood risk and required to be fully assessed and that sewer, ground water, reservoir and canal flooding did not require to be assessed further.

Hydrological analysis

Fluvial

Available gauged flow and level data from the area surrounding Arklow was collated and reviewed as well as all relevant Catchment Flood Risk Assessment and Management (CFRAM) reports in order to derive the hydrology.

In this FRA, the statistical method was used to estimate peak flows for the 1% AEP and 0.1% AEP floods. This method combines the index flood (usually QMED) and growth factors for each flood event.

The growth curves used in this study were taken from the Eastern CFRAM and Arklow CFRAM reports, with the index flood (QMED) derived using the Rathdrum gauge as a pivotal site. Hydrograph shape was established using catchment descriptors and a hydrologically similar gauged site to achieve a best fit curve.

The resultant peak flow for the 1% AEP event was 486m^3/s and 644m^3/s for the 0.1% AEP event. Based on OPW guidance, climate change was applied at 20% uplift to flow which represented the mid-range future scenario.

Joint probability and tidal boundary

The Avoca River discharges into the sea at Arklow Harbour and water levels in the river adjacent to the site may be influenced by tide levels and tide locking as well as fluvial flow in a joint event.

The Eastern CFRAM report undertook a joint probability analysis and found that the correlation between tidal water levels and fluvial flood flow within the region can be considered to be negligible. In the context of this study, the 1% and 0.1% AEP hydrographs are matched with a 50% AEP tide level of 1.05mOD at the downstream boundary.

A climate change uplift of 0.8m was applied to the tidal level, representing the mid-range future scenario.

Baseline flood risk

To assess fluvial flooding, a single hydraulic model was constructed of the Avoca River consisting of a one dimensional element representing the river channel and structures, and a two dimensional element representing the floodplain. A range of scenarios were modelling including current day, breach scenarios and inclusion of the Arklow Flood Relief Scheme.

Pluvial flooding was also assessed by constructing a simplified model which represented the topography and drainage arrangements on site.

Fluvial

During all modelled events, spill was seen to occur into the marsh land downstream of the site and on both banks between the upstream extent of the model and Arklow bypass bridge. Overtopping of the embankment protecting the site is only observed from the 0.1% AEP event, at the low point in Shelton Abbey grounds. During this current day event, flow is largely contained to the grassy area to the west of the industrial estate, with some flow continuing west in drainage ditches before spilling into a small section of the south eastern corner of the Substation site. During the 0.1% AEP plus climate change scenario (MRFS), the embankment is overtopped earlier, resulting in the entire Avoca River Park becoming inundated to a peak water level of 4.5mOD.

The Arklow Flood Relief Scheme is not found to affect flooding at the site.

Tidal

Tidal flooding was assessed by comparing site ground levels with the tidal levels outlined in the CFRAM reports. This demonstrated that tidal levels were significantly lower than ground levels to the east of Avoca River Park, which act as a barrier, and flooding as a result of high tide levels is not considered to be a risk.

The impact of tide locking was investigated through a modelling exercise. Flood levels at site were not found to be sensitive to changes in downstream boundary, demonstrating there is negligible tide locking risk.

Pluvial

Pluvial flooding from the catchment to the north was found to pose a flood risk to the substation site, which is low lying, cut off from natural drainage pathways by embankments and reliant on a pump system for drainage.

A peak flood level of 2.68mOD in the 0.1% AEP climate change (MRFS) event results in almost the entire substation site being inundated. It should be noted that pumps rates are assumed as further details have not been provided.

Ground water

High ground water levels are likely to be caused by levels in the Avoca River either as a result of high tides or high fluvial events and is not considered to be a source of flooding in its own right.

Residual

Breach of the embankments that protect the site is considered to pose a residual risk to the site and was assessed through a modelling exercise that included simulating two breach scenarios at the low point in the embankment which is considered to be a weak point in the defences.

Both breach scenarios were shown to completely inundate the site, with a peak flood level of 5.3mOD.

The breach assessment displays the residual risk to the site should the embankments fail. Flood levels on site were shown to increase significantly from baseline, highlighting the importance of maintaining the defences.

Development option flood risk

The proposed development consists of raising the substation platform above all flooding sources and raising of the low points in the flood embankment that protects Avoca River Park. The principals of raising the embankment have been established and granted planning permission through application 18/940.

Fluvial

Within this FRA, it is assumed that raising of the embankment is possible and detailed design will be informed by GI (ground investigations).

During the 0.1% AEP event with climate change (MRFS), raising the embankment showed significantly less flood water overtopping the embankment than in the baseline scenario. Almost all overtopping volume was contained to the open land to the west of the industrial estate with no floodwater affecting the substation site. This is compared to the baseline scenario which showed the entire site to be inundated.

It should be noted that water levels on the river side of the embankment are around 6.5mOD and that by raising the low point in the embankment to 6.5mOD there is no freeboard allowance.

Pluvial

The baseline Microdrainge source control model was updated to remove the platform footprint from the topographic representation of the site, representing the land being raised out with the floodplain.

By ensuring that the pump arrangement is appropriately sized for the full contributing catchment rather than just the industrial estate, the impact of any land raising and displacement of flood water can be compensated. The proposed development therefore results in no increase in pluvial flood risk elsewhere. The design level of the 0.1% AEP event with climate change (MRFS) is 2.64m OD. A freeboard allowance should be applied on top.

Recommendations

Based on the assessments, the following recommendations are made for the proposed substation site.

All elements are to be undertaken at detailed design stage with the exception of the maintenance inspection and repair programme which will be undertaken during the operational phase.

Embankment improvement works and maintenance

The proposed data centre has gained planning permission to raise the embankment to the west to 6.5mOD which was found in this FRA to eradicate fluvial flooding on site. It is therefore recommended, that embankment raising works at this low point be undertaken to reduce fluvial flood risk probability to the substation site. These works are included within the proposed development.

The entire Avoca River Business Park relies on the existing embankments for fluvial flood protection. Section 9.2.5 describes the residual risk to the site should the embankments fail, highlighting the importance of implementing a regular maintenance, inspection and repair programme to reduce this residual risk.

To allow suitable design to be developed for raising the low point of the embankment and to inform the maintenance, inspection and repair programme, a detailed topographic survey and GI inspection (including core sample of the embankment) will be undertaken to verify composition, permeability and stability of the embankment.

Should investigations determine that works are required to maintain or reinforce the existing embankments then these will be undertaken. While a range of approaches could be applied and a targeted approach (to certain areas of the embankment) might be possible, in a reasonable worst case scenario, the full length of the embankment may require to be reinforced, similar to the works at the low point.

The inspection and maintenance programme should also extend to cover the pump arrangement and drainage network, which should be detailed in the drainage design reporting.

Platform levels

Raising of the low point in the embankment will be subject to detailed design based on the findings of the GI. It is assumed in this study that raising is possible and with the embankment raised, fluvial flooding from the Avoca River is shown to be eradicated up to and including the 0.1% AEP event plus climate change (MRFS), meaning pluvial flooding is the key driver in determining the finished platform level.

As the substation is classed as essential infrastructure, platform levels should be set at the 0.1% AEP plus climate change flood level with an added freeboard allowance. The level excluding freeboard equates to 2.79mOD which represents the cumulative impact of land raising associated with the development and that associated with application 18/940.

A minimum platform level of 3.3mOD is recommended as this provides a 500mm freeboard in a conservative assessment whereby no attenuation is provided for either development. The assessment is based on surface water pumps accommodating the full contributing area Greenfiled runoff rate. Pump upgrades may be required to achieve this.

Additional flood mitigation measures

Regular inspections and maintenance of the embankment and pump arrangement reduced the likelihood of a breach or pump failure which would affect the requirements for additional flood prevention measures.

However, flood risk can never be fully removed, and additional measures can be put in place to further minimise risk. These could include use of flood resilient materials, provision of safe access and egress and demountable flood barriers and sealed air vents.

Suitability of site and development

The development site has been assessed based on a sequential approach in line with relevant guidelines. A rigorous assessment of an alternative site has been considered and no alternative is available for the proposed development. The development is based on a particular need and therefore no substitute type of development can be considered.

On that basis and on the back of detailed FRA undertaken, a justification test has been carried out in line with the Guidelines on the Planning System and Flood Risk Management' (DoEHLG/OPW, 2009.

Based on the findings of the justification test, the scheme addresses all the criteria, ensuring that the development is protected to the appropriate standard whilst ensuring no detrimental impact on the standard of protection to others.

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1. Introduction

1.1 Purpose

AECOM have been commissioned by Sure Partner's Limited (SPL) to carry out a Flood Risk Assessment (FRA) for a proposed substation at Avoca River Park, Arklow Co Wicklow. The FRA will inform the design, primarily platform level, and support the planning application for the development.

This document describes the development, assesses current flood risk from all sources, outlines the implications of the development in terms of flood risk and sets out recommendations on design so that the development falls in line with local guidance.

1.2 Sources of data

To inform this study, information have been obtained from the following sources:

- Site information and development proposals from SPL;
- Topographic survey of the site and the surrounding embankment undertaken in 2018 as part of the data centre application;
- Topographic cross section information from a variety of existing surveys, 2006, 2011, 2015 and 2019;
- 0.5m LiDAR which was undertaken as part of this study in June 2020;
- Office of Public Works (OPW) flood mapping;
- Previous flood risk assessments in and around Arklow, primarily undertaken by Byrne Looby;
- Wicklow County Council Development Plan (2016 – 2022) – Flood Management Objectives.

1.3 Flood risk terminology

In this document, flood events are defined according to their likelihood of occurrence. The term Annual Exceedance Probability (AEP) is used, meaning the chance of a particular flood event occurring or being exceeded in any given year. The 1000-year flood has an AEP of 0.1%; a 0.1% chance of occurring or being exceeded in any given year.

2. Project Background

2.1 Existing site

2.1.1 Location and description

The study area is outlined in Figure 2-1 and encompasses the wider industrial estate, which the proposed substation site sits within, as well as the wider floodplain to the tidal extent at Arklow.

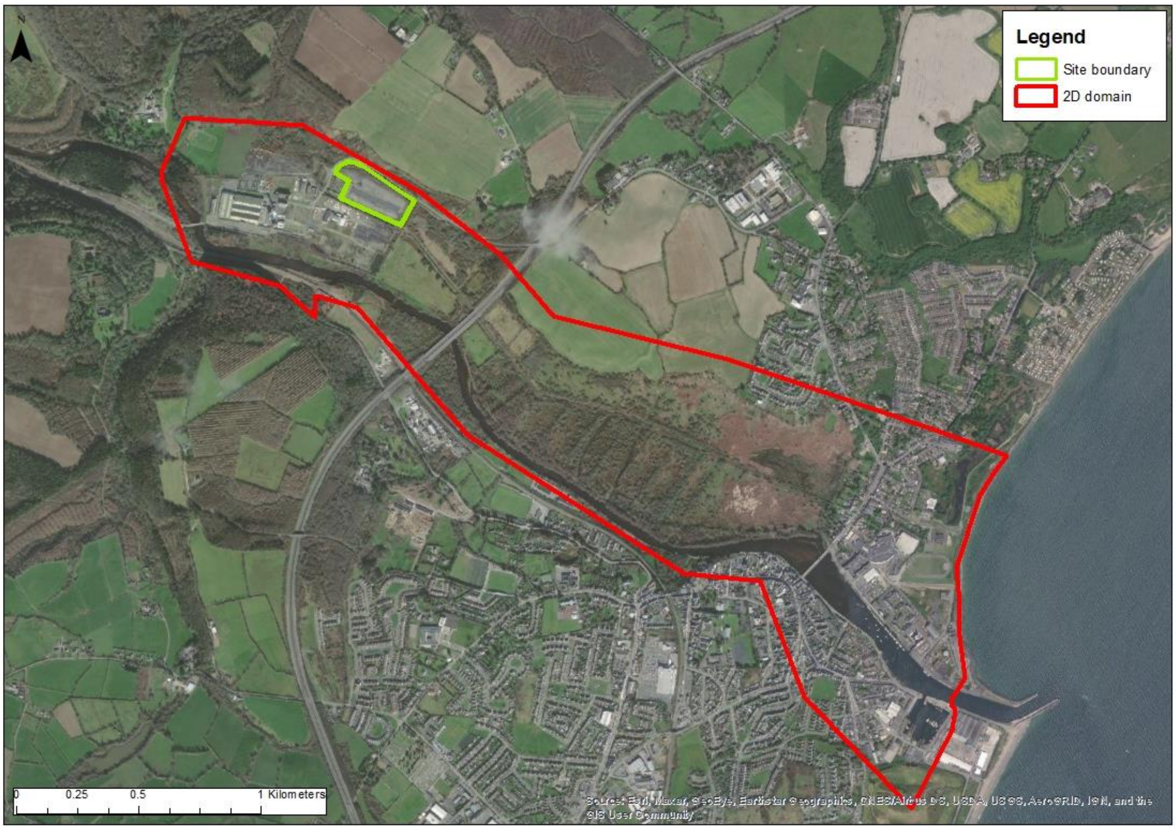


Figure 2-1: Study area and substation site area

The proposed substation site sits within the Avoca River Park industrial area, approximately 2km northwest of Arklow, Co Wicklow. The wider industrial site is a combination of brownfield site, a timber fabrication plant, plastic manufacturing plant and car storage for scrapped vehicles. The proposed substation site is entirely brownfield and is primarily tarmacked.

The substation site is bounded to the north by the access road into the Avoca River Park and to the south by a road and drainage ditch. To the east of the site there are extensive capped landfill sites which open out into marshland downstream of the bypass bridge. To the west is a combination of open forested area, maintained grassland as well as other tenants of the Avoca River Park.

Ground levels across the site range from 1.3mOD to 2.6mOD sloping west to east, with the low point located in the south east corner.

The drainage ditch to the south of the substation site was formally an extension of the canal that can still be seen to the east. This has since been blocked off and the ditch has a water level of approximately 1m,with the attenuation pond, which the ditch drains into, being slightly lower. A pump arrangement drains the pond into the Avoca river, although operating rates are unknown.

An earth and loose stone embankment bounds the site to the east, south and west, tying into higher ground. This embankment was constructed for flood defence purposes but its composition is unknown.

Surface water run-off on the site has been significantly modified by the presence of the canal and the flood defence embankment. The result is that natural run-off from the site to the Avoca River is no longer possible.

2.1.2 Site visit

A site walkover was undertaken in September 2020 to establish the general topography, condition and extent of the embankment and to identify potential sources of flooding and flow routes.

Figure 2-2 displays some of the key features mentioned in the text below.

The substation site was fenced off and access was not available at the time of the site visit. Given the detailed LiDAR and topographic survey of the area, this was not considered to affect the site assessment. It was seen to be largely tarmacked, with some vegetation growing through damaged areas. The drainage ditch running to the south of the site was between 2-3m in width and seen to be largely stagnant with plant and algae growth on the surface. Flow from this ditch was controlled by a sluice gate arrangement, diverting flows into the attenuation pond in the south eastern corner of the industrial site. The sluice gate appeared to be fully open and it was not clear if it was actively managed. The diversion channel extending from the south east corner of the site to the attenuation pond was not accessible, although reeds and long grasses could be seen from the rural grassland which was significantly higher than the industrial estate. The pond and associated pump station are located in the south eastern corner of the industrial estate and are used as a means of draining the site. An intake structure is located at the pump station and two pipes were seen to extend over the embankment towards the Avoca River, although it should be noted that the outfall was not viewed. The pipes were approximately 300mm and 450mm in diameter. A flap valve was seen on the banks of the Avoca River, but it was not clear where the pipe originated. No further details of pump rate or maintenance was gathered from the site visit.

The road to the south of the substation site rises to a high point at the south eastern corner. This high point ties in with earth embankments on either side, separating the canal from the drainage ditch and the rural land from the industrial estate. The embankment extending towards the Avoca River is seen to tie into the embankment along the southern side of the industrial site.

The embankment running between the Avoca River and the industrial site appears to be earth formed with loose rock covering the upper portions. It appears in reasonable condition although there are areas where concrete blocks and wooden planks have been added where erosion may be occurring or levels and materials have been displaced due to historic infrastructure. It is recommended that these areas be investigated further. This embankment ties in with a high point in the south west corner of the industrial site at the access bridge. The access bridge does not appear to be a blockage risk due to the high soffit and minimal pier width. From the bridge, the embankment continues north but is grass covered rather than exposed stones. For access reasons, it was not possible to view the embankment out with the industrial site boundary, but it has been picked up in some previous survey as extending up to the boundary of Shelton Abbey. Again, the embankment appears to be in reasonable condition although composition remains unknown.

When viewing mapping of the area, small watercourses are noted around the site and could potentially cause secondary flooding behind the embankment. No running water could be seen or heard in the areas where watercourses are marked on the mapping, primarily to the north of the site. It is likely that ditches do exist in these areas but vegetation cover was such that little could be seen. The fact that no water was seen does not mean that runoff would not concentrate in these areas during a storm event

Photographs can be found in Appendix A.

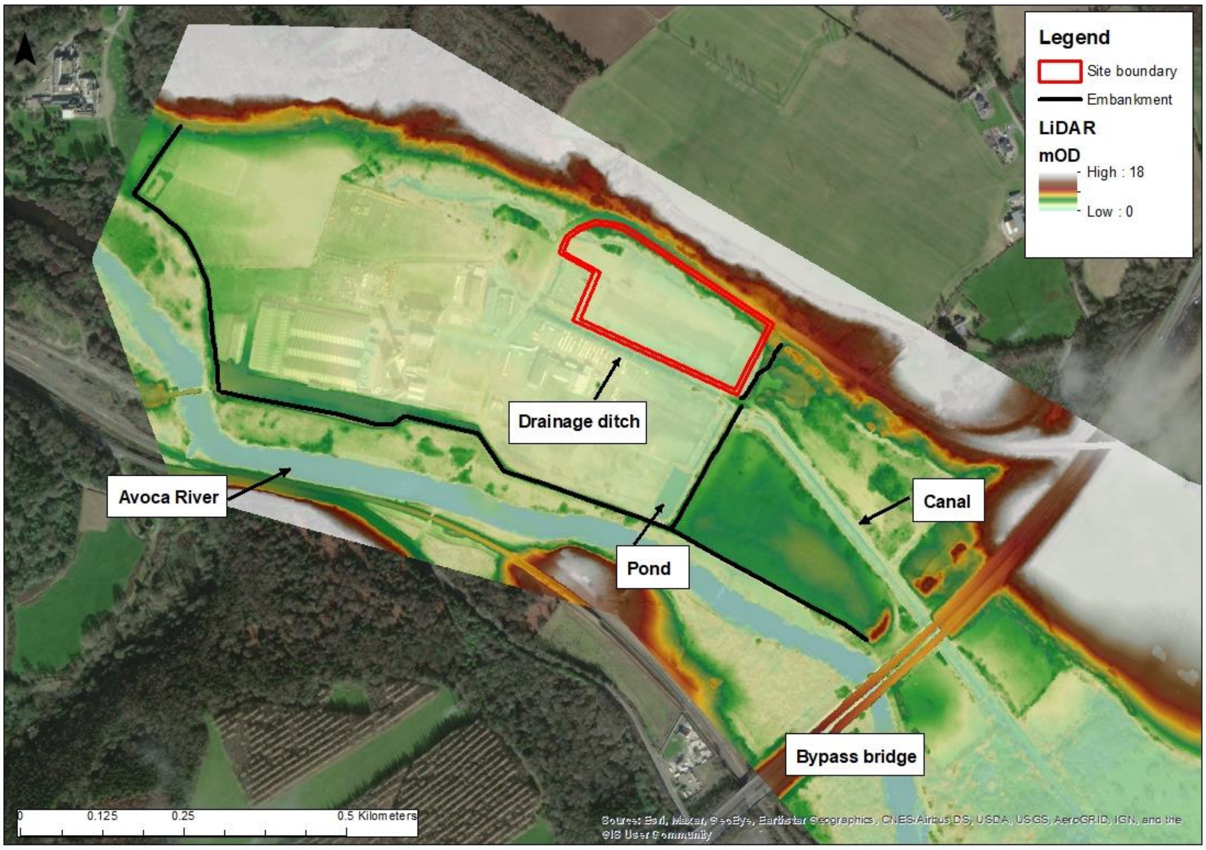


Figure 2-2: Site layout and surrounding features

2.2 Site flood vulnerability

2.2.1 Flood zoning

Flood Zone A is defined and designated in the Arklow and Environs Local Area 2018 Plan: Strategic Flood Risk Assessment Guidelines, where the probability of flooding from rivers and the sea is high (greater than 1% AEP for river flooding). Flood Zone B is assigned where the probability of flooding from rivers and the sea is moderate (between 1% and 0.1% AEP for rivers and between 0.5% and 0.1% AEP for coastal). Flood Zone C is where there is a low probability of flooding, less than a 0.1% AEP event.

Figure 2-3 is an extract from the Indicative Flood Zones Map SFRA 1 contained within the Arklow and Environs Local Area 2018 Plan Strategic Flood Risk Assessment. The information used in the preparation of these flood zones was collated from a number of sources including, OPW Preliminary FRA, National Coastal Protection Strategy Study, Flood maps, geology mapping, as well as discussions with Wicklow Council and local residents.

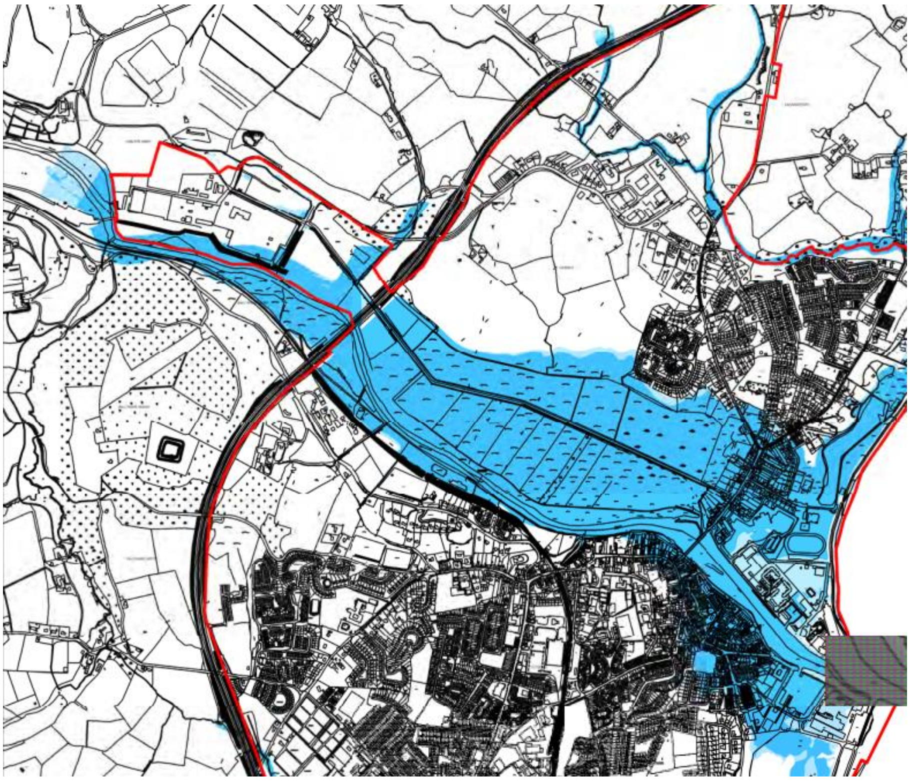


Figure 2-3: Arklow & Environs Local Area 2018 Plan SFRA Indicative Flood Zones Extract Map SFRA 1

This mapping in Figure 2-3 indicates that the site is at risk of very minor flooding in the south eastern corner of the substation site. A review of the flooding sources based on the flood map from the SFRA, shows that the low area within the site is at risk from coastal flooding as opposed to fluvial flooding (Figure 2-4). This flooding is not hydraulically linked to any sources of flooding. However, based on a precautionary approach the guidance based on the flood Zone A has been undertaken to ensure that flood risk is appropriately addressed.

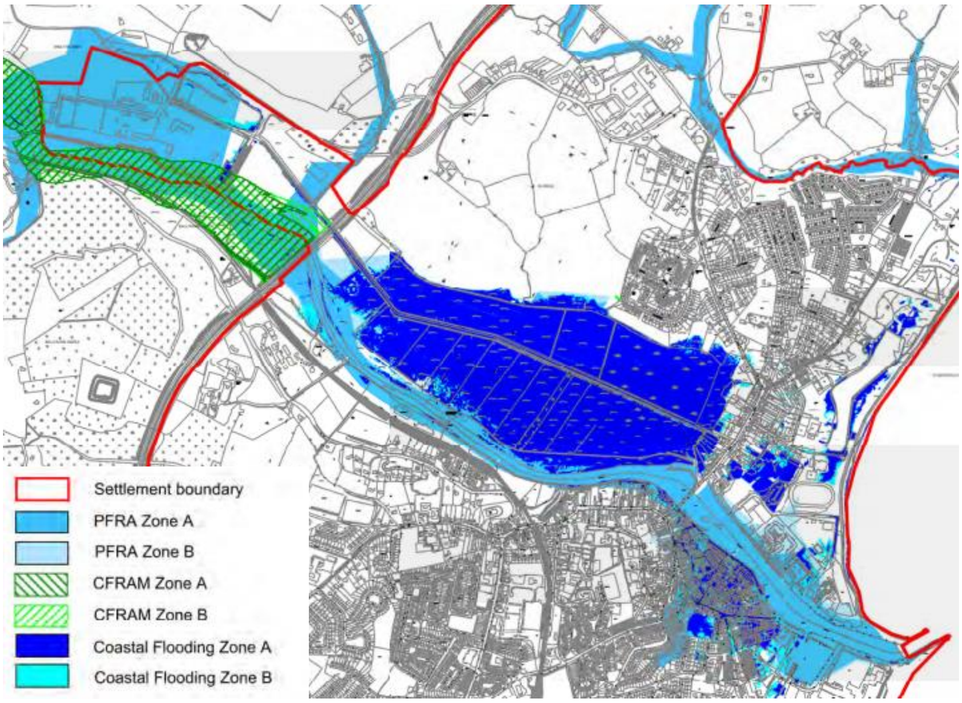


Figure 2-4: Arklow & Environs Local Area 2018 Plan SFRA Flood Map Extract SFRA 1

2.2.2 Justification test

Figure 2-5 displays a table excerpt from the Planning System and Flood Risk Management Guidelines for Planning Authorities (2009) which gives a detailed classification of vulnerability of different types of development. The proposed substation development falls under the category of essential infrastructure and as it is predominantly within Flood Zone C with a small part within Zone A and B based on the SFRA maps. Based on the precautionary approach, looking at the site as Zone A, a justification test is required for essential infrastructure within the zone.

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

Figure 2-5: Matrix of vulnerability versus flood zone (Table 3.2 from Guidelines on the Planning System and Flood Risk Management' (DoEHLG/OPW, 2009)

The Planning System and Flood Risk Management Guidelines details that a detailed proposals for flood risk and surface water management should be set out as part of a flood risk assessment (Figure 2-6). This FRA will investigate flooding from all sources and set out recommendations on how to mitigate any risk.

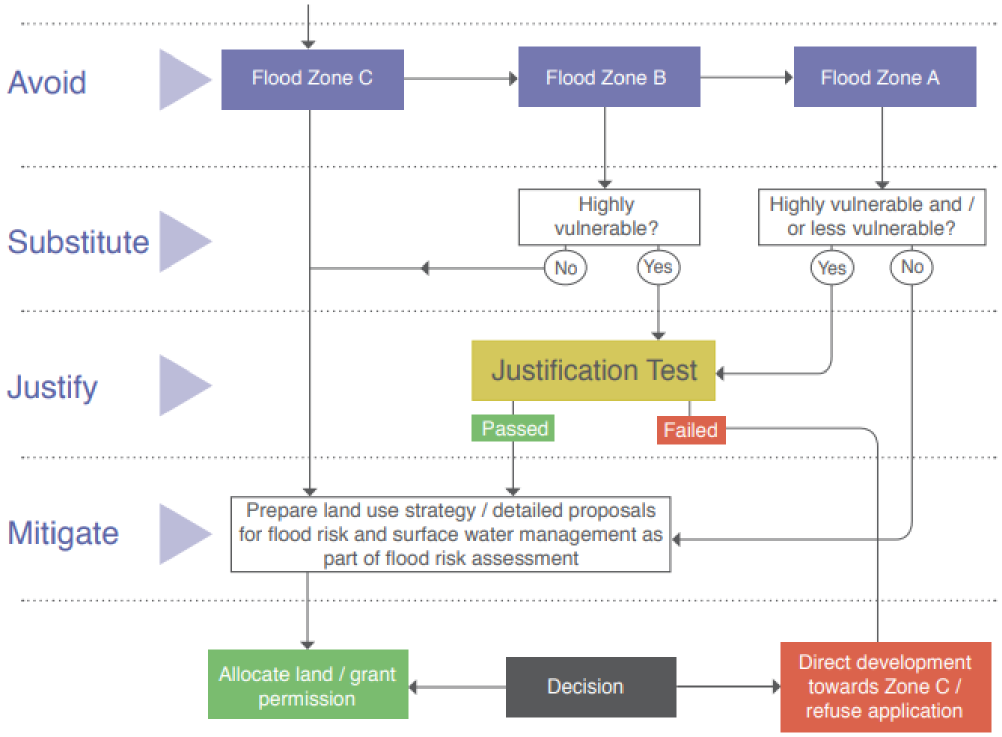


Figure 2-6: Justification test requirements - excerpt from Guidelines on the Planning System and Flood Risk Management' (DoEHLG/OPW, 2009)

The Justification Test has been designed to rigorously assess the appropriateness, or otherwise, of particular developments that, for the reasons outlined above, are being considered in areas of moderate or high flood risk. The test is comprised of two processes.

The first is the Local Plan-making Justification Test and is used at the Local Plan preparation and adoption stage where it is intended to zone or otherwise designate land which is at moderate or high risk of flooding. For the development site the SFRA concluded the following:

These lands are currently developed for permitted employment. As such, it is considered appropriate to retain the E zoning objective. Applications for minor development (e.g. extensions) are unlikely to raise significant flooding issues. Should expansion of existing uses be proposed, flood mitigation measures are required

The second is the Development Management Justification Test and is used at the planning application stage where it is intended to develop land at moderate or high risk of flooding for uses or development vulnerable to flooding that would generally be inappropriate for that land. As noted previously a justification test is being carried out based on the precautionary approach. The justification test is noted in Figure 2.7 below:

Box 5.1 Justification Test for development management (to be submitted by the applicant)

When considering proposals for development, which may be vulnerable to flooding, and that would generally be inappropriate as set out in Table 3.2, the following criteria must be satisfied:

1. 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 of these Guidelines.
2. The proposal has been subject to an appropriate flood risk assessment that demonstrates:
   (i) The development proposed will not increase flood risk elsewhere and, if practicable, will reduce overall flood risk;
   (ii) The development proposal includes measures to minimise flood risk to people, property, the economy and the environment as far as reasonably possible;
   (iii) 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; and
   (iv) 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.

The acceptability or otherwise of levels of residual risk should be made with consideration of the type and foreseen use of the development and the local development context.

Note: See section 5.27 in relation to major development on zoned lands where sequential approach has not been applied in the operative development plan.

Refer to section 5.28 in relation to minor and infill developments.

Figure 2-7: Justification Test for development management (Box 5.1 from Guidelines on the Planning System and Flood Risk Management' (DoEHLG/OPW, 2009)

The Arklow and environs Local Area Plan SFRA sets out clear guidance for development within a flood risk area.

These are noted below

FL4 Applications for new developments or significant alterations/extension to existing developments in a flood risk area shall comply with the following:

- Follow the 'sequential approach' as set out in the Flood Risk Guidelines.
- Flood risk assessments will be required with all planning applications proposed in areas identified as having a flood risk, to ensure that the development itself is not at risk of flooding

and the development does not increase the flood risk in the relevant catchment (both up and down stream of the application site).

- Where a development is proposed in an area identified as being at low or no risk of flooding, where the planning authority is of the opinion that flood risk may arise or new information has come to light that may alter the flood designation of the land, an appropriate flood risk assessment may be required to be submitted by an applicant for planning permission.
- Restrict the types of development permitted in Flood Zone A and Flood Zone B to that are 'appropriate' to each flood zone, as set out in Table 3.2 of the guidelines for Flood Risk Management (DEHLG/OPW, 2009). • Developments that are an 'inappropriate' use for a flood zone area, as set out in Table 3.2 of the guidelines, will not be permitted, except where a proposal complies with the 'Justification Test for Development Management', as set out in Box 5.1 of the Guidelines.
- Flood Risk Assessments shall be in accordance with the requirements set out in the Guidelines.
- Generally a Flood Impact Assessment will be required with all significant developments and a certificate (from a competent person stating that the development will not contribute to flooding within the relevant catchment) will be required with all small developments of areas of 1 hectare or less.

FL5 To prohibit development in river flood plains or other areas known to provide natural attenuation for floodwaters except where the development can clearly be justified with the Flood Risk Guidelines 'Justification test'. FL6 To limit or break up large areas of hard surfacing in new developments and to require all surface car parks to integrate permeability measures such as permeable paving.

FL7 Excessive hard surfacing shall not be permitted for new, or extensions to, residential or commercial developments and all applications will be required to show that sustainable drainage techniques have been employed in the design of the development.

FL8 To require all new developments to include proposals to deal with rain and surface water collected on site and where deemed necessary, to integrate attenuation and SUDS measures.

FL9 For developments adjacent to all watercourses of a significant conveyance capacity or where it is necessary to maintain the ecological or environmental quality of the watercourse, any structures (including hard landscaping) must be set back from the edge of the watercourse to allow access for channel clearing/ maintenance / vegetation. A minimum setback of up to 10m (or other width, as determined by the Council) will be required either side depending on the width of the watercourse.

2.3 Previous studies

2.3.1 Arklow Flood Relief Scheme

The Hydrology and Hydraulics Report, Avoca River (Arklow) Flood Relief Study (Cawley, 2007) was prepared in 2007 on behalf of OPW. It presented flood flows for use in the optioneering of the Arklow Flood Relief Scheme. The report also notes the flood information recorded during Hurricane Charlie in 1986. This event was estimated by Byrne Looby Partners April 2015 to be a 0.66% AEP event (1:150 year) in reference to a PH McCarthy Report (1989) with an associated flow rate of 695 m^3/s (excluding climate change).

In 2012, 2D hydraulic modelling of the Avoca River at Arklow (Cawley, 2012) was undertaken on behalf of the OPW to support the preliminary design of the Arklow Flood Relief Scheme, with particular emphasis on modelling the impact of Arklow Bridge on flood levels. The Arklow Flood Relief scheme includes measures such as flood walls and embankments in town, lowering the bed level around Arklow Bridge and a debris catcher located upstream of Arklow bridge.

2.3.2 Arklow Wastewater Treatment Plant Site Selection Process

In 2015 a HEC-RAS model of the Avoca River was prepared as part of a site selection process for the Arklow Wastewater Treatment Plant for Irish Water. The hydraulic modelling was commissioned by Irish Water (IW) but undertaken by Byrne Looby PH McCarthy (BLP).

As that hydraulic model was undertaken to assess flood risk in the same location as the proposed development site, permission was sought from both parties (IW and BLP) to obtain and utilise the data as part of this hydraulic modelling commission. Survey information from this 2015 study was used to construct part of the hydraulic model in this study.

2.3.3 Proposed development at Avoca River Park, Co Wicklow

An FRA was undertaken at the Avoca River Park in 2018-2020 and detailed flood risk and design proposals for a data centre. The data centre and the associated FRA is separate proposal to the substation site considered in this FRA. The data centre site covers the eastern section of the Avoca River Park. A 1D hydraulic modelling exercise was undertaken based on the 2015 survey from the Wastewater Site FRA detailed above and a small number of new survey sections. Hydrological inflows were taken from the Arklow Flood Relief Scheme modelling, undertaken by the OPW. Climate change was applied at 20%, representing the mid-range future scenario (MRFS).

The main recommendation of this report in relation to flood risk was to raise the low point in the embankment to the west to 6.5mOD tying in with levels across the embankment. This development was granted planning permission in February 2019, application number 18940.

3. Assessment of flood risk

3.1 Sources of flooding

Table 3-1 outlines the possible sources of flood risk to the site. This high-level assessment identifies those sources that require to be assessed in more detail within this study.

Table 3-1: Sources of flooding

Flood Type	Description	Assessment	Risk Identified
Fluvial flooding	Exceedance of river capacity, leading to overtopping of the riverbanks.	The Avoca River flows to the west and south of the site. The wider industrial estate is protected by embankments, reaching 3m high in some locations, which provide protection from the Avoca River. The standard of protection of the embankments is unknown, and the site is low lying , therefore fluvial flood risk is considered to be a source of flooding and will be assessed in this FRA.	Yes
Tidal flooding	Flooding from the sea as a result of high tide levels and / or wave action. Including propagation of high tides and storm surges up tidal river channels leading to overtopping of the riverbanks.	The Catchment Flood Risk Assessment and Management (CFRAM) 0.1% AEP tidal level is 1.75mOD, rising to 2.55mOD with climate change. This level is significantly lower than land to the immediate east of the site, which is generally 5mOD+. The low point in the embankment east of the site is also set at 4.2mOD, significantly higher than the 0.1%AEP +CC tide level. Flooding as a result of high tide levels is not considered to be a risk to the site. There may however be a risk whereby a fluvial event cannot drain efficiently due to raised tide levels and this joint probability risk will be assessed in this FRA.	Yes
Surface water and sewer flooding	Heavy or intense rainfall events exceeding the available infiltration capacity of the catchment and / or the drainage capacity of drainage networks leading to overland flow and surface water flooding.	Given the catchment is cut off from its natural drainage route by embankments, pluvial flooding is considered to be a risk. The drainage system is also reliant on a pump arrangement which further increases risk. Pluvial risk will be assessed in this FRA. The sewage network is not considered to be a flood risk as there is limited network in the area.	Yes
Groundwater flooding	Emergence of groundwater at the surface (and subsequent overland flows) or into subsurface voids as a result of abnormally high groundwater flows, the introduction of an obstruction to groundwater flow and / or the rebound of previously depressed groundwater levels.	Ground water flooding is likely to be as a result of levels in the Avoca River either due to high tides or high fluvial events. The lowest point on the site sits at around 1.3mOD. 50% AEP tidal levels are 1.05mOD and 50% fluvial levels are around 3mOD. Therefore, any groundwater flooding that may occur can be described as fluvial / tidal and not as a separate source of flooding. Groundwater flooding will not be assessed in more detail in this report.	No
Other sources of flood risk	Flooding from canals, reservoirs (breach or overtopping) and failure of flood defences.	The site is not located near any reservoirs. The water levels in the canal to the west of the site is around 3m lower than the embankment into the site. The canal is also largely filled from overtopping by fluvial flooding in the marshes and is not considered to cause a flood risk by itself. As the site is protected by embankments, there is a residual flood risk in the case of a breach. This will be assessed in the FRA.	Yes

3.2 Flood maps

3.2.1 OPW flood maps

The latest OPW flood maps were published in July 2016 and are available to view at the following link: https://www.floodinfo.ie/map/floodmaps/. These maps include flood extents for fluvial and tidal events for current and mid-range future scenarios (MRFS).

Both fluvial and tidal flood extents are shown not to affect the site, as seen in Figure 3-1. It should be noted that there are limitations in this flood mapping in that it is a strategic high-level assessment and should not be used in place of more site specific FRAs.

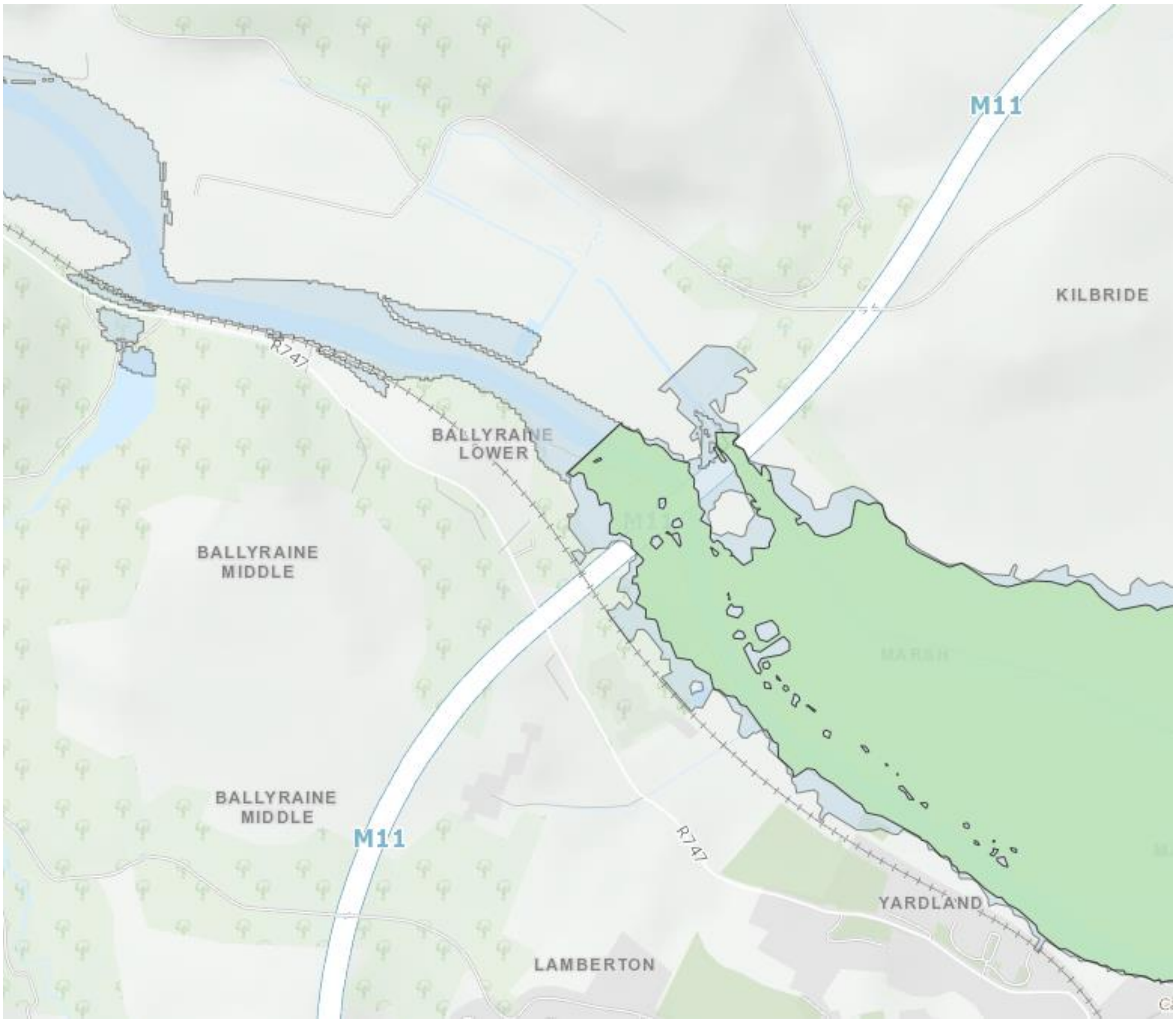


Figure 3-1: Fluvial and tidal flood extents for the 0.1% AEP event.

3.2.2 OPW Flood Hazard Mapping

The OPW Flood Hazard Mapping Website is a record of historic flood events and this database indicates that there are no reported instances of flooding at Avoca River Park (Figure 3-2). The hazard mapping can be viewed at https://www.floodinfo.ie/map/floodmaps/.

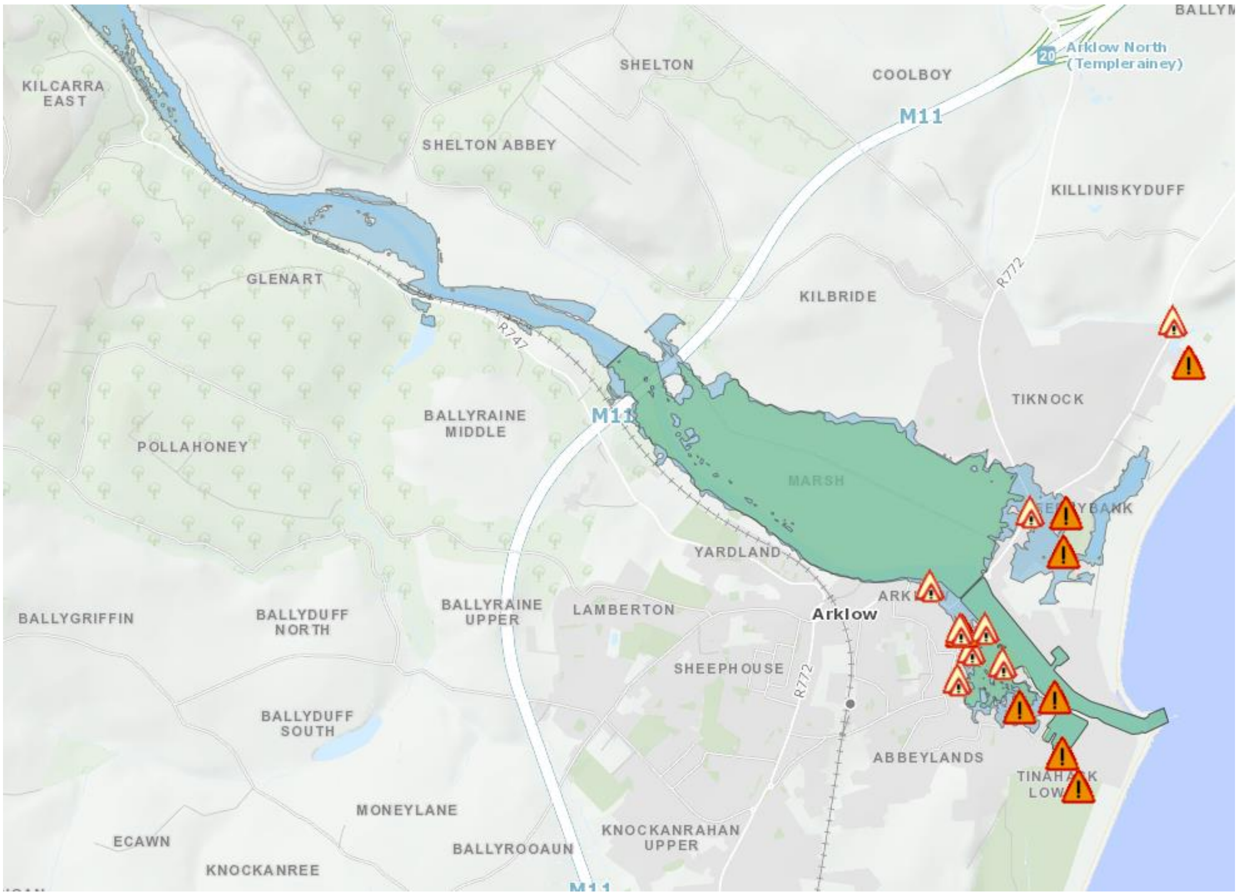


Figure 3-2: OPW hazard mapping

4. Policy

In preparing this FRA, AECOM have reviewed the Wicklow County Council Development Plan (2016 – 2022), in particular, the Flood Risk Management Objectives section.

4.1 Wicklow County Council Development Plan (2016-2022) – Flood Risk Management objectives

In order to properly manage flood risk, the following mitigation objectives are included in the County Development Plan 2016-2022 and will be followed within this FRA:

FL1 To prepare new or update existing flood risk assessments and flood zone maps for all zoned lands within the County as part of the review process for Local Area Plans, zoning variations and Town Plans, where considered necessary.

FL2 To implement the 'Guidelines on the Planning System and Flood Risk Management' (DoEHLG/OPW, 2009).

FL3 The zoning of land that has been identified as being at a high or moderate flood risk (flood zone A or B) shall be in accordance with the requirements of the Flood Risk Guidelines and in particular the 'justification test for development plans' (as set out in Section 4.23 and Box 4.1 of the guidelines).

FL4 Applications for new developments or significant alterations/extension to existing developments in a flood risk area shall comply with the following:

- Follow the 'sequential approach' as set out in the Flood Risk Guidelines.
- Flood risk assessments will be required with all planning applications proposed in areas identified as having a flood risk, to ensure that the development itself is not at risk of flooding and the development does not increase the flood risk in the relevant catchment (both up and downstream of the application site).
- Where a development is proposed in an area identified as being at low or no risk of flooding, where the planning authority is of the opinion that flood risk may arise or new information has come to light that may alter the flood designation of the land, an appropriate flood risk assessment may be required to be submitted by an applicant for planning permission.
- Restrict the types of development permitted in Flood Zone A and Flood Zone B to that are 'appropriate' to each flood zone, as set out in Table 3.2 of the guidelines for Flood Risk Management (DoEHLG/OPW, 2009).
- Developments that are an 'inappropriate' use for a flood zone area, as set out in Table 3.2 of the guidelines, will not be permitted, except where a proposal complies with the 'Justification Test for Development Management', as set out in Box 5.1 of the Guidelines.
- Flood Risk Assessments shall be in accordance with the requirements set out in the Guidelines.
- Generally, a Flood Impact Assessment will be required with all significant developments and a certificate (from a competent person stating that the development will not contribute to flooding within the relevant catchment) will be required with all small developments of areas of 1 hectare or less.

FL5 To prohibit development in river floodplains or other areas known to provide natural attenuation for floodwaters except where the development can clearly be justified with the Flood Risk Guidelines 'Justification test'.

FL6 To limit or break up large areas of hard surfacing in new developments and to require all surface car parks to integrate permeability measures such as permeable paving.

FL7 Excessive hard surfacing shall not be permitted for new, or extensions to, residential or commercial developments and all applications will be required to show that sustainable drainage techniques have been employed in the design of the development.

FL8 To require all new developments to include proposals to deal with rain and surface water collected on site and where deemed necessary, to integrate attenuation and SUDS measures.

FL9 For developments adjacent to all watercourses of a significant conveyance capacity or where it is necessary to maintain the ecological or environmental quality of the watercourse, any structures (including hard landscaping) must be set back from the edge of the watercourse to allow access for channel clearing/ maintenance / vegetation. A minimum setback of up to 10m (or other width, as determined by the Council) will be required either side depending on the width of the watercourse.

4.2 Flood Risk Management Guidelines

In September 2008 "The Planning System and Flood Risk Management" Guidelines were published by the Department of the Environment, Heritage and Local Government in Draft format. In November 2009 the adopted version of the document was published.

The Flood Risk Management Guidelines give guidance on flood risk and development. The guidelines recommend a precautionary approach when considering flood risk management in the planning system. The core principle of the guidelines is to adopt a risk based sequential approach to managing flood risk and to avoid development in areas that are at risk. The sequential approach is based on the identification of flood zones for river and coastal flooding.

The guidelines include definitions of Flood zones A, B and C as noted below. It should be noted that these do not take into account the presence of flood defences, as risks remain of overtopping and breach of the defences.

Zone A (high probability of flooding) is for lands where the probability of flooding is greatest (greater than 1% or the 1 in 100 for river flooding and 0.5% or 1 in 200 for coastal flooding).

Zone B (moderate probability of flooding) refers to lands where the probability of flooding is moderate (between 0.1% or 1 in 1000 and 1% or 1 in 100 for river flooding and between 0.1% or 1 in 1000 and 0.5% or 1 in 200 for coastal flooding).

Zone C (low probability of flooding) refers to lands where the probability of flooding is low (less than 0.1% or 1 in 1000 for both river and coastal flooding).

Once a flood zone has been identified, the guidelines set out the different types of development appropriate to each zone. Exceptions to the restriction of development due to potential flood risks are provided for through the use of the Justification Test, where the planning need and the sustainable management of flood risk to an acceptable level must be demonstrated. This recognises that there will be a need for future development in existing towns and urban centres that lie within flood risk zones, and that the avoidance of all future development in these areas would be unsustainable.

A three staged approach to undertaking an FRA is recommended:

- Flood Risk Identification (Stage 1) - Identification of any issues relating to the site that will require further investigation through a Flood Risk Assessment.
- Initial Flood Risk Assessment (Stage 2) - Involves establishment of the sources of flooding, the extent of the flood risk, potential impacts of the development and possible mitigation measures.
- Detailed Flood Risk Assessment (Stage 3) - Assess flood risk issues in sufficient detail to provide quantitative appraisal of potential flood risk of the development, impacts of the flooding elsewhere and the effectiveness of any proposed mitigation measures.

This report addresses the requirements for stages 1, 2 and 3.

5. Hydrological analysis

5.1 Introduction

The main fluvial flood risk to the site is from the River Avoca, which lies adjacent to the south west boundary of the site. The Avoca River discharges to the sea at Arklow Harbour, some 3.5km downstream; therefore, water levels in the river adjacent to the site may also be influenced by tide levels as well as fluvial flow.

The hydraulic model that was constructed for this FRA requires upstream and downstream boundaries, reflecting design fluvial flow hydrographs, and tide levels respectively. This section of the FRA covers the hydrology for the Avoca River contained in relevant Catchment Flood Risk Assessment and Management (CFRAM) reports and proposes design flow inputs and tide levels to be used in the FRA modelling.

In order to determine the flood zones as defined in the Planning System and Flood Risk Management guidelines, the fluvial 1% and 0.1% AEP events are required to be modelled with and without climate change. Suitable tidal downstream boundary levels also need to be set with due consideration of joint probability of coincidence of high fluvial flow and high tide levels.

5.2 Hydrometric data

The available flow and level gauges within the Avoca River catchment are located in the map below, and detailed in Table 5-1.

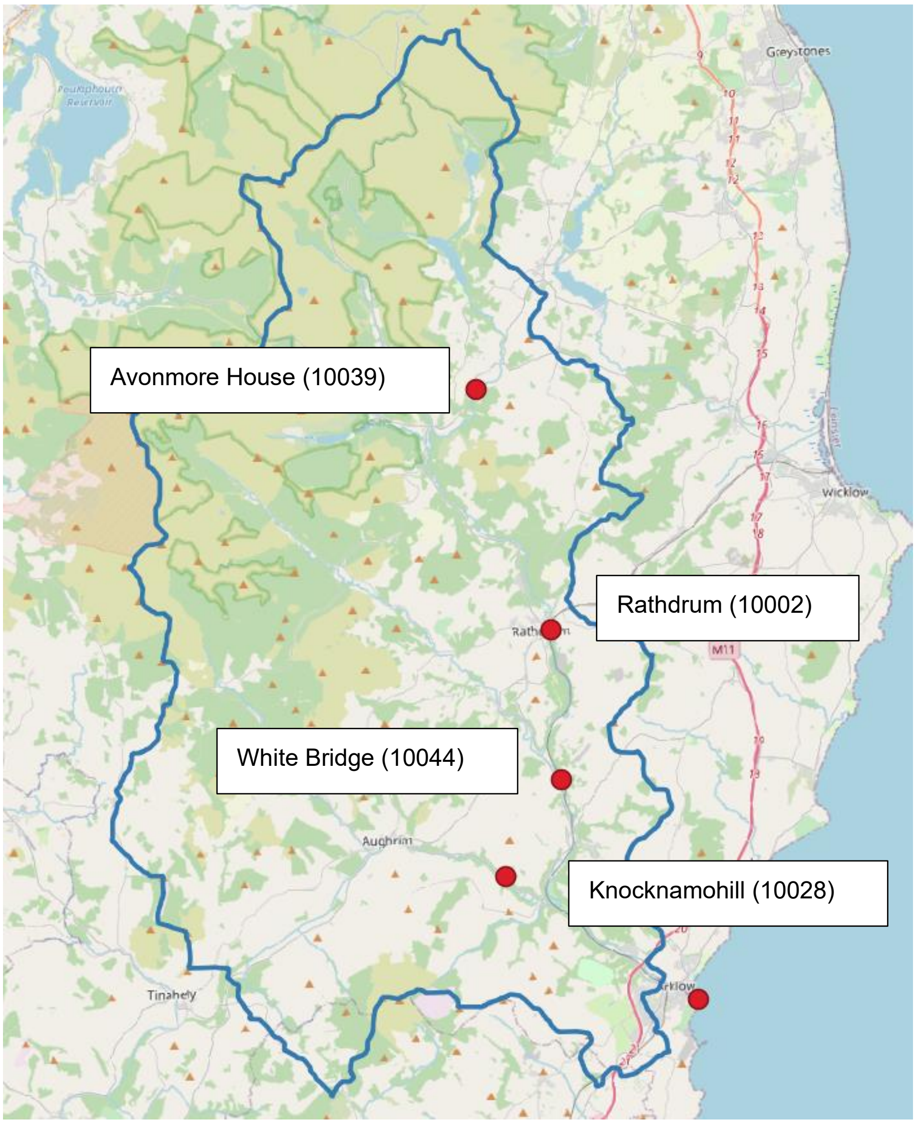


Figure 5-1: Location of flow and level gauges within the Avoca River catchment area

Table 5-1: Available flow and level gauges within Avoca River catchment area

Site	Gauge no	River	Gauge type	Period of record	Comments
Avonmore House	10039	Avonmore	Flow and level	EPA Hydronet 15 minute flow and level: 09/06/2004-present	Not classified
Rathdrum	10002	Avonmore	Flow and level	EPA Hydronet 15 minute flow: 26/03/1953 – 24/11/1999, 01/01/2018 - present 15 minute level: 20/09/1952-present Gaugings FSU Portal AMAX flow and level 1952 – 2004 Subject to rating review	FSU gauge, B class EPA rating “good”
White Bridge	10044	Avoca	Flow and level	EPA Hydronet 15 minute flow and level: 21/12/2009 - present	Not classified. EPA Hydronet states not suitable for high flow analysis
Knocknamohill	10028	Aughrim	Flow and level	EPA Hydronet 15 minute flow and level: 22/10/1986 – present FSU Portal AMAX flow and level 1952 - 2004	FSU gauge, B class EPA rating “good”
Arklow Harbour	10060	N/A	Level	EPA Hydronet 15 minute level: 26/08/2003 - present	

5.3 Review of CFRAM reports

CFRAM studies are district level flood risk assessments commissioned by the OPW to deliver the requirements of the EU Floods Directive and national flood policy. The studies involved hydrological assessment and hydraulic modelling in order to map flood risk

The two most relevant CFRAM reports undertaken are:

- Arklow CFRAM Flood Mapping – Hydrology and Hydraulics Report, Hydro Environmental Ltd, November 2015
- Eastern CFRAM Study HA10 Hydrology Report, April 2016

5.3.1 Eastern CFRAM Study HA10 Hydrology Report, April 2016

The 2016 Eastern CFRAM hydrology report details the estimation of flows and tide levels for the 13 fluvial hydrodynamic models within the HA10 area, shown in Figure 5-2. Model 11 is the Avoca River, representing the lower reaches of the Avoca River catchment from just upstream of the town of Avoca, past its confluence with the Aughrim River and on to the outfall to the sea at Arklow. The modelled catchment stops short of Arklow town as Arklow was subject to separate analysis as part of the Arklow flood relief scheme.

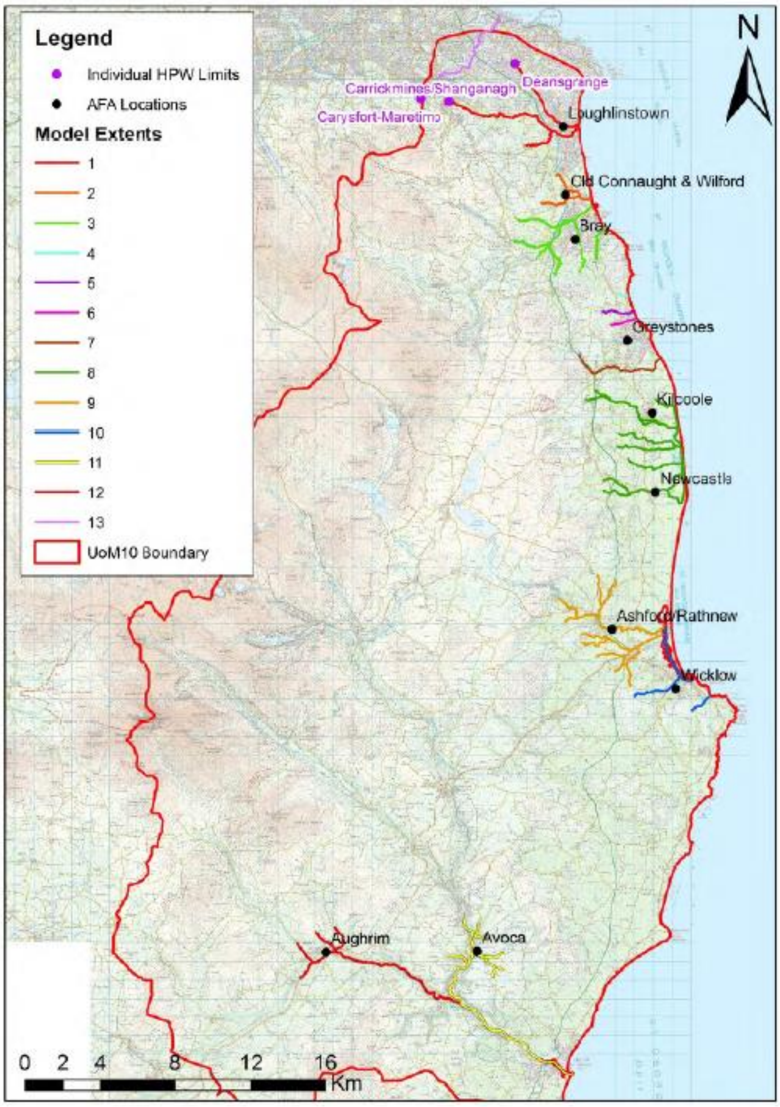


Figure 5-2: Location of Models within CFRAM HA10

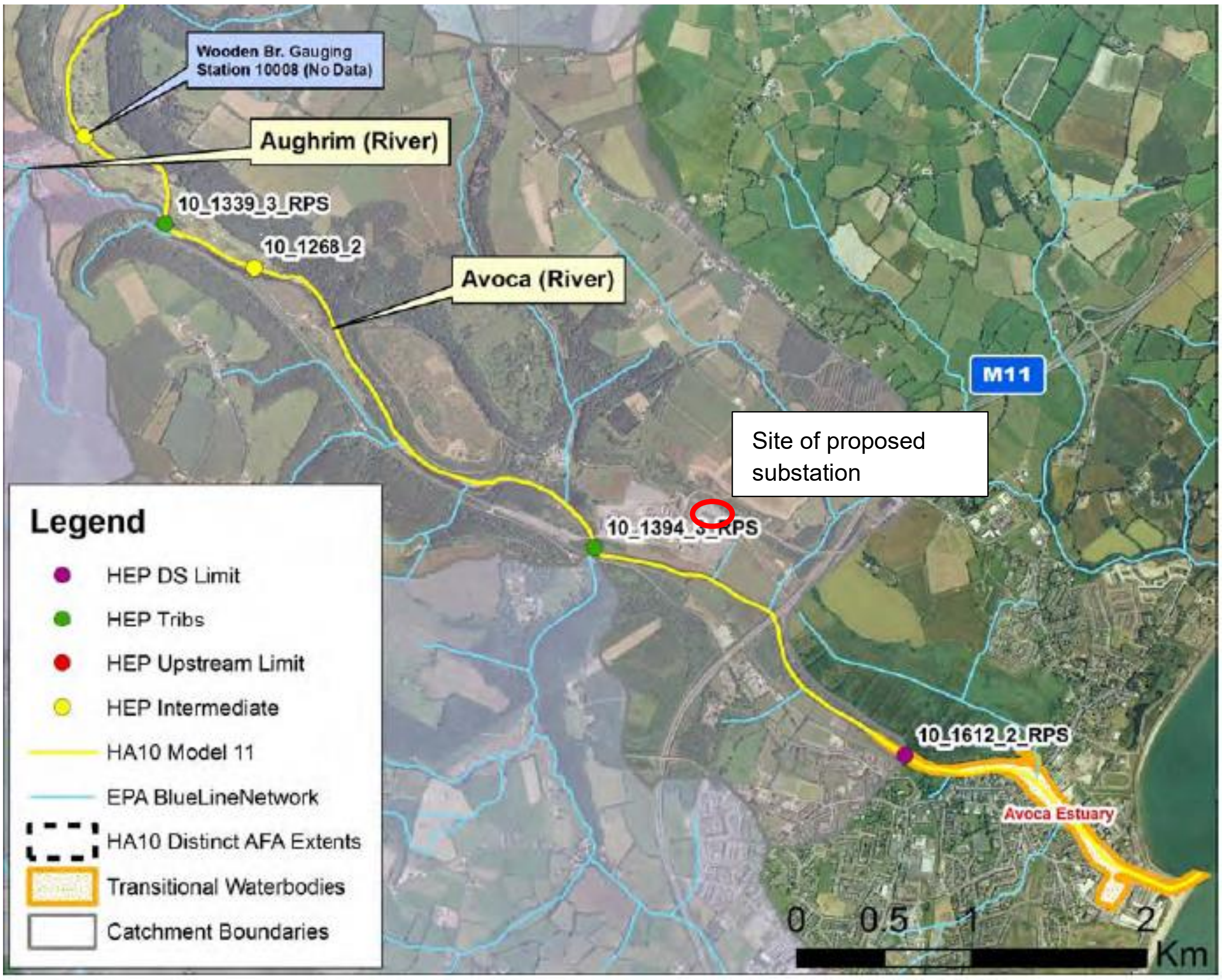


Figure 5-3: Flow estimation points within Avoca model

The hydrological estimation points (HEP) are shown in Figure 5-3. The site lies approximately 3.5km upstream of Arklow Harbour, located between main river HEP points 10-1268-2 and 10-1612-2-RPS.

Flow estimates were undertaken using the statistical method of flood frequency analysis, where an index flood is estimated and multiplied by a growth curve to obtain peak flow estimates at higher return periods.

QMED estimation in this report has been undertaken using the Flood Studies Update (FSU) physical catchment descriptor (PCD) equation, adjusted by a suitable pivotal site. For the Avoca model, the pivotal site chosen was the Rathdrum gauge, resulting in an adjustment factor of 1.33 (ratio of observed to catchment descriptor QMED). This gave QMED values of 615.24 m^3/s and 645.36 m^3/s for HEP points 10-1268-2 and 10-1612-2-RPS respectively.

It should be noted that the study also included rating reviews of both the Rathdrum and Knocknamohill gauges, which updated the rating equations at both gauges, extended the record from 2004 to 2010, and produced an updated AMAX record for each gauge. The impact of the updated and extended record was to increase the QMED at both gauges (6% increase at Rathdrum, and 48% increase at Knocknamohill).

Growth curves for all HEP's were estimated using the pooling group method, which combines growth curves from hydrologically similar gauging stations. Similarity was based on the Region of Influence (RoI) approach (also used in Flood Estimation Handbook (FEH)), using the distance measure from FSU (based on AREA, SAAR, BFI). Because of the climatic differences between the eastern and other parts of the country, the choice of pooling stations was restricted to 92 stations located in the eastern and south-eastern regions seen in Figure 5-4. Although not explicitly mentioned, it appears AMAX data for these stations includes data up to and including the 2010 hydrometric year.

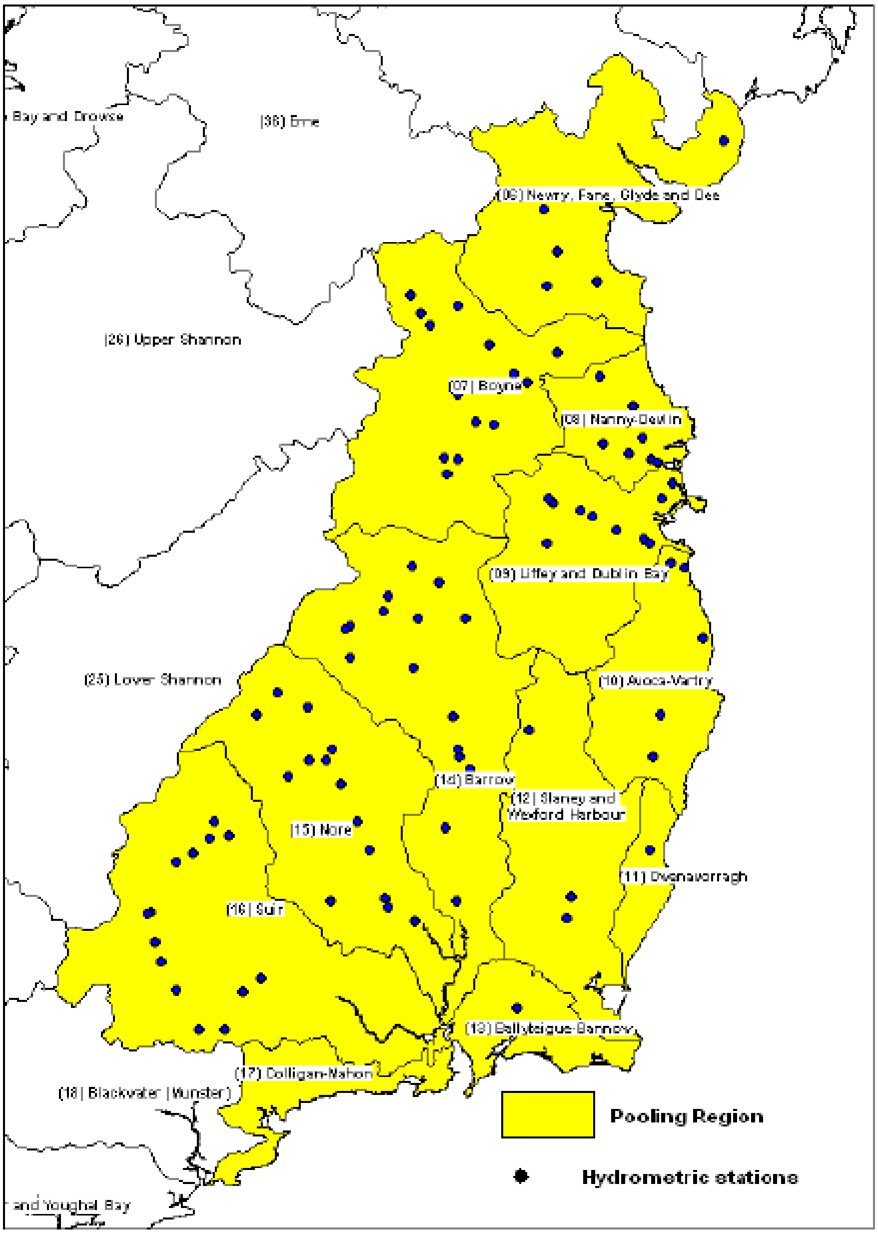


Figure 5-4: Location of 92 gauging stations within Eastern and South Eastern regions

In order to provide spatial consistency for the modelling, the growth curves were then rationalized by catchment area to provide generalized growth curves. For catchment areas greater than 200km^2, the report recommends the use of the **generalized** growth curve, shown in Table 5-2.

Table 5-2: Flood frequency estimates in Eastern CFRAM report for Avoca at Arklow

AEP	Return period	Growth factor (index flood QMED)	Flood frequency estimate	
			10-1268-2	10-1612-2-RPS
50%	2	1	161.62	164.62
20%	5	1.281	207.04	210.88
10%	10	1.478	238.87	243.31
5%	20	1.685	272.33	277.38
4%	25	1.755	283.64	288.91
2%	50	1.989	321.46	327.43
1%	100	2.248	363.32	370.07
0.5%	200	2.537	410.03	417.64
0.2%	500	2.975	480.82	489.74
0.1%	1000	3.351	541.59	551.64

5.3.2 Arklow CFRAM Flood Mapping – Hydrology and Hydraulics Report, Hydro Environmental Ltd, November 2015

Flood frequency estimates in this report use the same statistical method of estimating the index flood and growth curve to provide flow estimates for less frequent events.

Common index floods used are QBAR - the average of the annual maximum record, having a return period of approximately 2.3 years and QMED – the median of the annual maximum record, having a 50% annual exceedance probability. Growth curves for use with QBAR are therefore not directly comparable with those for use with QMED, however they can be amended to an equivalent growth curve for use with QMED.

The report considers a number of index flood estimates:

Table 5-3: index flood estimates in the Arklow CFRAM report

Method	Index flood m^3/s	Comment
FSU PCD QMED adjusted	169	Used Rathdrum as a pivotal site
FSR QBAR catchment characteristic equation	247	Report states that this equation overestimates QBAR compared to observed by factor of 1.33 at Rathdrum and by a factor of 1.61 at the Knocknamohill gauge
QBAR from average specific flow of 0.36 m^3/km^2	235	Based on the upper 66% confidence value of gauged QBAR at Rathdrum and Knocknamohill
QBAR from FSR rainfall-runoff	340	

Although the report states that the FSR QBAR catchment characteristic equation overestimated compared to gauged QBAR by a factor of 1.33 at the Rathdrum gauge and a factor of 1.61 at the Knocknamohill gauge, this index flood figure was chosen. The equivalent QMED figure (50% AEP) is 229 m^3/s.

A number of methods were used to generate growth curves for comparison, including FSR regional growth curve for Ireland, FSR rainfall-runoff, Bruen et al (2005) growth curve for Dublin area, FSU pooling, and single site analysis. The FSU pooling group was dominated by stations in the west and produced a very flat growth curve compared to the single site growth curves for Knocknamohill or Rathdrum. It was considered that there was insufficient gauged data available from similar catchments in the eastern region i.e. mountainous, steep gradients and impervious. The chosen method involved averaging the growth factors from single site analysis of 4 gauging stations considered to be similar to the Avoca catchment: Slaney at Scarrawalsh (12001), Owenavorragh at Boleany (11001), both flashy rivers the east region, Avonmore at Rathdrum (10002) and Aughrim at

Knocknamohill (10028), together with Bruen's Dublin growth curve. It should be noted that the Slaney catchment area is 1.6 times larger than the Avoca catchment to Arklow, and the Owenavorragh catchment is 4 times smaller. The final flow estimates are given in Table 5-4.

Table 5-4: Flood frequency estimates in Arklow CFRAM report for Avoca at Arklow

AEP	Return period	Growth factor (index flood QBAR)	Flood frequency estimate
50%	2	0.925	229
20%	5	1.296	315
10%	10	1.533	375
4%	25	1.832	453
2%	50	2.053	505
1%	100	2.275	560
0.5%	200	2.496	616
0.1%	1000	3.030	746

5.4 Update of index flood

The FSU portal contains gauging information up to 2004 and the Eastern CFRAM report used data up to 2010. There is therefore a significant amount of additional gauged data available since these studies were completed.

The AMAX series for both gauges within the catchment were taken from the Eastern CFRAM report, which provided AMAX data to 2010 using the updated rating equations. As these ratings differ from those used by the EPA to produce the 15 minute flow record on the Hydronet site (http://www.epa.ie/hydronet/), the 15 minute level data was downloaded, and the AMAX for 2011-2019 hydrometric years extracted. Using the updated rating equations, these were then converted to AMAX flow, increasing the record at Rathdrum to 61 years, and Knocknamohill to 31 years. Two other EPA gauges are located within the catchment: Avonmore at Avonmore House (10039), and Avoca at White Bridge (10044). The Hydronet site states that White Bridge gauge is not suitable for high flow analysis. No comment is made regarding the Avonmore House gauge. AMAX data for Avonmore House has been extracted from the EPA 15 minute flow record, however, given that no comment can be made on the accuracy of the rating or suitability for high flow analysis, this data must be viewed as having high uncertainty. The resulting AMAX record for each site is in Table 5-5. The table also shows QMED from the gauged data, the specific flow based on this figure, and a comparison of the gauged QMED with that predicted by FSU PCD equation.

Table 5-5: AMAX data gauges within Avoca catchment

Hydrometric year	Rathdrum (10002)	Knocknamohill (10028)	Avonmore House (10039)
1952	55.29		
1953	66.08		
1954	90.57		
1955	96.92		
1956	140.82		
1957	89.49		
1958	78.80		
1959	84.55		
1960	162.1		
1961	80.18		
1962	88.41		
1963	90.95		
1964	77.93		
1965	266.64		
1966	94.40		
1967	69.22		
1968	99.43		
1969	75.24		
1970	74.46		
1971	88.48		
1972	66.49		
1973	74.03		
1974	65.35		
1975	37.95		
1976	93.14		
1977	116.59		
1978	112.64		
1982	51.13		
1983	51.91		
1984	75.74		
1985	155.32		
1986	23.16	45.63	
1987	62.57	45.35	
1988	-	36.94	
1989	68.11	37.86	
1990	86.97	46.02	
1991	115.4	35.08	
1992	97.54	44.63	
1993	56.67	51.79	
1994	87.93	82.63	
1995	72.65	118.55	
1996	57.26	65.58	
1997	133.74	67.76	
1998	69.88	67.21	
1999	60.35	41.43	
2000	-	131.17	

Hydrometric year	Rathdrum (10002)	Knocknamohill (10028)	Avonmore House (10039)
2001	-	-	
2002	-	-	
2003	69.20	-	
2004	108.64	142.52	50.4
2005	69.70	49.35	30.8
2006	95.58	65.58	29.4
2007	107.23	116.77	43.1
2008	63.86	91.62	32.0
2009	259.96	220.40	92.3
2010	78.12	68.2	23.3
2011	160.86	68.20	66.3
2012	123.78	130.60	58.9
2013	102.52	149.85	44.5
2014	142.58	79.80	56.8
2015	157.71	131.03	68.3
2016	63.32	151.21	28.1
2017	168.64	47.14	71.6
2018	108.47	139.43	49.7
2019	82.47	142.82	40.8
QMED	86.97	74.00	47.1
Upper 68% confidence	92.06	79.54	52.81
FSU PCD QMED unadjusted	64.22	43.15	31.35
Catchment area km^2	230.89	202.92	96.74
QMED specific flow m^3/km^2	0.377	0.365	0.487

Several points are noteworthy from the table. First that the 9 years since 2010 contain a significant number of large events. At Rathdrum, 7 of the 9 years have AMAX greater than updated QMED and contain the 3rd, 5th and 6th highest recorded flows out of the 61 year record. At Knocknamohill, 8 of the 9 years are greater than QMED, and contain the 2nd, 3rd, 5th and 6th highest flows of the 31 year record. At Avonmore, 6 of the 9 years exceed QMED, and contain the 2nd, 3rd, 4th, 5th and 6th highest flows of the 16 year record. Compared to the QMED figures in the Eastern CFRAM report, there is little change in QMED for Rathdrum (negligible increase from 86.85 to 86.97 m^3/s) but results in a more significant increase of 13% in QMED for Knocknamohill (65.63 to 74 m^3/s).

Secondly, for all 3 gauges, the unadjusted FSU catchment descriptor equation significantly underestimates QMED, by factors varying from 1.35 to 1.71.

Although local data is not free of inaccuracy and uncertainty, it is regarded as more accurate than flow estimates based solely on regression equations using catchment descriptors. Both the FSU and UK FEH recommend use of gauged sites as donors to adjust the catchment descriptor estimates of QMED for ungauged sites. The FSU pivotal site methodology involves use of one suitable donor site to adjust QMED for the ungauged site by the ratio of QMED observed and QMED based on catchment descriptors. Updated recommendations for UK FEH uses multiple donors (up to 6) to make the same adjustment, with a moderating term for geographical distance between the gauged and ungauged site included.

With 61 years of data, and the rating having been reviewed, the Rathdrum gauge is considered the most suitable donor. The updated QMED for the Avoca River at Arklow is therefore based on the FSU PCD estimate for the catchment, adjusted by the ratio of observed QMED (inverse application of urban adjustment to give inferred value for rural catchment) and the FSU PCD QMED, which is 1.43. In order to be precautionary, and to account for any uncertainty in the gauged data, this ratio will be based on the upper 68% confidence figure, giving an adjusted QMED value of 192.06 m^3/s.

Table 5-6: FSU QMED estimate for Avoca River at Arklow

Subject rural QMED	132.71
Subject urban QMED	133.97
Pivotal gauged QMED	92.06
Pivotal adjustment factor QMED	1.43
Subject adjusted QMED	**192.06**

5.5 Growth curve and flood frequency estimation

The two CFRAM reports provides a number of possible growth curves with which to estimate flood frequency figures, shown in Figure 5-5. The Eastern CFRAM preferred curve is a generalized curve, based on the median of a number of site specific growth curves for catchments greater than 200km^2, generated for hydrological estimation points within the whole Eastern study area. There are also three values quoted in the report for the growth curve for the Avoca at Arklow (Table 5.15, HEP 10_1612_2_RPS), which are site specific rather than generalized, although the figure for the 0.5% AEP growth factor appears high and could be a mistype. The growth factors are tabulated below in Table 5-7 and graphed in Figure 5-5.

Single site growth curves (assuming EV1 distribution, which is recommended by FSU for single site analysis) and standardized AMAX values for Rathdrum and Knocknamohill are also shown in the figure. These are based on the updated AMAX record shown in Table 5-5.

Table 5-7: Growth curves reported in Arklow and Eastern CFRAM reports

		Growth factor				
AEP	Return period	Eastern CFRAM generalised	Eastern CFRAM site specific	Arklow CFRAM preferred	Rathdrum single site (EV1)	Knocknamohill single site (EV1)
50%	2	1	-	1	1	1
20%	5	1.281	-	1.376	1.406	1.528
10%	10	1.478	-	1.638	1.674	1.878
5%	20	1.685	-	-	1.932	2.213
4%	25	1.755	-	1.978	2.013	2.319
2%	50	1.989	-	2.205	2.265	2.647
1%	100	2.248	2.248	2.533	2.515	2.972
0.50%	200	2.537	2.975	2.690	2.764	3.297
0.20%	500	2.975	-	3.000	3.092	3.724
0.10%	1000	3.351	3.354	3.258	3.341	4.047

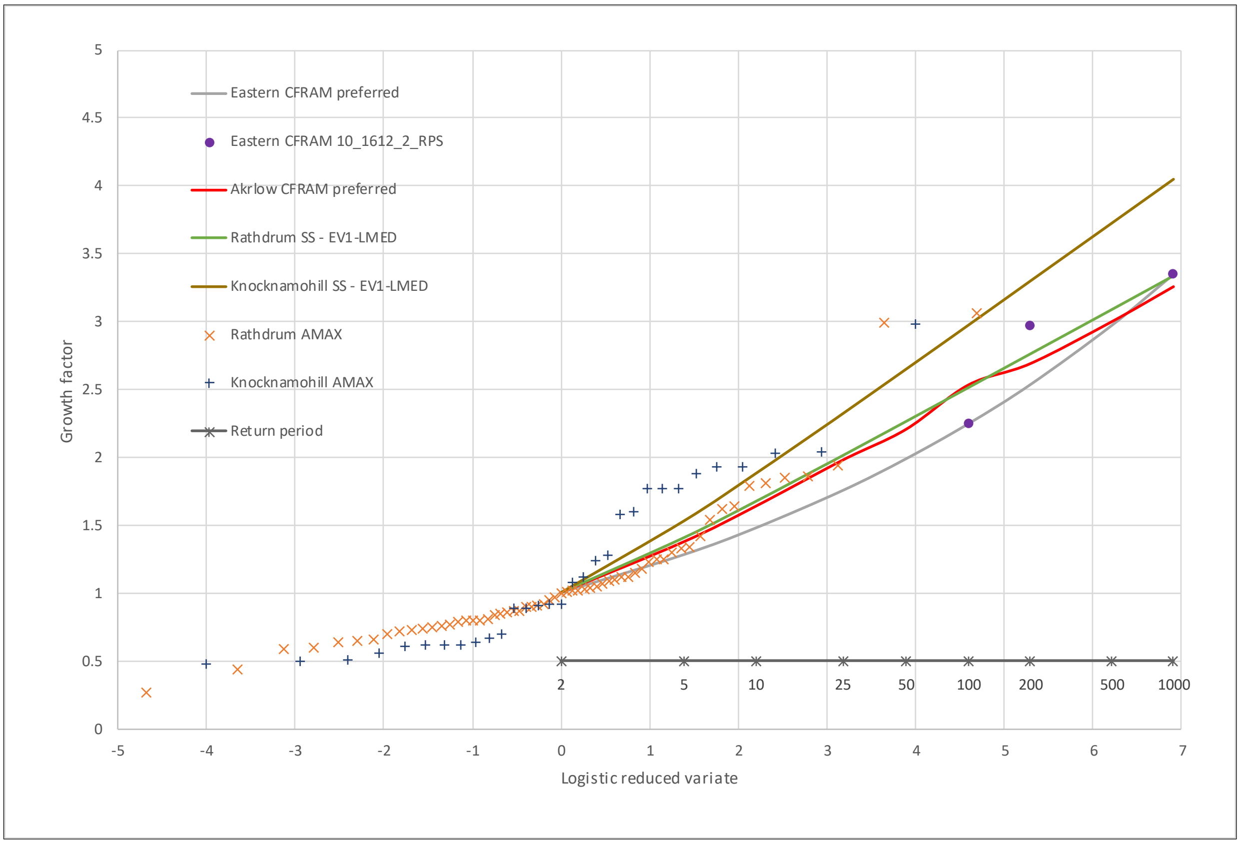


Figure 5-5: Growth curves presented in CFRAM reports

*note that the reported Arklow CFRAM growth factors are applicable to QBAR. The curve in Figure 5.5 uses corrected factors applicable to QMED.

The figure indicates that the 0.1% AEP event estimated growth factor for Arklow CFRAM, Eastern CFRAM generalized, Eastern CFRAM site specific and Rathdrum single site are close, ranging between 3.258 and 3.354. For the 1% AEP, both Eastern CFRAM estimates are lower than the Arklow CFRAM and Rathdrum single site. The Knocknamohill single site curves lies well above these curves.

The Knocknamohill gauge is classed as "B" by FSU, i.e. a site with good high-flow rating but there are some concerns as to the quality of the flood-flow rating. The period of record here is 31 years, meaning flood frequency estimates are only reliable for somewhere between a return period of 15 and 60 years, depending which guidance is followed. Either way, extrapolation of this period of record to the 0.1% AEP event is highly unreliable with a high standard error, and given the quality of the flood-flow rating, this curve cannot be considered to give a robust estimate of 0.1% AEP growth factor.

Similar arguments may be made for the Rathdrum single site curve, except that it has double the number of years of record, so is somewhat more reliable, at least for lower return period estimates. The standard error of the 1% AEP growth factor estimate will likely be considerably less than the 0.1% AEP growth factor estimate.

The Eastern CFRAM curve uses data up to 2010 but is a generalized equation, based on the median of a number of site specific growth curves for catchments greater than 200km^2, generated for hydrological estimation points within the whole Eastern study area. The three values quoted in the report for the growth curve are site specific rather than generalized, however the 0.1% AEP growth factors are very similar for both.

Both the generalized and site specific Eastern CFRAM report estimates are based on pooled analysis, a method which has been shown to have a smaller standard error than single site, assuming homogeneity of the pooling group. The Arklow CFRAM preferred growth curve does not strictly follow the pooling methodology but averages the growth factors from single site analysis of 4 gauging stations considered to be similar to the Avoca catchment:, together with Bruen's Dublin growth curve, and can therefore be considered more statistically robust than extrapolation of a single site curve.

Based on the above, and because it is site specific and gives the largest growth factor of the 3 "pooled" curves, that still compares well to the Rathdrum single site curve, the site specific Eastern CFRAM 0.1% AEP growth factor of 3.354 is considered the most appropriate to adopt for this study. This gives a 0.1% AEP peak flow estimate of 644 m^3/s.

The Eastern CFRAM 1% AEP growth factor estimates are lower than either the Arklow CFRAM or the Rathdrum single site estimates. Taking a precautionary approach, and because there is more confidence in the single site curve for lower return periods which agree well with the Arklow CFRAM estimates, the Arklow CFRAM 1% AEP growth factor of 2.533 is adopted for this study, giving a 1% AEP peak flow estimate of 486m^3/s.

5.6 Climate change

Most recent specific advice on climate change allowances for flood risk is given in Flood Risk Management, Climate Change Sectoral Adaptation Plan, OPW, September 2019. Table 5-1 of that publication suggests peak flood flows will increase by 20% under the Mid-range and 30% under the High-end future scenarios respectively, whilst the mean sea level rise can be expected to be 800mm and 1000mm under each scenario.

After consultation with SPL on preferred level of risk, a 20% climate change allowance will be applied to the peak flow estimates and a sea level rise of 800mm to the tide levels. This represents the mid-range future scenario.

5.7 Development of flood hydrograph

The flood frequency analysis described above produces only peak flow estimates for each event, not a full flood hydrograph. The recommended methodology to develop a flood hydrograph is contained in FSU Volume III – Hydrograph Analysis. For ungauged catchments, hydrograph shape parameters are estimated using catchment descriptors. A hydrologically similar pivotal site is then chosen, and the hydrograph shape parameters at the pivotal site are adjusted to achieve a best fit curve to the observed data for that site, this pivotal site adjustment is then applied to the hydrograph shape parameters for the ungauged site. Finally, the hydrograph shape is scaled to the estimated peak flow estimates.

The hydrological similarity between the ungauged and potential pivotal site is based on BFIsoil (geology), FARL (routing) and S1085 (slope). The FSU portal hydrograph width module was used to identify possible pivotal sites. The most hydrologically similar pivotal site available that had catchment descriptors within acceptable ranges was found to be 16012 Tar Br. Ranges considered acceptable are given in the table below, in accordance with various previous CFRAM reports (eg Shannon CFRAM, Jacobs).

Table 5-8: Acceptable ranges of catchment descriptors for hydrograph shape pivotal site

AREA	Between 0.25 and 4 x area of subject site
BFIsoil	± 25%
SAAR	± 25%
FARL	± 10%
URBEXT	± 2.5%
S1085	± 50%
ARTDRAIN	± 10%
ALLUV	± 3%

The resulting 1% AEP and 0.1% AEP hydrographs for the Avoca River at Arklow, including a 20% increase to allow for climate change, are shown in Figure 5-6. The figure shows the 1% AEP plus climate change peak flow is only slightly lower than the current day 0.1% AEP peak flow (632 m^3/s compared to 644 m^3/s), whilst the addition of climate change to the 0.1% AEP event results in a peak flow of 770 m^3/s.

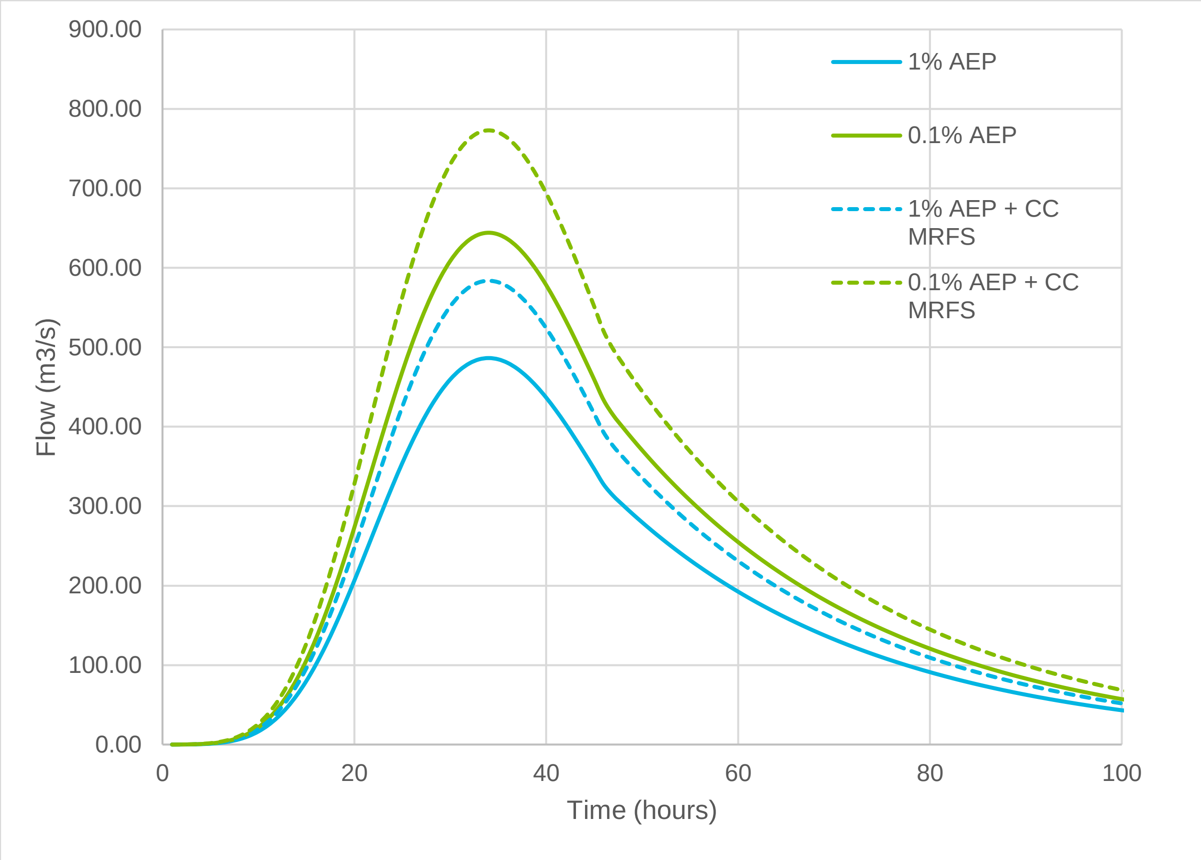


Figure 5-6: 1% and 0.1% AEP hydrographs for the Avoca River at Arklow

5.8 Joint probability

As stated above, whilst the main flood risk to the site is from the Avoca River, the river discharges to the sea at Arklow Harbour, some 3.5km downstream; therefore, whilst the site is not at risk of coastal flooding, water levels in the river adjacent to the site may be influenced by tide levels as well as fluvial flow. Appropriate tide levels to use as a downstream boundary for the model are therefore required, with due consideration of the joint probability of coincidence of high fluvial flows and high tides.

Joint probability can only properly be assessed using actual observed data. The Eastern CFRAM report undertook an analysis of the correlation between total water levels (i.e. tide plus surge) at Dublin Port and fluvial water levels in the Eastern (HA10) region rivers. This analysis found that the correlation between total water levels and fluvial flood flow within the region can be considered to be negligible. The report recommended a simplified conservative approach whereby the 50% AEP level or flow is maintained for one mechanism while the whole range of design events for the other mechanism is tested and vice versa. In the context of this study, this implies matching both the 1% and 0.1% AEP event hydrographs with a 50% AEP tide level at the downstream boundary.

The Arklow CFRAM report took a similar simplified approach but matched the fluvial events and used a high astronomical spring tide level of 0.6mOD.

5.8.1 Arklow Harbour Tide level

EPA Hydronet provides 15 minute level data for Arklow Harbour from August 2003 to present. This gives 17 years of AMAX data, sufficient to provide a robust estimate of the median (50% AEP) tide level. The AMAX data and 50% AEP tide level estimate are given in Table 5-9: Arklow Harbour (10060) observed AMAX water levelsTable 5-9.

Table 5-9: Arklow Harbour (10060) observed AMAX water levels

HYDROMETRIC YEAR	WATER LEVEL (mOD)
2003	0.915
2004	1.372
2005	1.037
2006	1.025
2007	1.185
2008	0.855
2009	1.039
2010	0.889
2011	0.979
2012	1.089
2013	1.149
2014	1.044
2015	1.202
2016	0.983
2017	0.875
2018	1
2019	1.437
50% AEP	**1.037**

The Irish Coastal Protection Strategy Study (ICPSS) provides extreme water levels that includes tide and surge. Table 5-10 from the South East Coast report provides the following figures for the model nodes nearest Arklow Harbour and Figure 5-7 displays their location.

Table 5-10: ICPSS tide levels near Arklow Harbour

Return period	Annual exceedance probability	Point 17 (E326226, N174323)	Point 18 (E325596, N171445)	Interpolated for Arklow Harbour
2 year	50%	106	1.04	1.05
5 year	20%	1.16	1.14	1.15
10 year	10%	1.24	1.22	1.23
20 year	5%	1.32	1.3	1.31
50 year	2%	1.41	1.39	1.40
100 year	1%	1.49	1.47	1.48
200 year	0.5%	1.57	1.55	1.56
1000 year	0.1%	1.76	1.73	1.75

Figure 5-7: ICPSS nodes closest to Arklow

The interpolation of the ICPSS model points gives a 50% AEP tide and surge level of 1.05mOD. This agrees well with the 50% AEP estimates from the observed data.

As a slightly higher figure that also includes consideration of surge, a 50% AEP tide level of 1.05mOD was adopted for the study when running both the 1% and 0.1% AEP fluvial events.

6. Fluvial hydraulic modelling

The Avoca River bounds the west and south sides of the wider industrial estate and has been identified as a potential source of fluvial flooding.

An assessment of the 1% and 0.1% AEP events, with and without climate change, has been undertaken to understand the flood risk. A single hydraulic model has been constructed of the Avoca River consisting of a one dimensional element representing the river channels and structures built in Flood Modeller and a two dimensional element representing the floodplain constructed in Tuflow, both being industry standard hydrodynamic modelling software.

6.1 Baseline modelling

6.1.1 One dimensional channel model

A one dimensional model of the Avoca River was created from surveyed cross sections, extending from Shelton Abbey to Arklow Harbour. No new survey information was gathered for this study and to create the full model extent, the cross sectional data was a combination of surveys from 2001, 2006, 2015, 2019. Details of the survey can be found in Appendix B. It should be noted that there is no LiDAR data available around sections 001-004 and the 1D sections were extended using 10m contour data. This is likely a simplification of the geometry but is not considered to affect model results. At the downstream extent of the model, the 2019 survey did not sufficiently represent the left side (north side) of the channel. The topographic survey states that the levels 'continue the same' from the last survey point at each section, which is approximately in the centre of the channel. This is not standard procedure and it is not understood why the survey only extended over part of the channel. For the data gaps, bathymetry data from 2006 was used to interpolate bed levels. Given the distance between these sections and the site it is not considered that these topographic modifications of the channel will affect results.

The topographic surveys were used to represent the channel geometry as well as structures. The model consists of 58 cross sections, 3 bridges and 1 weir, with between 50 – 150m spacing throughout the reach. This spacing was deemed suitable given the wide uniform nature of the channel. All bridges crossing the Avoca River in the reach were modelled. Where the downstream section of the bridge was not surveyed, a copy of the upstream face was used. During the model runs, all structures were assumed to be clear of obstruction.

The upstream extent of the 1D channel is located 580m upstream of the access bridge to the site. This allows for the model to stabilise before reaching the site and any potential spill locations. The downstream limit of the model is located at Arklow harbour.

Section labelling around the site can be seen in Figure 6-1.

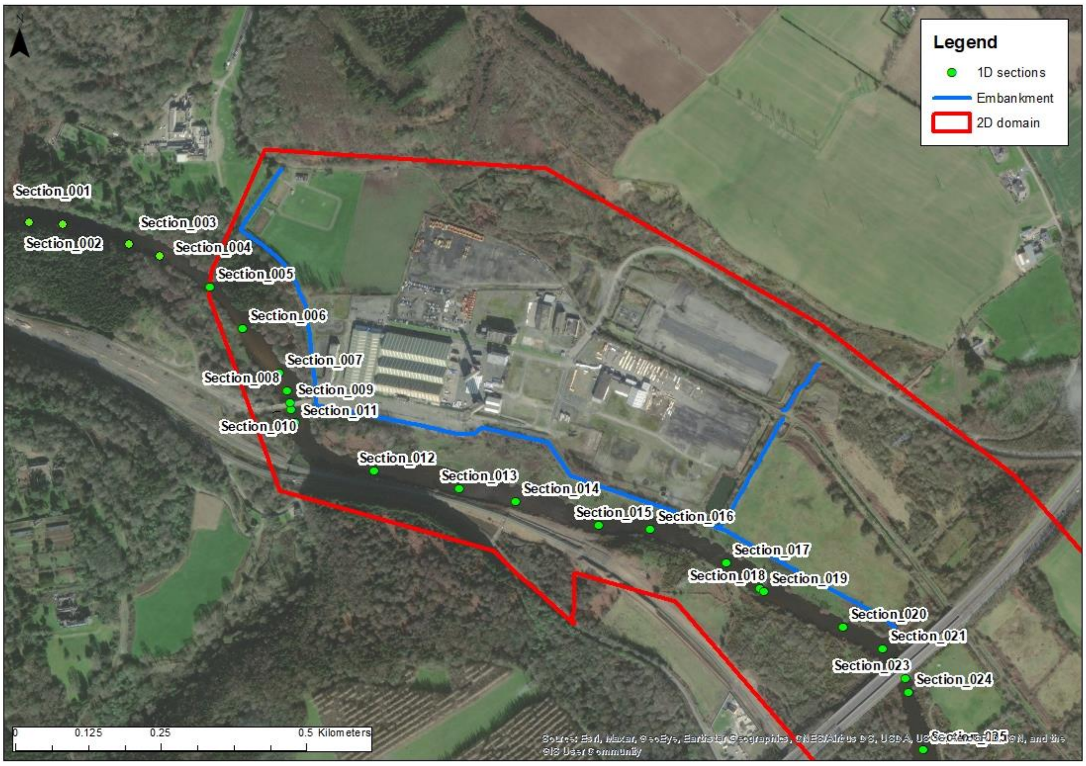


Figure 6-1: 1D node locations

The inflow hydrographs, as calculated in Section 5 of this report, were applied to Section 001 in the hydraulic model. The downstream boundary was represented as a constant Head Time boundary, of the 50% AEP tidal level.

Channel and bank Manning's 'n' roughness values were selected based on photographs, the site visit and existing modelling of the watercourse. In-channel roughness was set at 0.04 as this was consistent with previous modelling representing a clean winding channel with some pools and shoals. Given the flat, tidally influenced nature of the watercourse, 0.04 was deemed appropriate. Only minor sections of the floodplain were represented in the 1D model and these were set at 0.06 for scrubby banks and 0.08 for forested banks.

6.1.2 Two dimensional flood plain and coastal model

The 1D channel model was linked to a 2D domain (ground surface) to model the overland flood mechanisms. The 2D hydraulic model contained the following elements:

- Ground surface using 0.5m LiDAR Digital Terrain Model (DTM);
- 1D/2D links to allow free flow between the river channel and floodplain based on LiDAR levels and smaller sections of surveyed top of bank topography;
- Roughness layer depicting different surfaces based on opensource mapping, aerial photography and OSI vector mapping where available - representing buildings (n = 0.5), roads (n= 0.02), urban areas (n=0.07), wooded areas (n=0.08), overgrown scrub area (n=0.06), rough concrete yards (n=0.025), water (n=0.015), and grassland (n= 0.04);
- Buildings are represented by a roughness of 0.5;
- Additional topographic survey was used to refine the embankment around the industrial estate as well as across the Substation site;
- Cutting of the canal bed to give it a smoother profile;
- Further LiDAR refinements around bridge decks and at gaps in the LiDAR to best represent the topography.

Further details of the model build can be found in Appendix C.

6.1.3 Ground truthing

Ground truthing of the 0.5m LiDAR used to represent the 2D floodplain was undertaken using surveyed top of bank levels as well as levels across the site from the 2018 survey. This exercise was undertaken to ensure that the LiDAR provided a reasonable representation of the ground surface from which the flood maps would be generated.

In channel survey levels and levels around bridges were removed from the assessment as these were likely to be inaccurately represented in the LiDAR due to the resolution of the data and the inability for channel bed levels to be captured.

A total of 51 points were compared in the vicinity of the site to assess how well the LiDAR represented ground conditions. Levels between the survey and LiDAR were seen to vary by between -0.36m – 0.21m. The largest differences were noted next to the Avoca River and in the open land to the east of the site where there is more dense vegetation. Table 6-1 shows that of the 51 points compared, 96% displayed a difference of less than 300mm between the LiDAR and the survey, with 72% of the compared points having a difference of less than 100mm.

Based on this assessment, the LiDAR is considered to be a reasonable representation of the ground surface and suitable for the modelling exercise within this study.

Table 6-1: Results of ground truthing (LiDAR vs topographic survey)

	Number of points out of the total points tested	**Percentage**
LiDAR more than 300mm lower than the survey	0 / 51	0%
LiDAR between 100 – 300mm lower than the survey	1 / 51	2%
LiDAR within 100mm of the survey	37 / 51	72%
LiDAR between 100 – 300mm higher than the survey	11 / 51	22%
LiDAR more than 300mm higher than the survey	2 / 51	4%

6.1.4 Model run parameters

The 2D domain was set at a 4m grid size. This was deemed appropriate as the majority of the study area was rural or open space and there were no complex alleyways or walled off areas that require a finer resolution.

The 1D/2D model was run unsteady, i.e. time varying flow, for the required return periods, the 1% and 0.1% AEP events with and without climate change. This allowed for the flood progression to be fully assessed in both the 1D channel and the 2D floodplain. It also allowed for full representation of the flow pathways and duration required to fill of the flood cell at the industrial site. A 1 second 1D timestep and 2 second 2D timestep were used for all simulations.

Model run parameters were kept as default.

6.2 Breach scenario

To assess the residual risk to the site, two breach scenarios with differing start times were established.

The breach location was taken as the low point in the embankment to the west of the industrial estate where spill first occurs in the baseline. This would be considered a weaker point in the embankment as more overtopping would occur, which is the typical cause of breach in fluvial scenarios. This may be a simplification of the process but is appropriate in the absence of information relating to embankment stability.

A polygon was applied to the model to represent the breach and contained the following attributes based on guidance from the Environment Agency detailed in their Breach of Defence Guidance Technical Note:

- 40m length of breach - based on an earth embankment and fluvial river source;
- Depth of full breach set to level at toe of embankment;
- Two scenarios were undertaken – one where the breach commences when the water level reaches ¾ of the defence height as set out in the guidance, and one where the breach occurs once overtopping commences i.e. at the embankment crest elevation;
- Duration from breach commencement to full breach is instantaneous;
- It is assumed the breach will not be repaired during the event.

The simulations were run for the 0.1% AEP current day event as assessing residual flooding is about understanding risks that remain after mitigation options rather than necessarily informing design levels on site. The topography on site, with water levels in the Avoca River Park controlled by ground levels to the east, also meant there was unlikely to be a significant difference in water level between a current day and climate change scenario as the basin would effectively be filled in the current day event with no increase available in the climate change event.

6.3 Arklow Flood Relief Scheme

The Arklow Flood Relief Scheme is currently being designed and comprises several elements , which are discussed in Section 2.3. The scheme predominately consists of measures to contain the river and tidal waters in the channel through the reach of the River Avoca through the town and channel lowering at Arklow bridge to reduce the hydraulic constraint at the bridge. All but the debris catcher are considered unlikely to affect flood levels at the site. This is due to the scheme being designed largely to protect against tidal flooding, and localised elements such as wall and embankment raising will not affect water levels at the site during a fluvial event, as water will be able to discharge out to sea.

The debris catcher has the potential to affect fluvial water levels at the site as it forms a constriction in the channel which is located further upstream. No details of debris catcher were available and therefore a constriction to the channel of 50% has been taken as a conservative assessment of the impact of the debris catcher with debris build up. To represent this restriction, the 1D baseline model was altered at cross section 32 (approximate location of debris catcher) by raising bed levels across half the channel to 5mOD. This would effectively remove half the cross sectional area from the river in the same manner a large scale debris catcher would.

This simulation was run for the 0.1% AEP plus climate change (MRFS) scenario as this is the event the site is to be designed to.

6.4 Raising of low point in embankment – proposed development

A major development in Avoca River Park was granted planning permission in 2019, application number 18940. Part of the application was for the embankment to the west of the site to be raised to a consistent level where the low point currently exists.

The low point in the embankment where water first spills into the site is located out with the industrial estate in what is assumed to be Shelton Abbey grounds. The low point in the crest of 5.8mOD extends over 20m before joining up gradually to the surrounding 6.5mOD levels. Lower than average levels (below 6.5mOD) are experienced over a total length of 70m.

The baseline embankment line was raised in order to model this development option and understand what impact it would have on flood risk to the site and the surrounding area. As part of a granted planning permission, it is likely that this raising will go ahead and will form the new baseline. It should be noted that in modelling this development option, the embankment is assumed to be sound and capable of holding back floodwater. This will need to be confirmed prior to raising and ongoing maintenance will be required.

Whilst the principal of raising of the embankment has been established at the works granted planning permission. The works have not yet been constructed and therefore don't form part of the current baseline. The raising of the flood embankment therefore forms part of the 'with development' assessment

6.5 Sensitivity analysis

No calibration data was available for the site. Therefore, sensitivity checks were carried out on the hydraulic model parameters where they are considered to be inherently uncertain to explore the effect on model results.

The aim is to understand the range of model results that could be obtained with variation of these parameters. The intention is not to evaluate an accuracy range or otherwise quantify uncertainty; but to give an indication of the influence certain parameters have and identify if there are significant or disproportionate influences.

The model parameters tested for the 0.1% AEP event were:

- Flow;
- Manning's roughness;
- Downstream boundary;
- Structure blockages.

6.5.1 Flow

Increasing the flow by 20% increased the 0.1% AEP event channel water levels by between 75 and 450mm. These maximum increases are observed in the upstream extent of the model, with the lower increases at the downstream extent of the model.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 1 Appendix D.

Flooding in the 2D domain is seen to increase most significantly in the upper portions of the model, primarily affecting the spill over the embankment into the site. Flood extent is seen to increase significantly across the entire industrial estate with depths of between 1.8-2.9m where there had previously been no flooding. Elsewhere, floodplain extents are increased less significantly with depth increases in the order of 150-300mm.

Reasonable increases in channel and floodplain depths indicate that the model is sensitive to an uplift in flow. Whilst the increase in flood depth is not insignificant, the flow estimates used in the baseline model are deemed to be appropriate as they are based on best practice hydrological assessments. It is recommended that uncertainty in flows is addressed by adoption of an appropriate freeboard allowance.

6.5.2 Manning's roughness

Increasing the roughness by 20% increased channel water levels by between 40mm and 330mm. The largest increases were observed in the upstream portion of the channel with the lowest increases at the tidal boundary.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 1 Appendix D.

Flooding in the 2D domain is seen to increase most significantly in the upper portions of the model, primarily affecting the spill over the embankment into the site. The flood extent is seen to increase significantly across the entire industrial estate with depths of between 1-1.8m where there had previously been no flooding. Elsewhere in the model, floodplain extents are increased marginally with depth increases in the order of 100-200mm.

Reasonable increases in depths in the channel and on the floodplain indicate that the model is sensitive to the roughness values selected. Whilst the increase in flood depth is not insignificant, the roughness values used in the baseline model are deemed to be appropriate as they are based on channel type and geometry. It is recommended that uncertainty in channel and floodplain roughness is addressed by adoption of an appropriate freeboard allowance.

6.5.3 Downstream boundary

Section 5.8 sets out the tidal boundaries and joint probability analysis used in previous studies. The 50% AEP and High Astronomical Tide levels are both determined to coincide with larger fluvial events and the higher of the two, the 50% AEP tidal level, was applied to the baseline model. For the purposes of the sensitivity testing, the High Astronomical Tide of 0.6mOD was applied for the 0.1% AEP fluvial event to assess whether this affected levels at the site.

Tabulated results with changes to channel water elevations at various locations are displayed in Table 1 Appendix D.

Changing the downstream boundary from 1.05mOD to 0.6mOD affects water levels up to cross section 27, which is 500m downstream of Arklow bypass bridge. Channel water levels are seen to decrease between 30mm and 450mm when the high astronomical tide is applied.

Flooding in the 2D domain is reduced from the baseline throughout Arklow town, with decreases between 30-80mm in the marshland area. Upstream of the bypass bridge, water levels remain unchanged.

Altering the downstream boundary between the two recommended tidal levels was not seen to affect water levels and flooding around the site, the 50% AEP tidal event was deemed an appropriate downstream boundary for this FRA.

6.5.4 Blockages

Blockage scenarios were tested for the 0.1% AEP event to assess the impacts on flooding should a structure become partially blocked during a flood event. A total of three structures cross the Avoca River in the modelled reach and have the potential to cause increased flooding if they become partially blocked. There are no anecdotal accounts of any significant blockages at any of the structures. The risk of blockage at the Arklow Bridge is recognised and as a result debris capture is proposed upstream of the bridge as part of the proposed Arklow flood prevention scheme as noted in Section 6.3.

The structures were modelled as partially blocked to 20% of the flow area by reducing the cross sectional area accordingly.

Each blockage scenario was run separately, which assumes that a significant blockage would not occur on two structures at once. Blockage locations are shown in Figure 6-2. Tabulated results with changes to channel water elevations at various locations are displayed in Table 2 Appendix D.

Figure 6-2: Blockage locations

Decreasing the cross sectional area at the three structures increased channel water levels by 180mm, 70mm, and 200mm for blockage scenarios 1, 2, and 3 respectively. An increase in level was experienced up to the upstream extent of the model for scenario 1 and 2 and 1.3km upstream of Arklow bridge for scenario 3.

During blockage scenario 1, depths upstream of the bridge are higher, causing water to overtop the embankment into the site, inundating much of the industrial estate, which was previously not flooded. Depths across the site are between 0.5-1.2m. Flood depths downstream of the site remain largely consistent with the baseline scenarios, with depth increases of around 10mm.

During blockage scenario 2, floodplain depths immediately upstream of the bridge are around 70mm higher than in the baseline scenario, with depths approximately 10mm at the spill location into the industrial estate. This results in slightly more flow spilling over the embankment but it does not inundate the site.

During blockage scenario 3, depths upstream of the bridge in the marshland areas are 50-100mm higher than in the baseline scenario due to increased backing up behind the structure. Depths on the right bank at Arklow south are increased by around 70mm. Water levels upstream of the bypass bridge remain largely unchanged with increases of between 10-40mm. Blockage at the bridge does not impact on flood levels at the spill location at the upstream end of the business park and therefore flood risk at the site.

This sensitivity analysis is not an analysis on the likelihood of blockage, but is an assessment of the severity of flooding impacts should a blockage occur at a particular structure. There was no anecdotal evidence of structure blockage at bridges 1 and 2 and given the high decks and open design, it is considered unlikely they would pose a significant blockage risk. Structure 3 in Arklow has a greater potential to block due to lower soffits and narrower openings, however, a 20% blockage was not shown to impact water levels at the site.

Identifying the structures where blockage may result in increased flooding is useful for targeting either extra maintenance or additions such as trash screens or debris catchers. Close attention should be paid to the access bridge into the industrial estate for any blockage.

7. Pluvial modelling

Whilst the Avoca River is currently the main source of flood risk to the site, pluvial flooding from the catchment behind the embankment also poses a risk. The nature of the site, which is low lying, cut off from natural drainage pathways by the embankments and reliant on a pump system for drainage, may result in it being at increased risk of pluvial flooding.

Several small ditches are seen to run in and around the site. An assessment of the total contributing catchment has been undertaken in this modelling exercise; however, these minor features have not been considered in detail. For the purposes of his assessment, they are assumed to have been infilled meaning that recommended design and level of the platform do not rely on the final design of the ditches.

7.1 Baseline model build

Microdrainage source control software was used to develop a simplified model of the site so that peak water levels could be determined for a range of scenarios.

The baseline model build contained the following elements:

- FSR rainfall derived for Arklow – M5-60: 16.8mm and Ratio R 0.25;
- Cv values of 0.65 for summer and 0.74 for winter were applied to represent the large natural catchment contribution;
- The total catchment of 73ha (industrial estate as well as rural catchment to the north) was divided up based on duration rainfall would take to reach the site;
- A pond structure was used to represent the topography of the wider industrial estate. Total areas were calculated from LiDAR and split into depth bands;
- The outflow control was set as a pump with an assumed constant pump rate. As no pump rate information was available, 2 scenarios were investigated. The first was the 50% AEP greenfield runoff rate for just the industrial estate area and the second was the 50% AEP greenfield runoff rate for the total contributing catchment. Greenfield runoff rates were calculated using the IoH 124 method. Based on the age of the existing arrangement a pump rate equal to that required for the development site is likely to be more representative of the current arrangement.
- The model was run for a range of durations so the software could select the critical duration that gives the peak water level.

7.2 Development scenario

A development run was undertaken using the baseline model, but with a change to the pond area to represent the loss of floodplain as a result of platform raising at the substation site. This scenario assumed that additional attenuation capacity was not provided and is therefore conservative as alternative attenuation or an increase in pump rate would be provided in the drainage design.

7.3 Sensitivity testing

Given the uncertainties associated with the pump rates and drainage in the area, sensitivity testing was undertaken to improve confidence in the peak flood level estimates. These amendments to the baseline model included:

- A scenario where pumps failed for a 24h period. 24h was selected as it is assumed additional transportable pumps could be brought to site within this time period;
- A scenario where the area of the data centre building to the south were raised out of the floodplain and additional attenuation was not provided. It should be noted that the data centre is currently unconfirmed and designs are not finalised. As part of final design, the development should include an adequate drainage design and attenuation for misplaced water, and by not providing any in this sensitivity assessment, it is considered to be conservative.

8. Model results

8.1 Fluvial Baseline

8.1.1 Current conditions scenarios

Hydraulic modelling simulations have been carried out to determine the flood risk to the site under current conditions based on the indicative standard set out under the planning conditions and with an allowance for climate change for design purposes to ensure that the development is provide the appropriate levels of protection over its lifetime.

The development site has been assessed based on the 1%AEP together with the 0.1% AEP with and without climate change (based on the MRFS).

During the 1% AEP current day and with climate change scenarios, spill occurs into the marsh land and on both banks between the upstream extent of the model and Arklow bypass bridge, building to depths of around 1.4m in the current day scenario and 1.8m in the climate change scenario. Some flood inundation is experienced through the town of Arklow. No overtopping of the embankment at Avoca River Park is observed in either the current day or baseline events, and the site remains free of flooding.

Figure 8-1 displays the baseline 1% AEP event. Full flood maps can be seen in Appendix E.

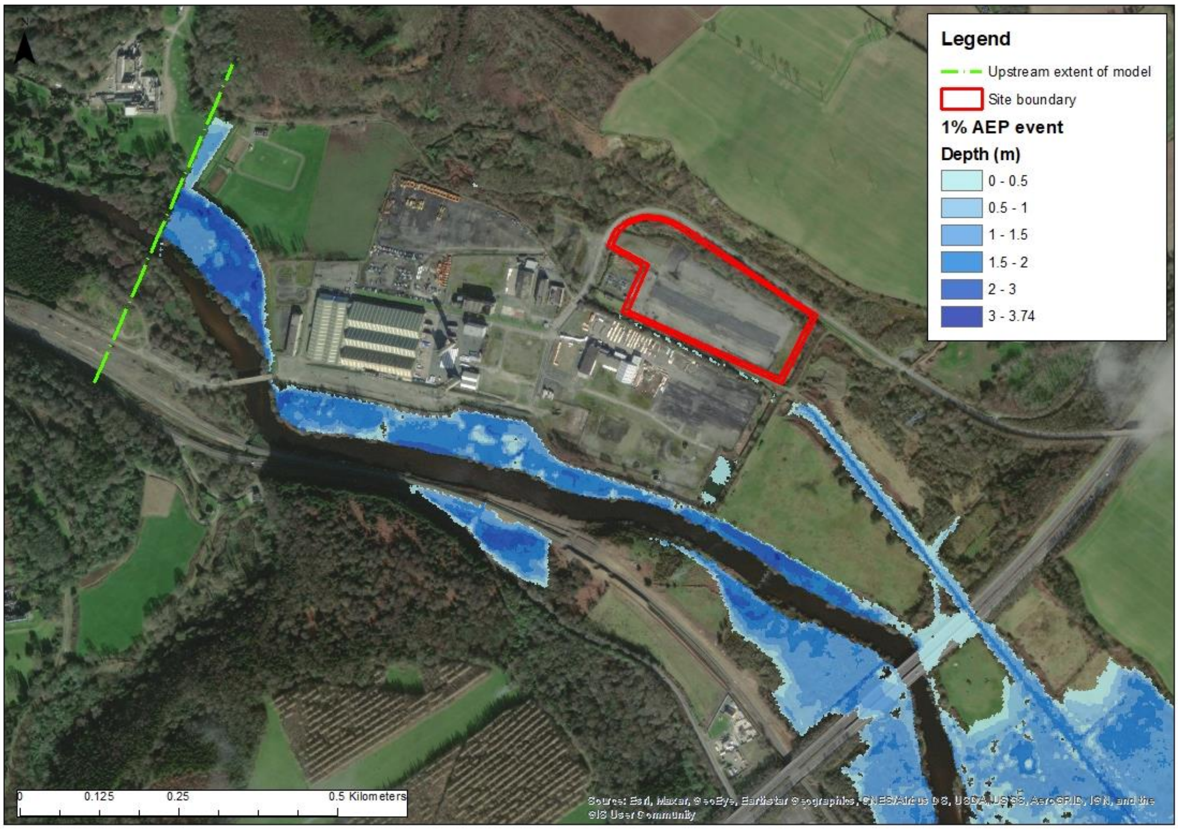


Figure 8-1: 1% AEP event– baseline

During the 0.1% AEP current day scenario, spill occurs into the marsh land and on both banks between the upstream extent of the model and Arklow bypass bridge, building to depths of around 1.8m. As the event progresses, spill occurs on both banks between the upstream extent of the model and the Arklow bypass bridge. River banks within the town of Arklow are exceeded resulting in extensive flooding. This is not the focus of the study and has not been represented fully in the modelling given its distance downstream. The areas identified continue to increase in depth as the peak is approached, with the canal backing up from the marsh.

The embankment running to the west of the site is overtopped approximately 4h before the peak at a low point within Shelton Abbey grounds. The height of the embankment at this location is 5.8m, and this low point extends approximately 20m, although lower than average crest levels are experienced over 70m. Flow is seen to be largely contained to this grassy area to the west of the industrial estate, where there is a low lying depression, building to depths of 850mm. Some flow however continues west in drainage ditches before joining the drainage ditch that runs between the Substation site and the data centre site. A small amount of spill occurs from this drainage ditch affecting the south eastern corner of the Substation site to depths of 300mm (1.8mOD).

Figure 8-2 displays the baseline 0.1% AEP event. Full flood maps can be seen in Appendix E.

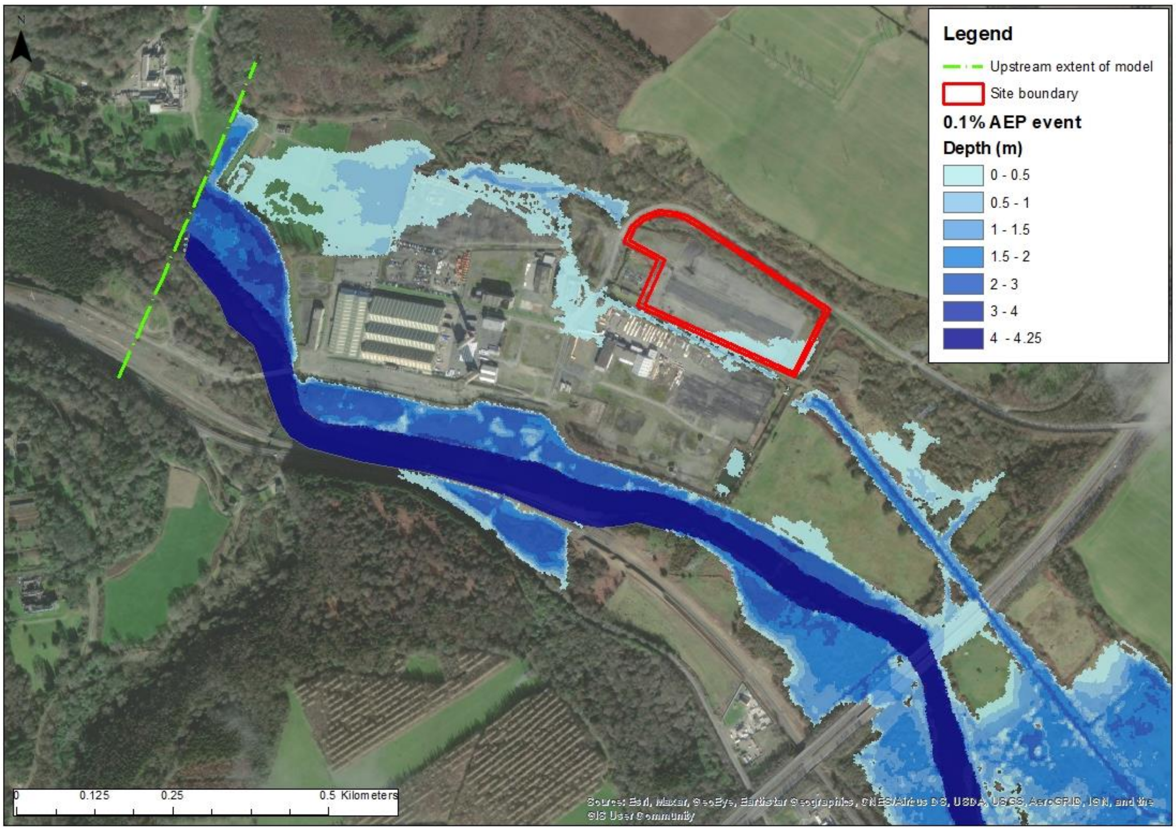


Figure 8-2: 0.1% AEP event current day – baseline

During the 0.1% AEP plus climate change scenario (MRFS), spill occurs first into low lying marsh land between the site and Arklow, inundating much of the left bank, to depths of up to 2.3m. As the event progresses, spill occurs on both banks between the upstream extent of the model and the Arklow bypass bridge. River banks within the town of Arklow are exceeded resulting in extensive flooding. This is not the focus of the study and has not been represented fully in the modelling given its distance downstream. These areas continue to increase in depth as the peak is approached, with the canal backing up from the marsh.

The embankment running to the west of the site is overtopped approximately 7h before the peak at a low point within Shelton Abbey grounds. Spill over this embankment occurs over 17h with a peak flow of 21.5m^3/s. The entire Avoca River Park is seen to become inundated, with depths reaching 2.7m (4.5mOD).

Figure 8-3 displays the baseline 0.1% AEP event plus climate change (MRFS). Full flood maps can be seen in Appendix E.

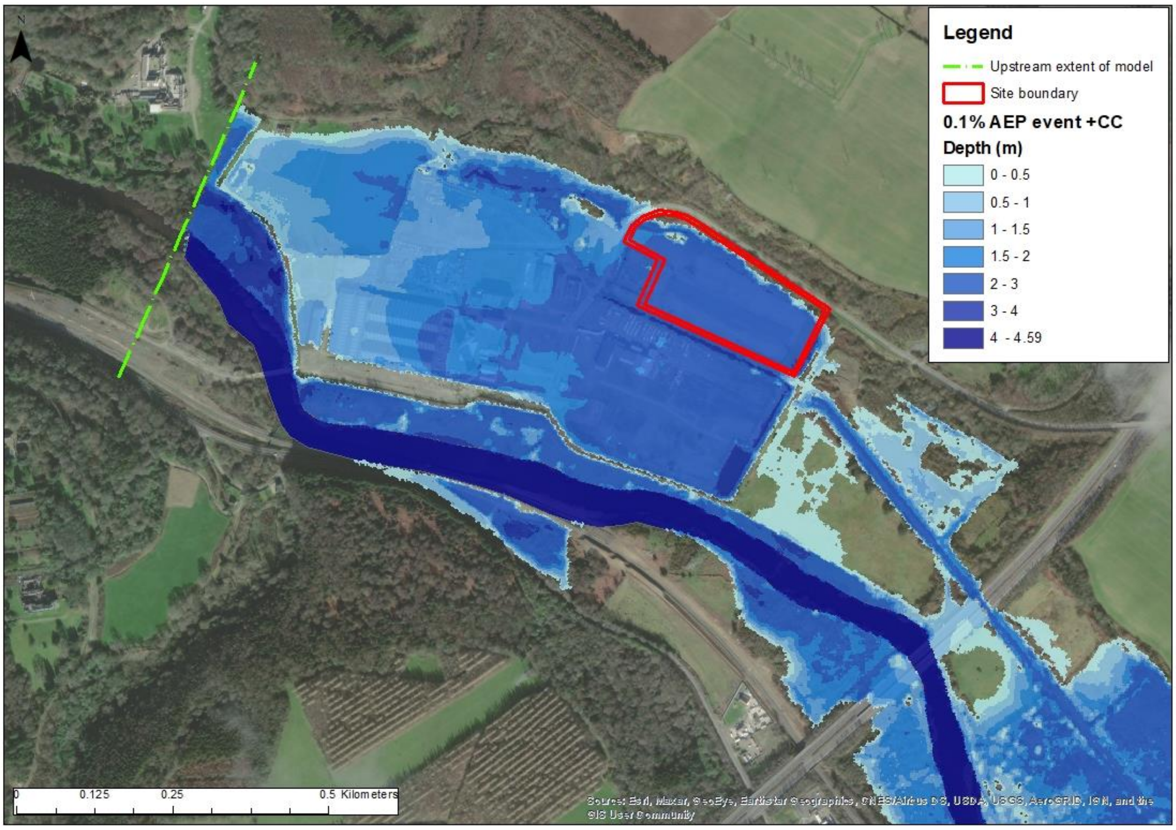


Figure 8-3: 0.1% AEP event + CC – baseline

8.1.2 Breach scenario

The two breach scenarios were run for the 0.1% AEP current day event but contained different breach parameters. The details of the model build can be found in Section 6.2.

During the ¾ height scenario, floodwaters breach at 25.5h and reach a maximum overtopping peak flow of 90m^3/s and the overtopping occurs for a period of 24.5 hours. During the crest of embankment scenario, floodwaters breach at 29.5h and reach a maximum overtopping peak flow of 100m^3/s with overtopping occurring over a period of 20 hours.

Both breach scenarios, one beginning when water level reaches ¾ of the embankment height and one that begins at the crest of the embankment, were shown to inundate the site to the same extent. Flood depths across the site were 3.05m for both scenarios, which equates to a water level of 5.3mOD.

The climate change scenario was not run for the breach scenarios as it was shown that a large increase in volume, as a result of the breach that started earlier, did not affect water levels on the site demonstrating this was the maximum level water could build to before spilling.

Figure 8-4 displays the 0.1% AEP event breach scenario. Full flood maps can be found in Appendix E.

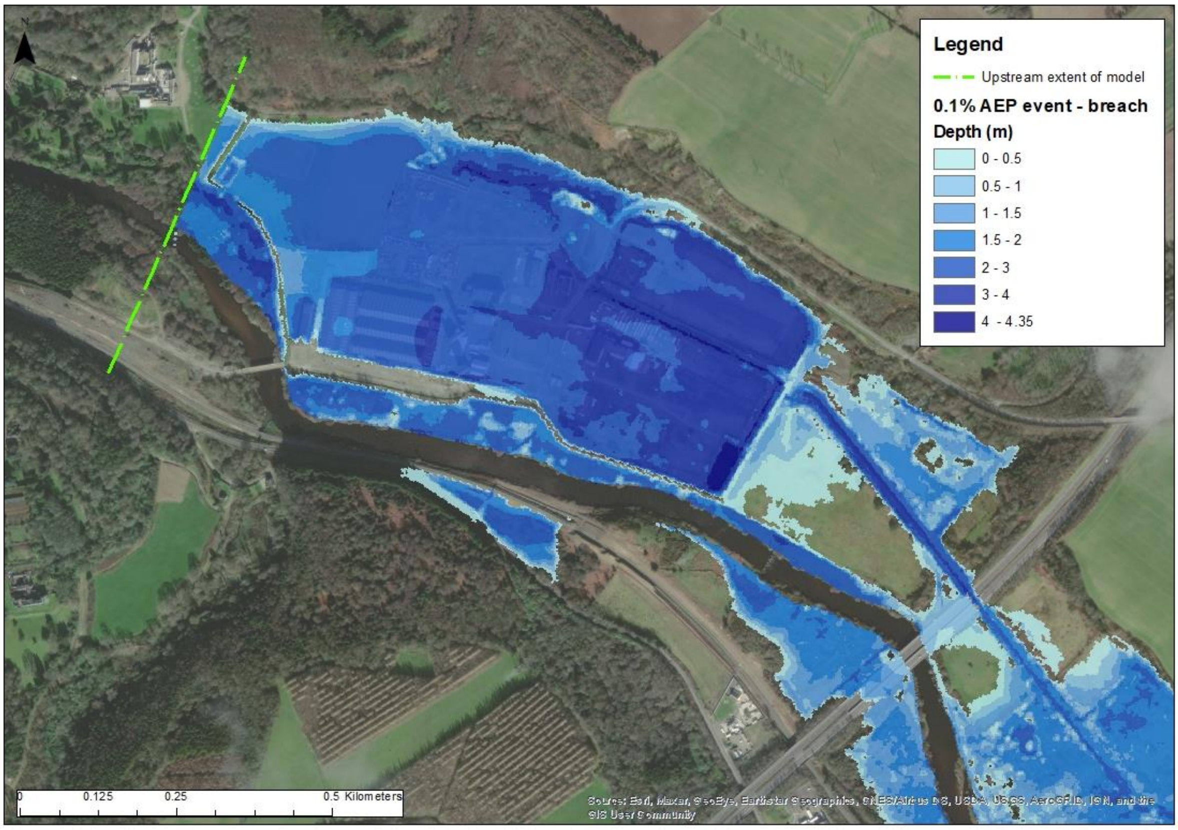


Figure 8-4: 0.1% AEP event – breach

The breach assessment displays the residual risk to the site should the embankments fail. Water levels on site increase from 1.8mOD to 5.3mOD, a 3.5m increase in flood water depth. The significant impact should a breach occur highlights that it will be very important to investigate the composition of the embankment as well as developing an ongoing maintenance plan.

8.1.3 Arklow Flood Relief Scheme

The proposed flood relief in Arklow consists of localised containment measures in the town and channel lowering at Arklow Bridge and the construction of a debris capture upstream of the bridge. In blocking off half of the channel at the location of the debris catcher, proposed as part of the Scheme, water levels upstream were found to be slightly increased, around 10-20mm, as were floodplain depths in the immediate vicinity. Water levels were not however found to increase upstream of the Arklow Bypass.

Installing a debris catcher as part of the Arklow Flood Relief Scheme was not found to adversely affect flood risk at the site due to the large floodplain capacity in the mash land effectively absorbing any increase in flood lift and the Scheme will not be considered further.

8.2 Pluvial baseline

Given that fluvial flood risk from the Avoca River can be effectivity removed from the substation site by raising of the embankment low point, understanding the implications of pluvial flooding on platform levels becomes more important.

During the 0.1% AEP current day and climate change (MRFS) simulations, peak water levels on the substation site range from 2.41 – 2.68mOD, with critical durations ranging from 720 – 4320 minutes. Table 8-1 displays the results of the baseline simulations.

It is anticipated as set out in Section 7.1 that the current pump rate would be equal to the Greenfield rate for the industrial site only. Given the lack of data relating to pump rates, further simulations have been carried out based on a Greenfield rate for the entire contributing area behind the defence following a review of the local topography.

Table 8-1: Baseline - critical duration and peak water levels

	Critical duration	Peak water level (mOD)
0.1%AEP – Industrial site 50% AEP greenfield pump rate Water levels (mOD)	2880 minutes - winter	2.57
0.1%AEP- Full catchment 50% AEP greenfield pump rate Water levels (mOD)	720 minutes - winter	2.41
0.1%AEP +CC – Industrial site 50% AEP greenfield pump rate Water levels (mOD)	4320 minutes - winter	2.68
0.1%AEP +CC – Full catchment 50% AEP greenfield pump rate Water levels (mOD)	960mins - winter	2.51

From the results, it can be seen that water levels do not vary significantly on site between different pump arrangements and with added climate change. This is due to the large plan area of the overall industrial estate meaning a large increase in volume does not equate to a large uplift in flood level. A peak level of 2.68mOD results in almost the entire substation site being inundated to depths up to 1.2m.

The uncertainty test, whereby pumps were modelled to fail for a 24h period, produced a peak water level of 2.85mOD for the 0.1% AEP plus climate change event, an uplift of 170mm from the highest peak level modelled with pump in place (as outlined in Table 8-1). It is important to understand risk of failure in an artificially drained area as consequences could be severe. This assessment has demonstrated that peak water levels do rise but not significantly. Platform levels and freeboard allowances should therefore be calculated using information from this assessment as a means of managing overall risk and reducing flood risk.

8.3 Development option

8.3.1 Fluvial

The principal of raising the flood bund around the Avoca River Park has been established and granted as part of planning application 18/940. The proposed development is grounded on the basis of the works being carried out to the embankment as set out in that application. In the event that the proposed development does not progress, ensuring that the embankment is raised (and associated pre-raising investigations) will transfer on to the applicant for the sub-station and will form part of the flood mitigation works associated with the sub station. The low point in the embankment will be raised to a level of 6.5mOD as noted in Section 6.5. Within this FRA for the substation, it is assumed that raising is possible and detailed design will be verified by GI. Figure 8-5 displays the approximate extent where crest raising works require to be undertaken.

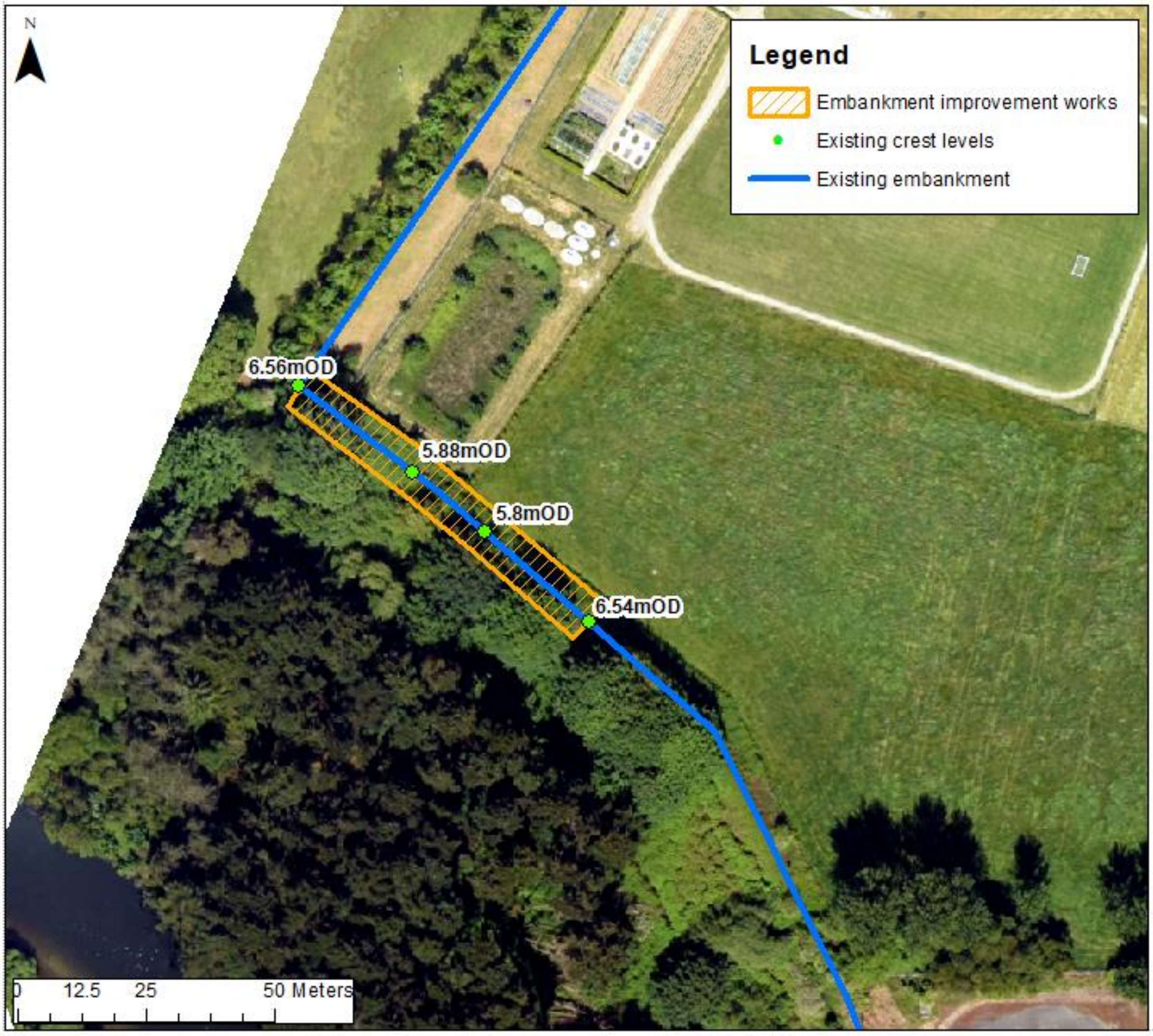


Figure 8-5: Indicative extent of embankment improvement / raising works.

By undertaking these works, the 0.1% AEP event is contained with no flood waters spilling into the industrial estate.

During the 0.1% AEP with climate change (MRFS) the volume of overtopping over the embankment is substantially reduced. The majority of the overtopping volume is contained to the open land to the west of the industrial estate. A small amount of flow enters the drainage ditch between the substation site and the data centre site but no floodwater is observed on the substation site itself.

Figure 8-6 displays the 0.1% AEP + Climate Change flood extent with the low point in the embankment raised up to 6.5mOD. Full flood maps can be seen in Appendix E.

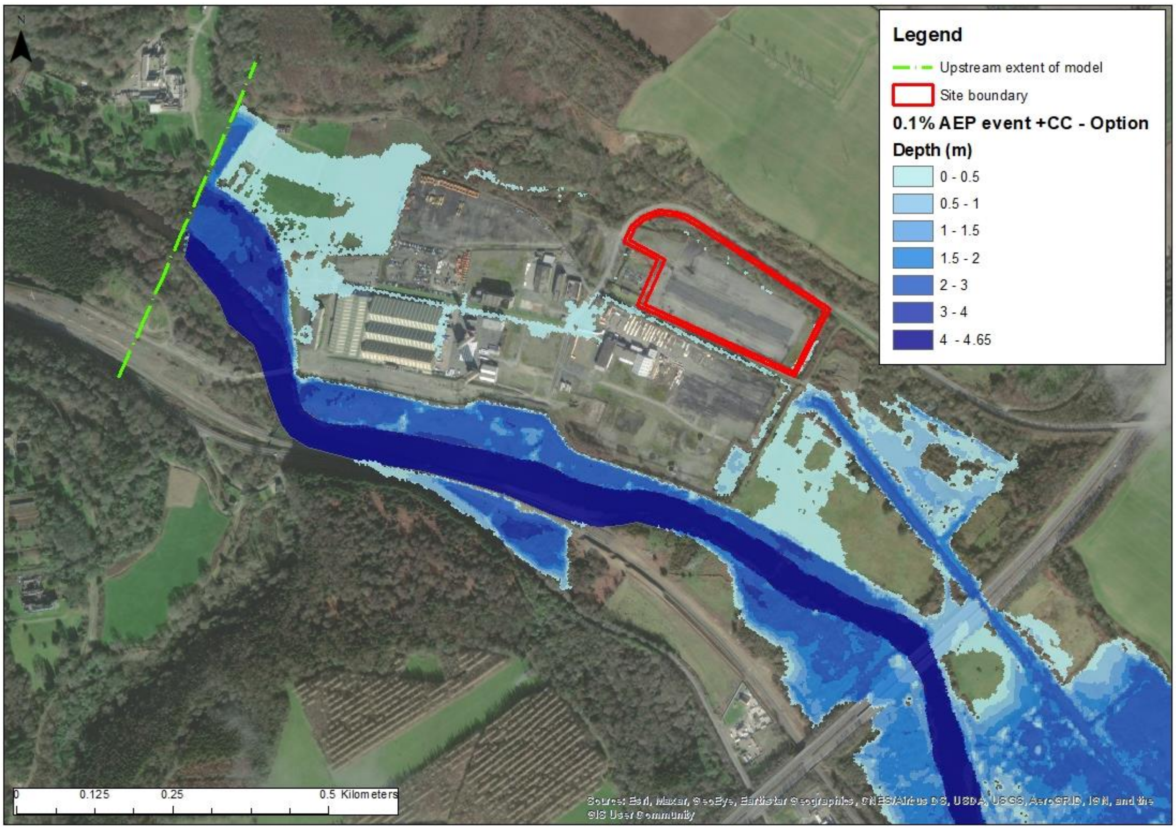


Figure 8-6: 0.1% AEP event + climate change (MRFS) – proposed embankment raising

By raising a portion of the flood embankment, flooding on site is been completely eradicated in the 0.1% AEP event plus climate change event, where previously there were depths of around 2.6m on site. It should be noted that water levels on the river side of the embankment are around 6.5mOD and that by raising the low point in the embankment to 6.5mOD there is no freeboard allowance. Appropriate freeboard should be included as part of the embankment raising works, or erosion protection measures should be included on the embankment to minimise the risk of erosion during spill events.

8.3.2 Pluvial

In order to protect the development from all flooding sources, the development platform is to be raised above current ground levels ensuring that the site is protected against pluvial flood risk and any residual flood risk associated with surface water pump failure etc. The development platform is therefore to be raised above the 0.1%AEP pluvial flood levels with an allowance for climate change and freeboard. For the purpose of this assessment it is assumed that under current conditions the pump rate is in line with industrial site greenfield rate whilst the with development scenario is based on the Greenfield rate associated with the wider contributing area.

During the development scenario 0.1% AEP plus climate change (based on the mid-range scenario) event, which is the standard required for this development, peak water level is 2.64mOD.

Table 8-2 displays the results of the baseline simulations and with development simulations.

Table 8-2: With and without development – pluvial flood risk peak water levels

	Baseline conditions Peak water level (mOD) with Industrial Estate Greenfield rate	With Development Peak water level (mOD) with full contributing area Greenfield rate	Change
0.1%AEP –Water levels (mOD)	2.57	2.52	- 0.05
0.1%AEP +CC (MRFS) – Water levels (mOD)	2.68	2.64	- 0.04

By ensuring that the pump arrangement is appropriately sized for the full contributing area, rather than the industrial estate alone, the impact of any land raising and displacement of flood water is compensated. The proposed development therefore results in no increase in pluvial flood risk elsewhere in the Avoca River Park.

A further sensitivity test has been carried out based on the cumulative impact of platforming the sub station site as well as that associated with planning application 18/940. Whilst the development site remains to be an uncommitted project and designs have yet to be finalised, it has been granted planning permission and it is therefore important to assess the impact of any platform raising associated with the project. Details of the amendments to the development option model can be found in Section 7.3. Based on raising the proposed development platform together with that associated with application 18/940 the pluvial flood level with the full contributing area pump rate is 2.79mOD for the 0.1% plus climate change scenario (MRFS).

Platform levels and freeboard allowances should therefore be calculated using information from this assessment as a means of managing overall risk and reducing flood risk.

It should be noted that good drainage design should accommodate lost attenuation due to land raising elsewhere and that the design does not increase flood risk elsewhere. For this reason, the increased levels produced in this assessment are considered conservative.

9. Conclusions

The following sections summarise the assessment undertaken and provides recommendations for the development of the proposed substation site.

9.1 Hydrology

The Avoca River, which lies adjacent to the south west boundary of the site, is a source of flood risk. The Avoca River discharges to the sea at Arklow Harbour, some 3.5km downstream; therefore, water levels in the river adjacent to the site may also be influenced by tide levels as well as fluvial flow.

The hydrological approach which was used in the hydraulic modelling is summarised below.

9.1.1 Fluvial Inflows

Flow and water level gauges were first identified in the Arklow catchment in order to aid the development of fluvial inflows. CFRAM reports, commissioned by the OPW were also reviewed as these documents contained hydrological assessments for both the Eastern area as well a site specific assessments for Arklow.

The statistical method was used to estimate peak flows for the 1% AEP and 0.1% AEP floods. This method uses an index flood (usually QMED, the median of the annual maximum series) and a growth curve giving growth factors for any return period. Combining the index flood and the appropriate growth factor provides an estimate of peak flow for a specific return period flood event.

The index flood QMED for the site was derived using the FSU catchment descriptor equation, adjusted using the Rathdrum gauge as pivotal site. The annual maximum series of the Rathdrum gauge was updated to 2019 and used the updated gauge rating contained in the Eastern CFRAM report.

In the Eastern CFRAM report, peak flow estimates for a range of catchments were established using the statistical method, estimating QMED (index flood) from catchment descriptors and applying a pooled group growth curve. These growth curves were then rationalised by catchment area to provide generalised growth curves for the Eastern area. A similar methodology was undertaken for the Arklow specific CFRAM report, although the growth curve was developed by averaging a number of single site growth curves, rather than strictly following the pooling approach of averaging the L-moments.

The Eastern CFRAM generalised area curve (median of several catchment's growth curves), the Eastern CFRAM site specific curve, and the Arklow CFRAM curve were plotted and compared to single site growth curves for the two gauges in the catchment. Taking a precautionary approach, and the Eastern CFRAM site specific curve was selected for generating the 0.1% AEP peak flow and the Arklow site specific CFRAM curve was selected for generating the 1% AEP event peak flow.

The resultant peak flow for the 1% AEP event was 486$m^{3/}$s and 644m^3/s for the 0.1% AEP event.

Based on OPW guidance, climate change was applied at 20% uplift to flow which represented the mid-range future scenario.

The above assessment only produces peak flow, meaning that hydrograph shape had to be determined using the methodology set out in FSU Volume III – Hydrograph Analysis. For ungauged catchments, hydrograph shape parameters are estimated using catchment descriptors. A hydrologically similar pivotal site is then chosen, and the hydrograph shape parameters at the pivotal site are adjusted to achieve a best fit curve to the observed data for that site. The most hydrologically similar pivotal site available that had catchment descriptors within acceptable ranges was found to be 16012 Tar Br and hydrograph shape was derived from this station.

9.1.2 Joint probability

The Avoca River discharges to the sea at Arklow Harbour; therefore, whilst the site is not at risk of coastal flooding, water levels in the river adjacent to the site may be influenced by tide levels as well as fluvial flow. Appropriate tide levels to use as a downstream boundary for the model were required, with due consideration of the joint probability of coincidence of high fluvial flows and high tides.

Joint probability can only properly be assessed using actual observed data. The Eastern CFRAM report undertook a joint probability analysis and found that the correlation between total water levels and fluvial flood flow within the region can be considered to be negligible. The report recommended a simplified conservative approach whereby the 50% AEP level or flow is maintained for one mechanism while the whole range of design events for the other mechanism is tested and vice versa. In the context of this study, this implies matching both the 1% and 0.1% AEP hydrographs with a 50% AEP tide level at the downstream boundary. The Arklow CFRAM report took a similar simplified approach but matched the fluvial events with high astronomical spring tide level of 0.6mOD.

For the purposes of this study, a 50% AEP tide was applied as the downstream boundary with a sensitivity test using the high astronomical tide.

9.1.3 Tidal boundary

EPA Hydronet provides 15 minute level data for Arklow Harbour from August 2003 to present. This gives 17 years of AMAX data, sufficient to provide a robust estimate of the median (50% AEP) tide level. The 50% AEP tide level of 1.037mOD was calculated from the AMAX data.

The Irish Coastal Protection Strategy Study (ICPSS) provides extreme water levels that includes tide and surge for points along the coastline. The interpolation of the ICPSS nearby model points gives a 50% AEP tide and surge level of 1.05mOD. This agrees well with the 50% AEP estimates from the observed data (1.037mOD).

As a slightly higher figure that also includes consideration of surge, a 50% AEP tide level of 1.05mOD will be adopted for the study.

A climate change uplift of 0.8m was applied to the tidal level and represented the mid-range future scenario.

9.2 Baseline flood risk

All sources of flooding have been investigated in this FRA, either through interrogation of available data or through detailed modelling.

9.2.1 Fluvial scenario

9.2.1.1 Current conditions

A single hydraulic model was constructed of the Avoca River consisting of a one dimensional element representing the river channel and structures, and a two dimensional element representing the floodplain.

During the 1% AEP scenario, spill occurs into the low lying marshland as well as the left and right banks between the upstream extent of the model and the bypass bridge. Some flood inundation is experienced through the town of Arklow. The embankment running to the west of the site contains the flood waters and no flooding is experienced within the Avoca Business Park and the development site.

During the 0.1% AEP current day scenario, spill occurs into the low lying marshland as well as the left and right banks between the upstream extent of the model and the bypass bridge. Some flood inundation is experienced through the town of Arklow. The embankment running to the west of the site is overtopped approximately 4h before the peak at a low point within Shelton Abbey grounds. Spill over this embankment occurs over a 4 hour duration and results in inundation of the south eastern corner of the site, up to depths of 300mm (1.8mOD).

During the 0.1% AEP plus climate change, mid-range future scenario, spill occurs into the low lying marshland as well as the left and right banks between the upstream extent of the model and the bypass bridge. Some flood inundation is experienced through the town of Arklow. The embankment is overtopped approximately 7h before the peak at a low point. Spill over this embankment occurs over 17h with a peak flow of 21.5m^3/s. The entire Avoca River Park is seen to become inundated, with depths reaching 2.7m (4.5mOD).

9.2.1.2 Arklow Flood Relief Scheme

The Arklow Flood Relief Scheme is currently being designed and could potentially affect flooding on site. Several elements make up the scheme, discussed in Section 2.3, however all but the debris catcher are considered unlikely to affect site flood levels. The debris catcher was added to the hydraulic model to assess its impact.

In blocking off half of the channel at the location of the debris catcher, water levels upstream were found to be slightly increased, around 10-20mm, as were floodplain depths in the immediate vicinity. Water levels were not however found to increase upstream of the Arklow Bypass and flood risk to the site remained unaffected.

Installing a debris catcher as part of the Arklow Flood Relief Scheme was not found to adversely affect flood risk at the site due to the large floodplain capacity in the mash land effectively absorbing any increase in flood lift and will not be considered further.

9.2.2 Tidal

Tidal flooding was assessed by comparing existing ground levels around the site with the tidal levels outlined in the CFRAM reports. High tidal scenarios were not modelled.

The CFRAM 0.1% AEP tidal level is 1.75mOD, rising to 2.55mOD with climate change (based on the mid-range projection). This level is significantly lower than land to the immediate east of the site, which is generally 5mOD+. The low point in the embankment east of the site is also set at 4.2mOD, significantly higher than the 0.1%AEP +CC tide level. Flooding as a result of high tide levels is not considered to be a risk to the site.

The impact of tide locking was investigated through a modelling exercise whereby a sensitivity scenario was run adjusting the downstream tidal boundary. The 50% AEP and High Astronomical Tide level have both been identified in the Eastern CFRAM and Arklow CFRAM reports as appropriate downstream levels for high fluvial events and both have therefore been tested to assess how this impacts flooding at the site. A higher tidal AEP event would likely provide more of a tide locking impact but given the CFRAM joint probability analysis, it is not considered realistic to test this.

Flood levels in the channel and floodplain around the site did not change between the two tidal scenarios, demonstrating that the tidal influence does not provide a tide locking risk.

9.2.3 Pluvial

Pluvial flooding from the catchment behind the embankment is likely to pose a flood risk to the substation site, which is low lying, cut off from natural drainage by the embankments and reliant on a pump system for drainage.

A Microdrainge source control model was developed to represent the inflows, topography of the site and the pump arrangement. Two pump rates were assessed as existing rates are currently unknown.

During the 0.1% AEP current day and climate change (MRFS) simulations for the baseline scenario, peak water levels ranged from 2.41 – 2.68mOD, with critical durations ranging from 720 – 4320 minutes. A peak level of 2.68mOD results in almost the entire substation site being inundated to depths up to 1.2m.

Water levels do not vary significantly on site between different pump arrangements and with added climate change. This is due to the large plan area of the site meaning a large increase in volume does not equate to a large uplift in flood level.

9.2.4 Ground water

High ground water levels are likely to be caused by levels in the Avoca River either as a result of high tides or high fluvial events.

The lowest point on the site sits at around 1.3mOD. 50% AEP tidal levels are 1.05mOD and 50% fluvial levels are around 3mOD. Therefore, any groundwater flooding that may occur can be described as fluvial / tidal and not as a source of flooding in its own right.

Ground water is not considered to be a source of flood risk.

9.2.5 Residual – breach scenario

Canals and reservoirs are not considered to provide any residual flood risk to the site either due to lack of proximity or levels around the site.

Breach of the embankments that protect the site is however a residual risk and was assessed through a modelling exercise that included simulating two breach scenarios at the low point in the embankment. This low point was selected as the breach location as in fluvial scenarios, breaches typically occur as a result of overtopping and this area would be seen to overtop first. The low point is considered a weak point in the embankment in the absence of information relating to embankment stability.

Both breach scenarios, one beginning when water level reaches ¾ of the embankment height and one that begins at the crest of the embankment, were shown to inundate the site to the same extent and to the same depth. Flood depths across the site were 3.05m for both scenarios, which equated to a water level of 5.3mOD.

The breach assessment displays the residual risk to the site should the embankments fail. Water levels on site have increased from 1.8mOD to 5.3mOD, a 3.5m increase in flood water depth. The significant impact should a breach occurs highlights the importance of investigating the composition of the embankment as well as developing and ongoing maintenance plan

9.3 Development option flood risk

The proposed development consists of raising the development platform above all flooding sources and raising of the low points in the flood embankment that protects Avoca River Park. As noted previously, the principals of raising the embankment have been established and have been granted planning permission (application 18/940).

The following section looks at the flood risk to the development following these works and the impact this has on food risk elsewhere.

9.3.1 Fluvial

As part of the granted planning permission, the data centre seeks to raise the low point in the embankment to 6.5mOD to reduce spill from the Avoca River into the site. Within this FRA for the substation, it is assumed that raising is possible and detailed design will be verified by GI and topographic survey.

During the 0.1% AEP event with climate change (MRFS), the development option scenario, where the embankment low point has been raised, showed significantly less flood water overtopping the embankment. Almost all of the overtopping volume was contained to the open land to the west of the industrial estate. A small amount of flow entered the drainage ditch between the substation site and the data centre site but no floodwater was observed on the substation site itself.

Channel and floodplain depths were increased marginally on the river banks around the industrial estate as flood attenuation had been cut off from entering the site. Flood depths in the channel and on the floodplain were increased by around 40mm upstream of the bypass bridge, with smaller increases downstream.

By raising a portion of the flood embankment, flooding on site has been completely eradicated in the 0.1% AEP event plus climate change event, where previously there were depths of around 2.6m. It should be noted that water levels on the river side of the embankment are around 6.5mOD and that by raising the low point in the embankment to 6.5mOD there is no freeboard allowance.

9.3.2 Pluvial

The baseline Microdrainge source control model was updated to remove the platform area from the topographic representation of the site.

By ensuring that the pump arrangement is appropriately sized for the full contributing area rather than the industrial estate alone the impact of any land raising and displacement of flood water is compensated. The proposed development therefore results in no increase in pluvial flood risk elsewhere. The design level of the 0.1% AEP event with climate change (MRFS) is 2.64m OD.

A further sensitivity test has been carried out based on the cumulative impact of platforming the substation site as well as that associated with planning application 18/940. Whilst the development site remains to be an uncommitted project, and designs have yet to be finalised, it has been granted planning permission and it is important to assess the impact of any platform raising associated with the project. Details of the amendments to can be found in Section 7.3. Based on raising the proposed development platform together with that associated with application 18/940 the pluvial flood level with the full contributing area is 2.79mOD.

9.4 Recommendations

Based on the assessment undertaken, the following recommendations are made for the proposed substation site.

All elements set out in the recommendations section are to be undertaken at detailed design stage with the exception of the maintenance inspection and repair programme which will be undertaken during the operational phase.

9.4.1 Embankment improvement works and maintenance

The proposed data centre has gained planning permission to raise the embankment to the west to 6.5mOD which was found in this FRA to eradicate fluvial flooding on site. It is therefore recommended, that embankment raising works at this low point be undertaken to reduce fluvial flood risk probability to the substation site. These works are included within the proposed development.

The entire Avoca River Business Park relies on the existing embankments for fluvial flood protection. Section 9.2.5 describes the residual risk to the site should the embankments fail, highlighting the importance of implementing a regular maintenance, inspection and repair programme to reduce this residual risk.

To allow suitable design to be developed for raising the low point of the embankment and to inform the maintenance, inspection and repair programme, a detailed topographic survey and GI inspection (including core sample of the embankment) will be undertaken to verify composition, permeability and stability of the embankment.

Should investigations determine that works are required to maintain or reinforce the existing embankments then these will be undertaken. While a range of approaches could be applied and a targeted approach (to certain areas of the embankment) might be possible, in a reasonable worst case scenario, the full length of the embankment may require to be reinforced, similar to the works at the low point.

The inspection and maintenance programme should also extend to cover the pump arrangement and drainage network, which should be detailed in the drainage design reporting.

9.4.2 Platform levels

Raising of the low point in the embankment will be subject to detailed design based on the findings of the GI. Within this FRA it is assumed the embankment can be raised and that fluvial flooding from the Avoca River is effectively eradicated up to and including the 0.1% AEP event plus climate change (MRFS). This means that pluvial flooding is the key driver in raising of current ground levels to form the finished platform level.

As the substation is classed as essential infrastructure, platform levels should be set at the 0.1% AEP plus climate change levels with an added freeboard allowance.

Based on the cumulative impact of landraising associated with the development and application 18/940, platforms level should be set above the sensitivity simulation level of 2.79 mOD with an appropriate freeboard.

A minimum platform level of 3.3mOD is recommended as this provides a freeboard of approximately 500mmm in a conservative assessment whereby no attenuation is provided for either development. The assessment is based on surface water pumps being able to accommodate the full contributing area Greenfiled runoff rate. Pump upgrades may be required to achieve this.

9.4.3 Additional flood mitigation measures

Regular inspections and maintenance of the embankment and pump arrangement reduced the likelihood of a breach or pump failure which would affect the requirements for additional flood prevention measures.

However, flood risk can never be fully removed, and additional measures can be put in place to further minimise risk. These could include:

- Flood resilient materials used where appropriate;
- Diversion or infilling of ditches running in and around the site should be fully assessed at detailed design stage to identify preferred options of addressing localised pluvial flows;
- Where practicable, provision of safe access and egress should be provided to the site. It is recommended that an access road to the platform be set above the 0.1% AEP event level of 2.79mOD;
- Placing of sensitive elements at higher elevations where possible;
- Demountable flood barriers and sealed air vents on any buildings associated with the development.

9.5 Suitability of site and development

9.5.1 Sequential approach

The development site has been assessed based on a sequential approach in line with guidelines. A rigorous assessment of alternative sites has been considered and no alternative is available for the proposed development. The development is based on a particular need and therefore no substitute type of development can be considered.

On that basis and on the back of detailed flood risk assessment undertaken, a justification test has been carried out in line with the Guidelines on the Planning System and Flood Risk Management' (DoEHLG/OPW, 2009).

9.5.2 Justification test

Justification Test Criteria	Response based on findings of FRA
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 of these Guidelines	The development site has been zoned for employment within the local plan following a sequential test through the SFRA and local plan process. The Arklow area has been identified through IT14 as an area to support and facilitate the development of landing locations for any cross channel power interconnectors.
The proposal has been subject to an appropriate flood risk assessment that demonstrates the following points:	
The development proposed will not increase flood risk elsewhere and, if practicable, will reduce overall flood risk	The development has been shown to not impact on flood risk elsewhere
The development proposal includes measures to minimise flood risk to people, property, the economy and the environment as far as reasonably possible	The proposed development is appropriately protected to the 0.1% event with an allowance for climate change taking consideration of all flooding sources and mechanisms
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	Residual flood risk has been assessed based on both breach of flood defences and surface water drainage pumps. Appropriate management measures are to be put in place taking account of these residual risks. Access and egress routes are maintained to the site during residual flood risk events.
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	The proposed development supports renewable regeneration and therefore is in line with wider planning objectives. Vibrant and active streetscape is not regarded as being applicable in this case based on the nature of the development
The acceptability or otherwise of levels of residual risk should be made with consideration of the type and foreseen use of the development and the local development context	Residual flood risk has been assessed based on both breach of flood defences and surface water drainage pumps. Appropriate management measures are to be put in place taking account of these residual risks.

Based on the findings of the justification test above, the scheme addresses all the criteria ,ensuring that the development is protected to the appropriate standard whilst ensuring no detrimental impact on the standard of protection to others.

Appendix A – Site visit photographs

Canal/ drainage ditch to south of substation site

Road between data centre site and substation site looking west


Canal looking east from site boundary


Sluice gate arrangement at diversion channel to pond

Looking across the data centre site from embankment to the east

Pond and intake structure with trash screen

Pipes running up the side of the embankment from the pond

Pump arrangement


Flap vale from opposite side of the embankment from the pond


Embankment along southern side of site

Location of possible erosion or changes in embankment level associated with historic infrastructure on southern embankment.

Access track road bridge


Sections of braided channel looking from the access bridge


Western embankment

Western side embankment looking south

Likely location of ditch to the north of the substation site


Likely location of drainage ditch to west of site

Appendix B – Topographic Survey

Below is a summary of the topographic surveys that were used in the hydraulic modelling exercise.

2006 survey of unknown origin and included:

- River cross sections from the bypass bridge to the harbour

2014 survey of unknown origin and included:

- Bathymetry of the tidal reaches through Arklow – from the harbour to Arklow bridge

2015 survey undertaken for Byrne Looby for a Wastewater Treatment site selection and included:

- River cross sections from the upstream extent of the model to immediately downstream of the bypass bridge
- Embankment crest heights along the entire embankment- southern and western

2018 survey undertaken as part of the Data centre FRA and included:

- Topography of Avoca River Park
- 5 river cross sections

2019 Avoca River park embankment undertaken as part of the data centre FRA and included:

- Crest levels along the southern bounding embankment
- Condition assessment report

2019 Arklow River survey undertaken for Wicklow County Council and included:

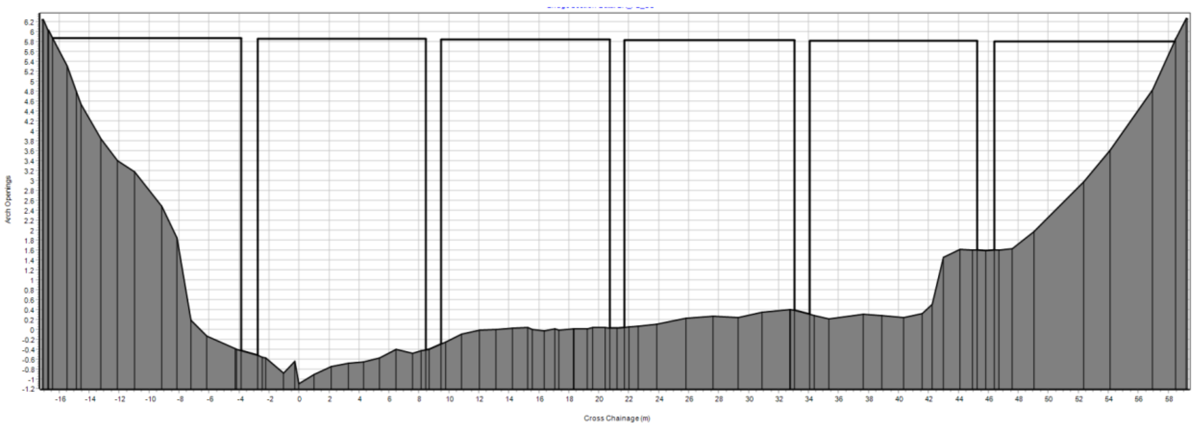
- River cross sections between the bypass bridge and the harbour

For the purposes of the modelling, the survey from 2015 was used to represent the channel from the upstream extent of the model to the bypass bridge. Between the bypass bridge and Arklow harbour, the 2019 Wicklow Council survey was used and supplemented with the 2006 survey where section spacing was too large. The 2014 bathymetry survey was also used to supplement the 2019 bed levels through Arklow.

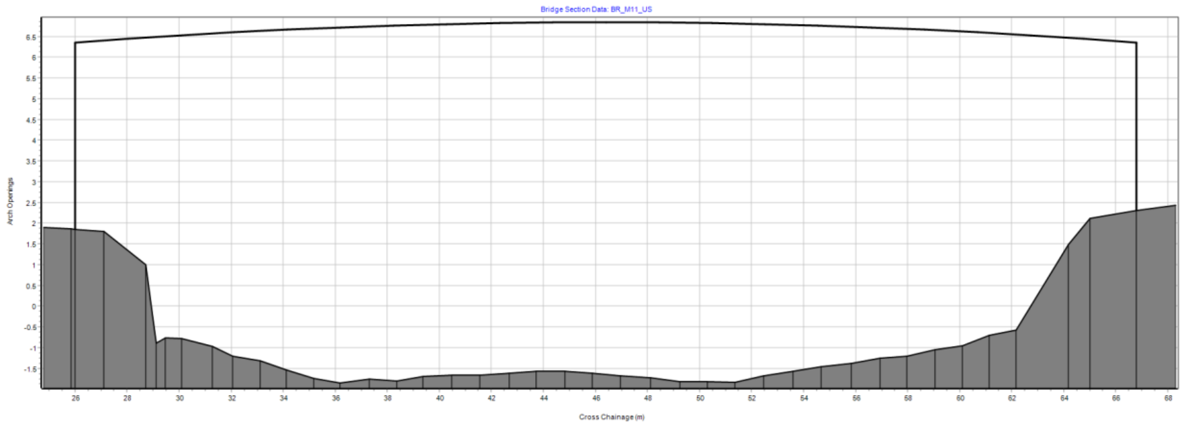
Crest levels of the embankment were taken from the 2015 survey and the 2019 embankment condition report was reviewed when making recommendations.

Appendix C – Model Build

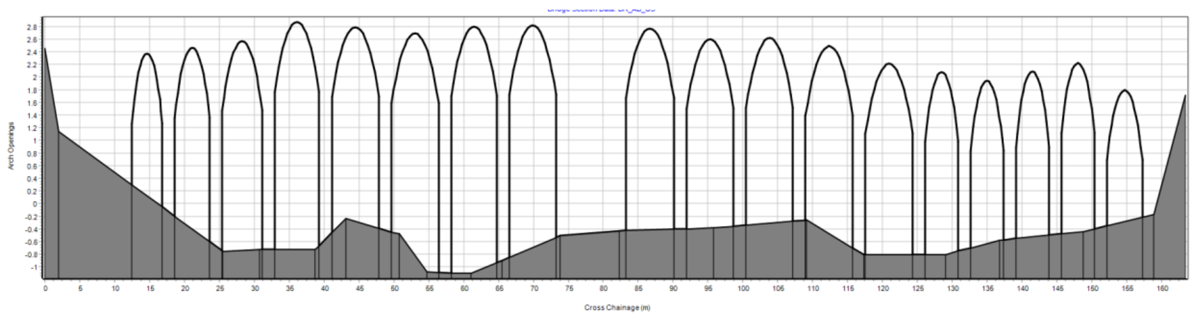
Structures



Access bridge to industrial estate

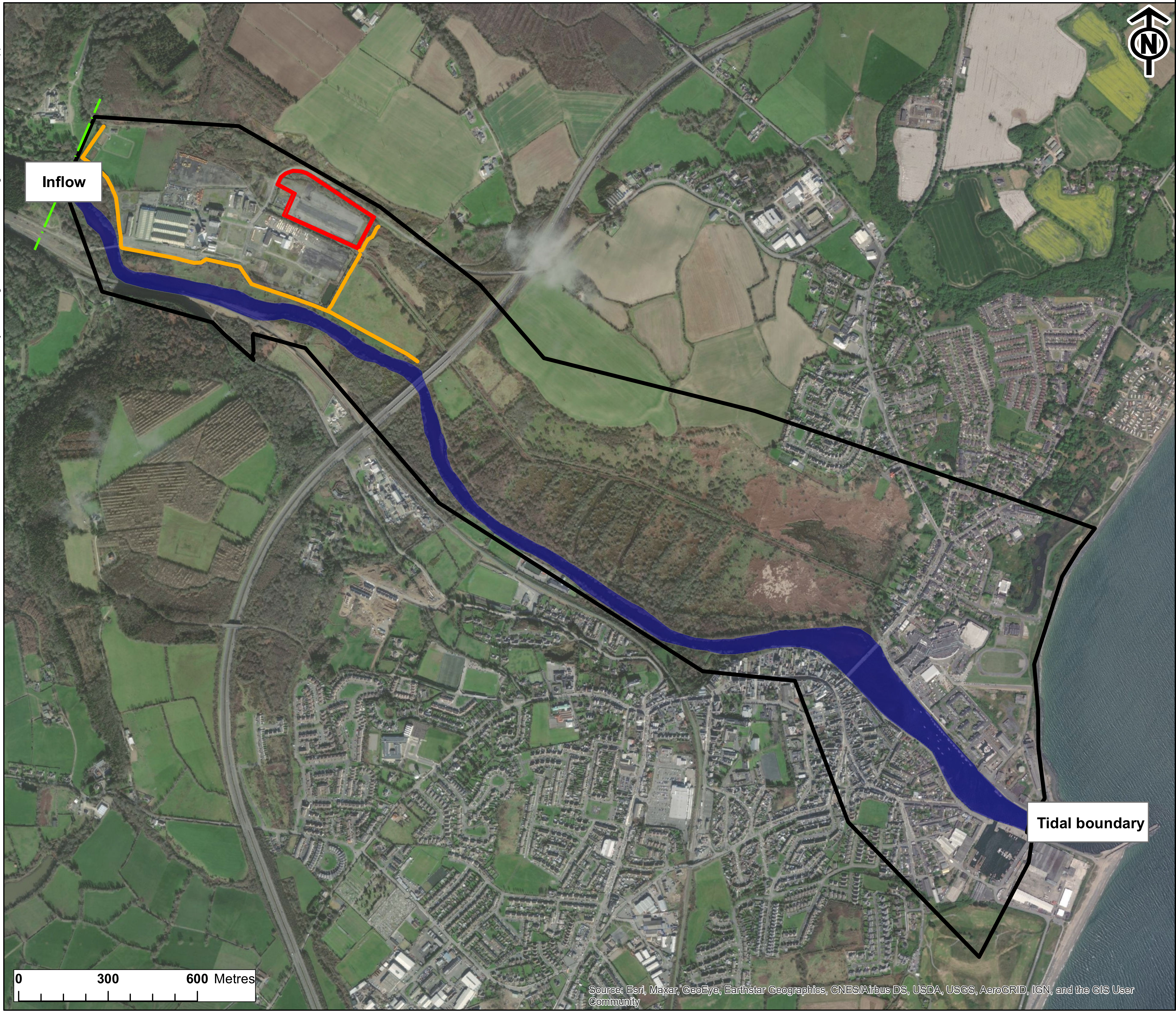


Arklow bypass bridge – additional opening modelled in the 2D domain



Arklow Bridge

Project Management Initials SH Designer: MH Checked: SH Approved: DH



PROJECT

Arklow Substation, Avoca River Park - FRA

CLIENT

SSE

Legend

- Upstream extent of model
- Embankment
- Site boundary
- 2D domain

Scale 1:10,000

PROJECT NUMBER

60605933

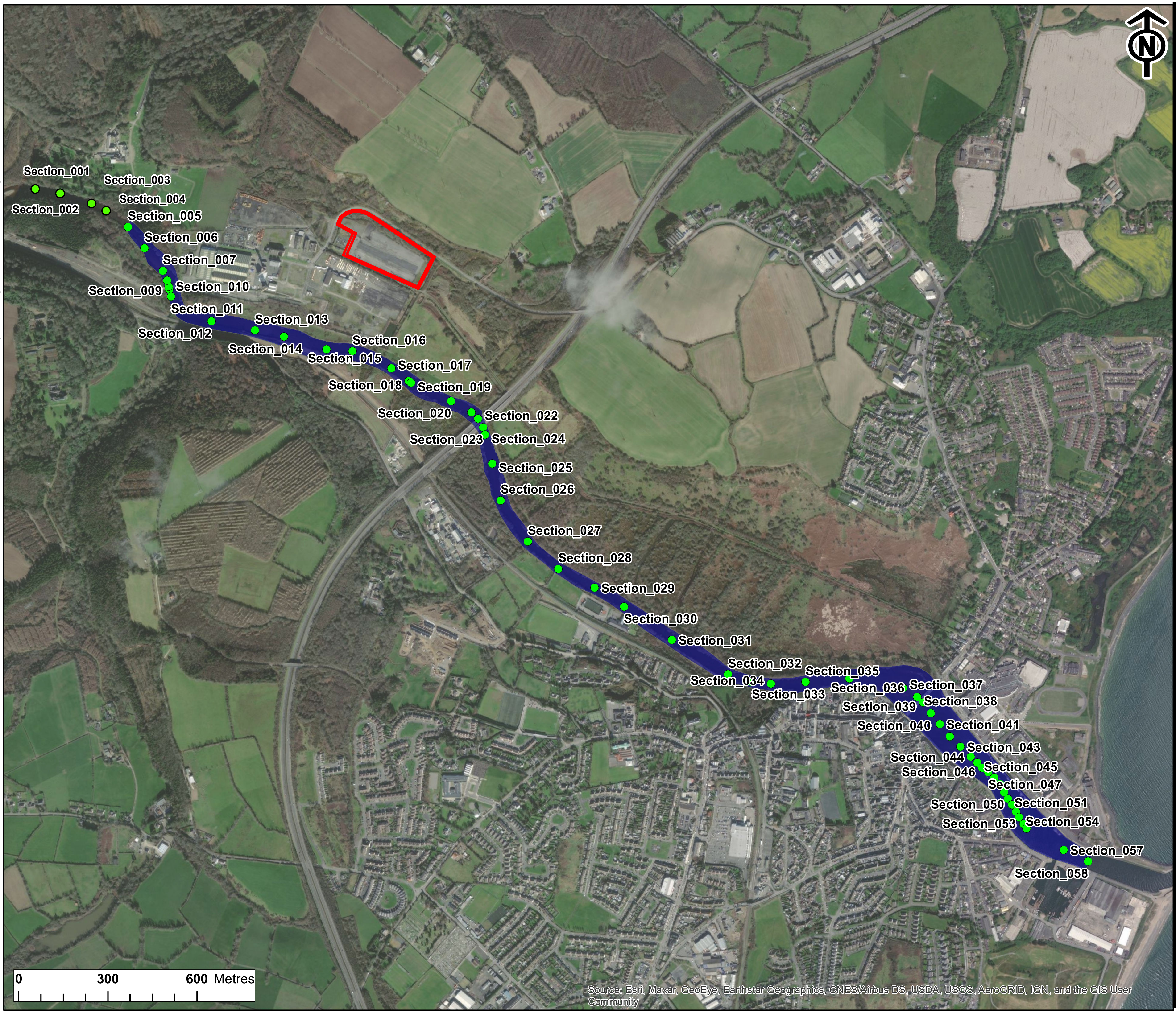
SHEET TITLE

Figure 1: Model build schematisation

SHEET NUMBER

Sheet 1 of 1

Project Management Initials SH Designer: MH Checked: SH Approved: DH



PROJECT

Arklow Substation, Avoca River Park - FRA

CLIENT

SSE

Legend

- 1D sections
- Site boundary

Scale 1:10,000

PROJECT NUMBER

60605933

SHEET TITLE

Figure 2: Section labelling

SHEET NUMBER

Sheet 1 of 1

Appendix D – Tabulated results

Table 1: roughness, flow and downstream boundary sensitivity testing results (all 0.1% AEP event)

	20% roughness increase			20% flow increase			Downstream boundary		
Label	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)
Section_001	6.491	0.254	0.916	6.61	0.295	1.061	6.176	0.295	1.016
Section_002	6.47	0.277	0.903	6.594	0.321	1.046	6.161	0.323	1.06
Section_003	6.38	0.326	1.169	6.511	0.378	1.361	6.068	0.377	1.357
Section_004	6.376	0.315	0.825	6.519	0.355	0.929	6.077	0.352	0.926
Section_005	6.312	0.237	0.839	6.455	0.269	0.963	6.013	0.269	0.929
Section_006	6.289	0.191	0.805	6.44	0.21	0.925	5.993	0.209	0.908
Section_007	6.192	0.209	1.148	6.337	0.237	1.307	5.894	0.22	1.261
Section_008	6.115	0.221	1.488	6.241	0.268	1.716	5.813	0.244	1.615
Section_009	6.069	0.235	1.658	6.183	0.271	1.926	5.767	0.26	1.786
Section_010	5.922	0.247	1.698	5.966	0.29	2	5.615	0.271	1.836
Section_011	6.024	0.174	0.871	6.115	0.2	1.009	5.734	0.199	0.975
Section_012	5.778	0.264	1.835	5.855	0.298	2.083	5.484	0.294	1.996
Section_013	5.605	0.275	1.97	5.665	0.32	2.298	5.321	0.307	2.15
Section_014	5.496	0.269	1.847	5.565	0.312	2.152	5.223	0.302	2.022
Section_015	5.358	0.26	1.794	5.433	0.302	2.096	5.114	0.286	1.936
Section_016	5.182	0.296	2.084	5.229	0.346	2.443	4.952	0.317	2.215
Section_017	4.631	0.437	2.846	4.38	0.576	3.655	4.31	0.506	3.189
Section_018	5.192	0.207	1.35	5.37	0.232	1.468	5.06	0.242	1.4
Section_019	4.771	0.167	1.209	4.876	0.183	1.337	4.604	0.177	1.258
Section_020	4.366	0.338	2.169	4.476	0.361	2.335	4.215	0.358	2.26
Section_021	4.231	0.301	2.011	4.313	0.335	2.261	4.09	0.322	2.118
Section_022	4.049	0.365	2.425	4.084	0.419	2.794	3.885	0.399	2.611
Section_023	4.056	0.372	2.395	4.093	0.427	2.757	3.891	0.408	2.584
Section_024	3.767	0.518	2.989	3.704	0.622	3.556	3.558	0.591	3.309
Section_025	3.693	0.335	2.181	3.668	0.409	2.655	3.537	0.379	2.423
Section_026	3.6	0.318	2.066	3.603	0.394	2.553	3.476	0.364	2.328
Section_027	3.352	0.319	2.049	3.359	0.391	2.513	3.23	0.372	2.354
Section_028	3.12	0.402	2.32	3.113	0.503	2.887	2.879	0.507	2.896
Section_029	3.05	0.293	1.747	3.068	0.37	2.25	2.833	0.373	2.246
Section_030	2.968	0.317	1.625	3.002	0.393	2.028	2.735	0.397	2.053
Section_031	2.875	0.293	1.389	2.931	0.357	1.694	2.647	0.369	1.736
Section_032	2.81	0.218	1.195	2.883	0.262	1.442	2.587	0.283	1.548
Section_033	2.771	0.234	1.327	2.848	0.283	1.605	2.542	0.308	1.743
Section_034	2.746	0.208	1.193	2.829	0.252	1.44	2.516	0.278	1.578
Section_035	2.679	0.277	1.295	2.772	0.337	1.57	2.439	0.398	1.8
Section_036	2.526	0.254	1.276	2.635	0.307	1.465	2.251	0.382	1.696
Section_037	2.27	0.238	1.236	2.369	0.267	1.394	1.953	0.301	1.46
Section_038	2.116	0.305	1.515	2.204	0.344	1.729	1.758	0.396	1.813
Section_039	1.971	0.234	1.296	2.001	0.272	1.515	1.609	0.288	1.51
Section_040	1.884	0.273	1.488	1.905	0.319	1.749	1.626	0.344	1.752
Section_041	1.801	0.3	1.63	1.814	0.354	1.924	1.627	0.383	1.934
Section_042	1.724	0.296	1.639	1.739	0.349	1.934	1.642	0.378	1.944
Section_043	1.654	0.291	1.666	1.67	0.342	1.965	1.698	0.367	1.96
Section_044	1.546	0.322	1.852	1.549	0.381	2.194	1.74	0.409	2.196

	20% roughness increase			20% flow increase			Downstream boundary		
Label	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)
Section_045	1.532	0.279	1.702	1.548	0.329	2.01	1.751	0.338	1.966
Section_046	1.507	0.268	1.691	1.524	0.315	1.998	1.802	0.316	1.931
Section_047	1.48	0.263	1.701	1.497	0.31	2.01	1.794	0.306	1.929
Section_048	1.427	0.283	1.832	1.434	0.336	2.171	1.8	0.334	2.083
Section_049	1.388	0.28	1.857	1.393	0.332	2.201	1.829	0.332	2.102
Section_050	1.386	0.258	1.698	1.406	0.304	2.006	1.837	0.306	1.921
Section_051	1.38	0.247	1.606	1.407	0.291	1.895	1.844	0.296	1.822
Section_052	1.367	0.243	1.555	1.398	0.286	1.832	1.856	0.292	1.769
Section_053	1.367	0.22	1.417	1.408	0.258	1.666	1.866	0.263	1.607
Section_054	1.342	0.231	1.464	1.381	0.27	1.722	1.88	0.276	1.667
Section_055	1.36	0.18	1.213	1.413	0.211	1.424	1.892	0.21	1.358
Section_056	1.365	0.155	1.106	1.424	0.181	1.299	1.898	0.179	1.224
Section_057	1.231	0.216	1.551	1.269	0.254	1.828	2.338	0.249	1.718
Section_058	1.05	0.291	2.056	1.05	0.345	2.441	0.6	0.342	2.318

Table 2: Blockage scenarios results

	Blockage scenario 1			Blockage scenario 2			Blockage scenario 3		
Label	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)
Section_001	6.325	0.291	0.998	6.188	0.293	1.005	6.177	0.293	1.009
Section_002	6.311	0.317	1.037	6.173	0.32	1.043	6.161	0.319	1.042
Section_003	6.234	0.37	1.333	6.082	0.376	1.354	6.069	0.376	1.354
Section_004	6.241	0.351	0.923	6.09	0.352	0.926	6.077	0.352	0.926
Section_005	6.186	0.267	0.875	6.027	0.268	0.924	6.013	0.268	0.929
Section_006	6.17	0.208	0.859	6.007	0.209	0.904	5.993	0.209	0.908
Section_007	6.083	0.217	1.192	5.91	0.22	1.256	5.895	0.22	1.261
Section_008	6.009	0.229	1.534	5.829	0.243	1.608	5.813	0.244	1.615
Section_009	5.966	0.244	1.704	5.783	0.258	1.779	5.767	0.26	1.785
Section_010	5.602	0.271	1.83	5.632	0.27	1.829	5.615	0.271	1.836
Section_011	5.72	0.199	0.974	5.751	0.198	0.969	5.735	0.199	0.975
Section_012	5.471	0.294	1.993	5.505	0.292	1.983	5.485	0.294	1.995
Section_013	5.309	0.306	2.145	5.344	0.304	2.137	5.322	0.307	2.15
Section_014	5.211	0.302	2.017	5.249	0.299	2.007	5.224	0.302	2.022
Section_015	5.102	0.285	1.931	5.141	0.283	1.923	5.114	0.286	1.936
Section_016	4.942	0.316	2.207	4.982	0.315	2.2	4.953	0.317	2.215
Section_017	4.309	0.503	3.169	4.336	0.504	3.186	4.311	0.506	3.189
Section_018	5.049	0.231	1.398	5.091	0.231	1.379	5.06	0.231	1.4
Section_019	4.595	0.176	1.254	4.649	0.173	1.236	4.605	0.176	1.257
Section_020	4.207	0.358	2.256	4.287	0.345	2.19	4.217	0.358	2.258
Section_021	4.083	0.321	2.112	4.137	0.321	2.123	4.092	0.321	2.116
Section_022	3.879	0.398	2.602	3.908	0.407	2.668	3.888	0.399	2.607
Section_023	3.885	0.407	2.576	3.901	0.418	2.649	3.894	0.407	2.581
Section_024	3.554	0.589	3.297	3.526	0.618	3.441	3.563	0.589	3.3
Section_025	3.535	0.377	2.413	3.522	0.389	2.482	3.543	0.378	2.418

	Blockage scenario 1			Blockage scenario 2			Blockage scenario 3		
Label	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)
Section_026	3.474	0.363	2.318	3.475	0.367	2.349	3.483	0.363	2.323
Section_027	3.231	0.37	2.342	3.237	0.371	2.353	3.244	0.368	2.338
Section_028	2.9	0.499	2.853	2.907	0.5	2.861	2.95	0.492	2.808
Section_029	2.857	0.368	2.21	2.863	0.368	2.216	2.91	0.363	2.171
Section_030	2.769	0.391	2.016	2.776	0.391	2.018	2.835	0.388	1.998
Section_031	2.689	0.355	1.682	2.697	0.355	1.682	2.766	0.352	1.67
Section_032	2.636	0.261	1.434	2.644	0.261	1.434	2.72	0.258	1.417
Section_033	2.597	0.281	1.596	2.605	0.281	1.596	2.687	0.277	1.574
Section_034	2.575	0.251	1.433	2.583	0.251	1.433	2.67	0.246	1.411
Section_035	2.51	0.336	1.563	2.519	0.336	1.563	2.616	0.328	1.532
Section_036	2.352	0.306	1.461	2.362	0.306	1.462	2.489	0.296	1.391
Section_037	2.102	0.267	1.35	2.111	0.267	1.352	2.279	0.241	1.246
Section_038	1.948	0.343	1.651	1.956	0.343	1.654	2.156	0.302	1.508
Section_039	1.793	0.258	1.396	1.8	0.259	1.401	1.799	0.256	1.386
Section_040	1.711	0.302	1.6	1.717	0.303	1.606	1.716	0.3	1.594
Section_041	1.634	0.332	1.75	1.639	0.332	1.756	1.638	0.331	1.747
Section_042	1.569	0.324	1.748	1.574	0.325	1.755	1.574	0.323	1.745
Section_043	1.512	0.314	1.763	1.517	0.315	1.77	1.517	0.313	1.76
Section_044	1.415	0.346	1.952	1.419	0.347	1.961	1.421	0.345	1.95
Section_045	1.416	0.296	1.778	1.42	0.297	1.786	1.42	0.296	1.779
Section_046	1.398	0.281	1.759	1.402	0.283	1.767	1.402	0.282	1.761
Section_047	1.378	0.273	1.764	1.381	0.275	1.773	1.381	0.274	1.767
Section_048	1.331	0.294	1.896	1.334	0.295	1.906	1.333	0.295	1.9
Section_049	1.301	0.291	1.915	1.304	0.292	1.925	1.303	0.291	1.92
Section_050	1.309	0.267	1.747	1.312	0.269	1.756	1.312	0.268	1.752
Section_051	1.31	0.256	1.651	1.313	0.257	1.659	1.312	0.257	1.656
Section_052	1.303	0.252	1.596	1.305	0.253	1.604	1.305	0.253	1.602
Section_053	1.31	0.227	1.452	1.313	0.228	1.459	1.312	0.228	1.457
Section_054	1.289	0.238	1.499	1.292	0.239	1.507	1.291	0.238	1.505
Section_055	1.314	0.184	1.239	1.317	0.185	1.245	1.316	0.185	1.243
Section_056	1.322	0.158	1.128	1.325	0.159	1.133	1.324	0.159	1.132
Section_057	1.206	0.22	1.575	1.208	0.221	1.584	1.208	0.221	1.581
Section_058	1.05	0.294	2.078	1.05	0.296	2.09	1.05	0.295	2.086

Table 3: 1% and 0.1% AEP events with and without climate change

	1% AEP		1% AEP + CC		0.1% AEP			0.1% AEP + CC	
Label	Max Stage (mOD)	Max Velocity (m/s)	Max Stage (mOD)	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Velocity (m/s)
Section_001	5.536	0.996	5.946	0.987	6.177	0.293	1.009	6.61	1.061
Section_002	5.521	1.034	5.931	0.962	6.161	0.32	1.043	6.595	0.973
Section_003	5.405	1.342	5.831	1.339	6.069	0.376	1.354	6.511	1.349
Section_004	5.414	0.921	5.84	0.857	6.077	0.352	0.926	6.52	0.863
Section_005	5.349	0.903	5.776	0.917	6.013	0.268	0.929	6.456	0.962
Section_006	5.325	0.892	5.754	0.904	5.993	0.209	0.908	6.441	0.925

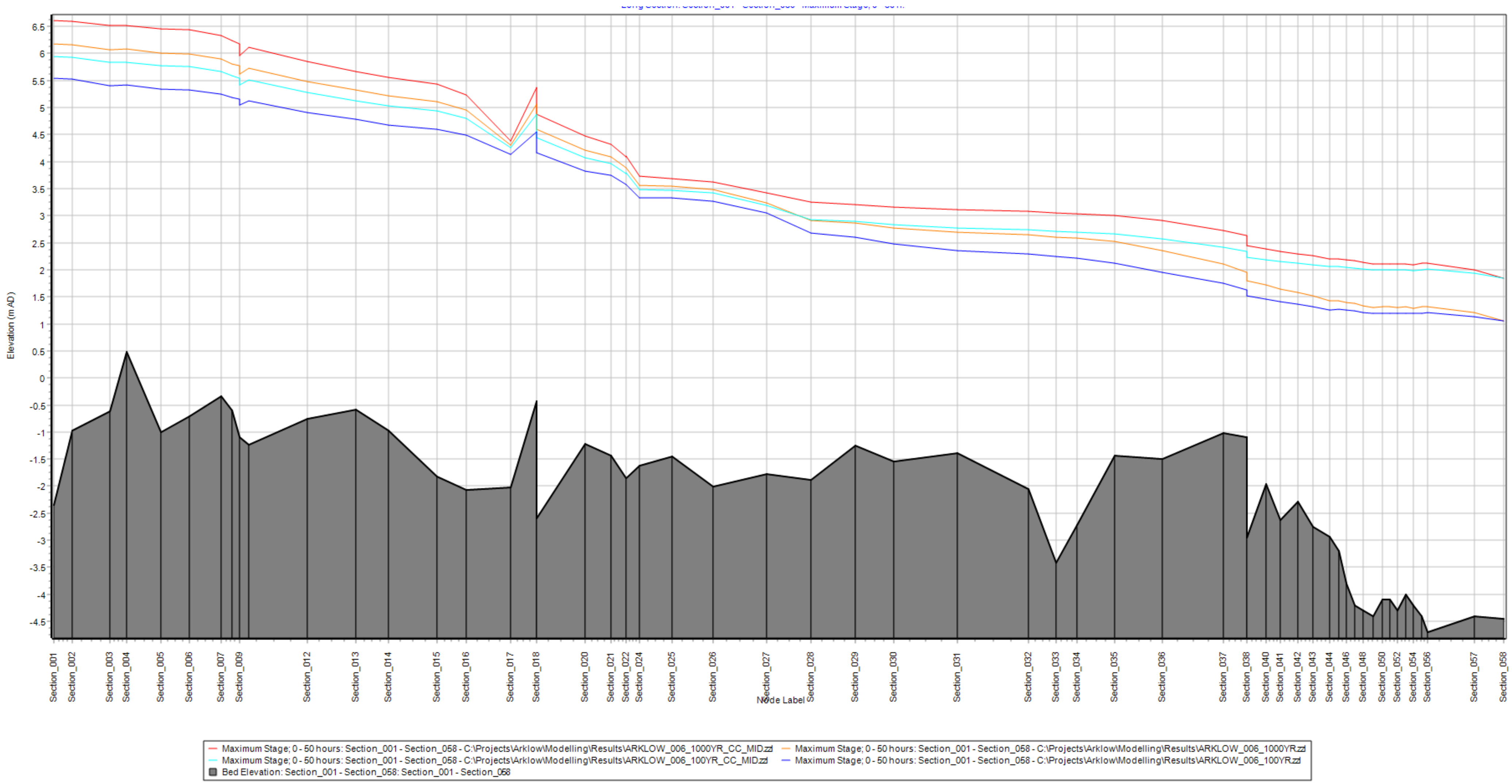
	1% AEP		1% AEP + CC		0.1% AEP			0.1% AEP + CC	
Label	Max Stage (mOD)	Max Velocity (m/s)	Max Stage (mOD)	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Velocity (m/s)
Section_007	5.248	1.131	5.663	1.217	5.895	0.22	1.261	6.338	1.306
Section_008	5.186	1.425	5.589	1.546	5.813	0.244	1.615	6.242	1.716
Section_009	5.155	1.544	5.549	1.697	5.767	0.26	1.786	6.184	1.926
Section_010	5.051	1.576	5.416	1.74	5.615	0.271	1.836	5.967	2
Section_011	5.129	0.91	5.519	0.954	5.734	0.199	0.975	6.116	1.009
Section_012	4.903	1.83	5.277	1.938	5.484	0.294	1.996	5.856	2.083
Section_013	4.777	1.899	5.13	2.058	5.321	0.307	2.15	5.667	2.297
Section_014	4.684	1.807	5.034	1.943	5.223	0.302	2.022	5.566	2.151
Section_015	4.605	1.676	4.936	1.841	5.114	0.286	1.936	5.435	2.096
Section_016	4.498	1.861	4.797	2.082	4.953	0.317	2.215	5.231	2.442
Section_017	4.132	2.479	4.26	2.93	4.31	0.506	3.189	4.382	3.655
Section_018	4.558	1.287	4.885	1.36	5.06	0.231	1.4	5.372	1.467
Section_019	4.163	1.125	4.451	1.211	4.604	0.177	1.258	4.881	1.336
Section_020	3.82	2.073	4.081	2.189	4.215	0.358	2.259	4.483	2.329
Section_021	3.741	1.86	3.971	2.027	4.091	0.321	2.117	4.321	2.255
Section_022	3.582	2.275	3.784	2.491	3.886	0.399	2.609	4.096	2.78
Section_023	3.584	2.263	3.789	2.47	3.892	0.408	2.583	4.105	2.743
Section_024	3.324	2.894	3.486	3.153	3.56	0.59	3.306	3.728	3.522
Section_025	3.328	2.036	3.476	2.278	3.539	0.379	2.421	3.692	2.636
Section_026	3.265	1.983	3.418	2.19	3.478	0.364	2.326	3.63	2.531
Section_027	3.049	2.053	3.198	2.208	3.235	0.37	2.348	3.426	2.431
Section_028	2.681	2.685	2.929	2.634	2.907	0.499	2.855	3.249	2.684
Section_029	2.607	2.111	2.895	2.035	2.863	0.368	2.212	3.209	2.124
Section_030	2.473	1.993	2.832	1.786	2.777	0.391	2.016	3.164	1.811
Section_031	2.363	1.662	2.777	1.347	2.697	0.355	1.682	3.112	1.394
Section_032	2.297	1.419	2.742	1.07	2.644	0.261	1.434	3.078	1.147
Section_033	2.246	1.581	2.716	1.123	2.605	0.281	1.596	3.052	1.197
Section_034	2.219	1.42	2.703	1.037	2.583	0.251	1.433	3.039	1.1
Section_035	2.13	1.55	2.663	1.032	2.519	0.336	1.563	2.999	1.083
Section_036	1.957	1.454	2.571	1.118	2.362	0.306	1.461	2.91	1.161
Section_037	1.75	1.226	2.424	1.055	2.111	0.267	1.352	2.733	1.162
Section_038	1.623	1.461	2.343	1.255	1.956	0.343	1.654	2.631	1.409
Section_039	1.526	1.17	2.233	1.079	1.8	0.259	1.401	2.454	1.255
Section_040	1.466	1.336	2.189	1.227	1.718	0.303	1.606	2.392	1.448
Section_041	1.41	1.447	2.152	1.322	1.639	0.332	1.756	2.338	1.579
Section_042	1.364	1.43	2.122	1.318	1.574	0.325	1.755	2.296	1.585
Section_043	1.326	1.426	2.098	1.326	1.517	0.315	1.77	2.261	1.601
Section_044	1.264	1.559	2.056	1.436	1.42	0.347	1.961	2.202	1.738
Section_045	1.265	1.408	2.056	1.334	1.42	0.297	1.786	2.201	1.624
Section_046	1.255	1.385	2.047	1.331	1.402	0.283	1.768	2.186	1.625
Section_047	1.242	1.383	2.036	1.34	1.381	0.275	1.773	2.17	1.641
Section_048	1.214	1.481	2.011	1.435	1.334	0.295	1.906	2.133	1.763
Section_049	1.196	1.49	1.993	1.464	1.304	0.292	1.925	2.103	1.808
Section_050	1.201	1.36	1.998	1.342	1.312	0.269	1.756	2.11	1.66
Section_051	1.201	1.287	1.999	1.272	1.313	0.257	1.659	2.109	1.578
Section_052	1.196	1.244	1.996	1.229	1.306	0.253	1.604	2.103	1.529

	1% AEP		1% AEP + CC		0.1% AEP			0.1% AEP + CC	
Label	Max Stage (mOD)	Max Velocity (m/s)	Max Stage (mOD)	Max Velocity (m/s)	Max Stage (mOD)	Max Fr	Max Velocity (m/s)	Max Stage (mOD)	Max Velocity (m/s)
Section_053	1.2	1.132	2.001	1.121	1.313	0.228	1.46	2.112	1.395
Section_054	1.187	1.168	1.991	1.149	1.292	0.239	1.507	2.096	1.433
Section_055	1.202	0.964	2.011	0.968	1.317	0.185	1.245	2.116	1.211
Section_056	1.207	0.876	2.021	0.896	1.325	0.159	1.134	2.122	1.126
Section_057	1.139	1.212	1.973	1.257	1.208	0.221	1.584	2.002	1.616
Section_058	1.05	1.578	1.85	1.632	1.05	0.296	2.09	1.85	2.122

Table 4: Arklow Scheme (debris catcher), breach and development option scenarios

	Arklow Scheme (0.1% AEP +CC)		Breach (0.1% AEP)		Option development (0.1% AEP +CC)	
Label	Max Stage (mOD)	Max Velocity (m/s)	Max Stage (mOD)	Max Velocity (m/s)	Max Stage (mOD)	Max Velocity (m/s)
Section_001	6.595	0.973	5.884	1.113	6.685	1.041
Section_002	6.511	1.346	5.864	1.043	6.67	0.968
Section_003	6.52	0.86	5.726	1.354	6.593	1.349
Section_004	6.456	0.962	5.738	0.926	6.601	0.863
Section_005	6.441	0.925	5.651	1.06	6.541	0.942
Section_006	6.338	1.306	5.643	0.967	6.524	0.918
Section_007	6.242	1.715	5.572	1.184	6.419	1.307
Section_008	6.183	1.925	5.503	1.498	6.322	1.721
Section_009	4.879	1.334	5.467	1.638	6.261	1.943
Section_010	5.967	1.999	5.344	1.677	6.024	2.025
Section_011	6.116	1.008	5.438	0.931	6.178	1.014
Section_012	5.856	2.082	5.208	1.883	5.917	2.095
Section_013	5.667	2.296	5.073	1.984	5.723	2.319
Section_014	5.566	2.15	4.982	1.873	5.622	2.171
Section_015	5.434	2.095	4.894	1.765	5.487	2.12
Section_016	5.231	2.441	4.769	1.987	5.277	2.478
Section_017	4.382	3.653	4.302	2.749	4.384	3.748
Section_018	5.372	1.465	4.852	1.31	5.42	1.479
Section_019	4.482	2.326	4.449	1.158	4.921	1.349
Section_020	4.32	2.252	4.123	2.107	4.524	2.337
Section_021	4.095	2.775	4.042	1.897	4.355	2.275
Section_022	3.055	1.567	3.798	2.488	4.128	2.804
Section_023	4.105	2.738	3.803	2.467	4.137	2.765
Section_024	3.729	3.513	3.5	3.151	3.754	3.552
Section_025	3.693	2.629	3.486	2.286	3.715	2.667
Section_026	3.631	2.526	3.425	2.206	3.652	2.564
Section_027	3.431	2.418	3.199	2.232	3.453	2.448
Section_028	3.26	2.661	2.906	2.75	3.284	2.686
Section_029	3.222	2.102	2.862	2.144	3.245	2.13
Section_030	3.176	1.798	2.78	2.016	3.2	1.816
Section_031	3.145	1.322	2.7	1.682	3.149	1.398
Section_032	3.054	1.09	2.646	1.434	3.114	1.153

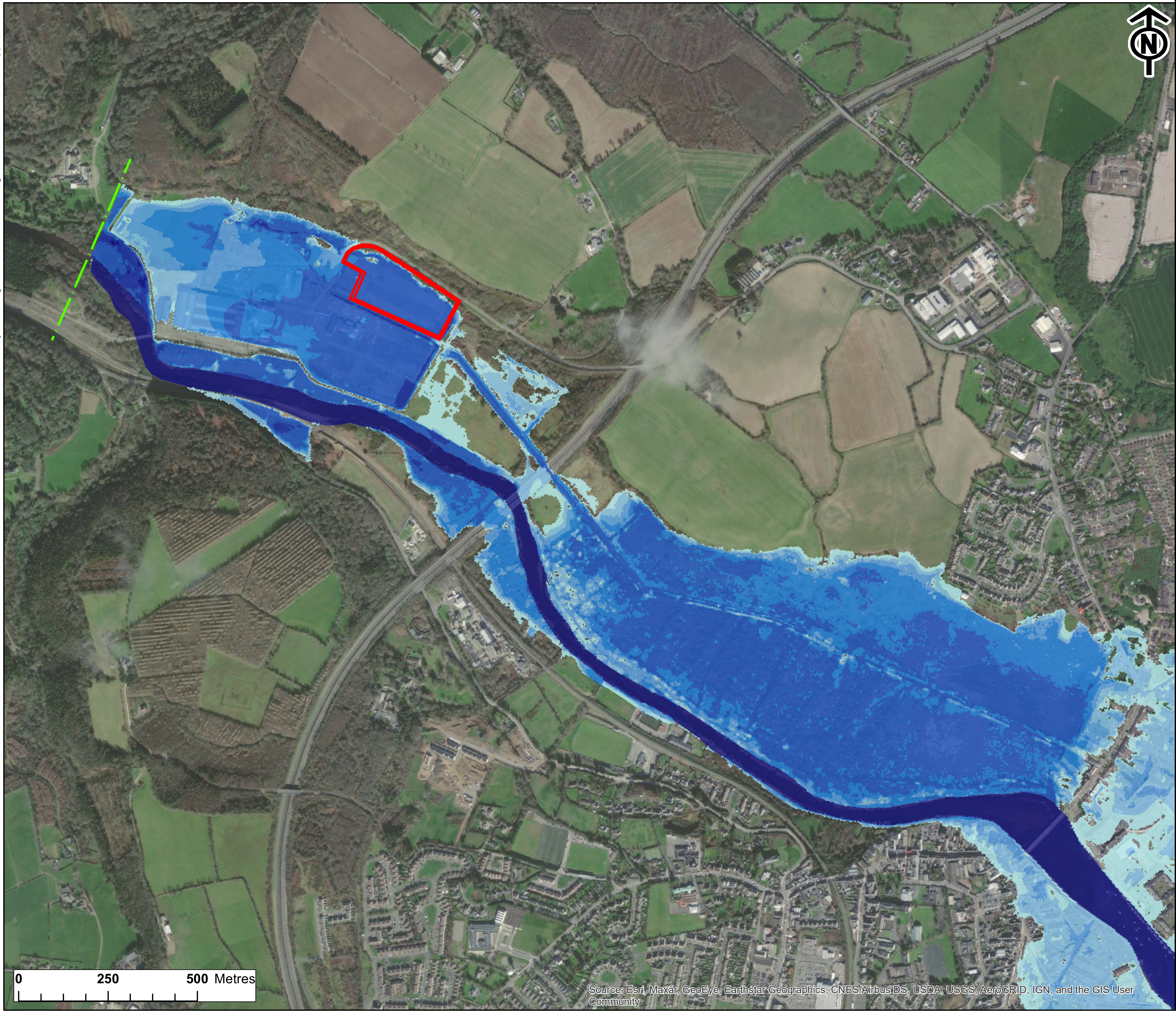
Section_033	3.041	1.019	2.607	1.596	3.088	1.202
	Arklow Scheme (0.1% AEP +CC)		**Breach (0.1% AEP)**		**Option development (0.1% AEP +CC)**	
Label	**Max Stage (mOD)**	**Max Velocity (m/s)**	**Max Stage (mOD)**	**Max Velocity (m/s)**	**Max Stage (mOD)**	**Max Velocity (m/s)**
Section_034	3.001	1.026	2.584	1.433	3.075	1.105
Section_035	2.911	1.132	2.52	1.563	3.036	1.086
Section_036	2.732	1.159	2.364	1.459	2.948	1.163
Section_037	2.63	1.408	2.112	1.352	2.77	1.167
Section_038	2.63	0.02	1.957	1.654	2.667	1.417
Section_039	2.392	1.447	1.801	1.401	2.48	1.269
Section_040	2.338	1.578	1.718	1.606	2.416	1.466
Section_041	2.296	1.584	1.64	1.757	2.36	1.6
Section_042	2.261	1.6	1.575	1.755	2.317	1.609
Section_043	2.202	1.737	1.518	1.771	2.281	1.625
Section_044	2.201	1.623	1.42	1.962	2.22	1.765
Section_045	2.186	1.625	1.42	1.787	2.219	1.65
Section_046	2.171	1.641	1.402	1.768	2.204	1.652
Section_047	2.133	1.762	1.382	1.773	2.187	1.669
Section_048	2.103	1.808	1.334	1.907	2.148	1.793
Section_049	2.11	1.659	1.304	1.926	2.117	1.841
Section_050	2.109	1.578	1.313	1.757	2.124	1.69
Section_051	2.103	1.529	1.313	1.66	2.123	1.607
Section_052	2.112	1.395	1.306	1.605	2.117	1.558
Section_053	2.096	1.433	1.313	1.46	2.126	1.422
Section_054	2.117	1.211	1.292	1.508	2.109	1.461
Section_055	2.122	1.126	1.317	1.246	2.13	1.235
Section_056	2.002	1.616	1.325	1.134	2.136	1.149
Section_057	1.85	2.122	1.209	1.584	2.01	1.654
Section_058	4.095	0.02	1.05	2.091	1.85	2.174



Long section showing 1% and 0.1% AEP events with and without climate change

Appendix E – Flood maps

Project Management Initials SH Designer: MH Checked: SH Approved: DH



PROJECT

Arklow Substation, Avoca River Park - FRA

CLIENT

SSE

Legend

Upstream extent of model

Site boundary

0.1% AEP event +CC

Depth (m)

0 - 0.5

0.5 - 1

1 - 1.5

1.5 - 2

2 - 3

3 - 4

4 - 4.59

* River levels are not shown depth varied

Scale 1:10,000

PROJECT NUMBER

60605933

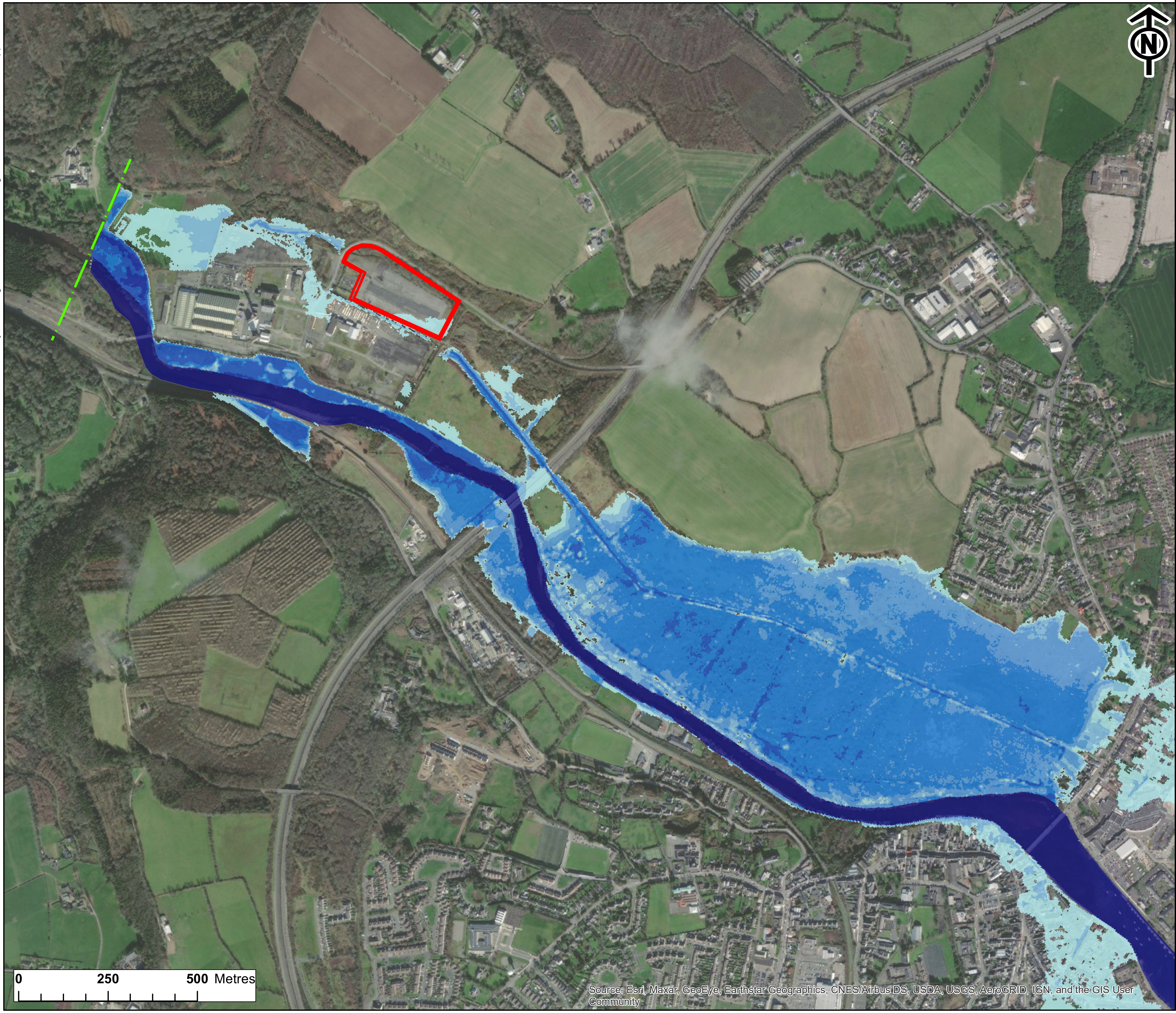
SHEET TITLE

Figure 1: 0.1% AEP +CC event

SHEET NUMBER

Sheet 1 of 7

Project Management Initials SH Designer: MH Checked: SH Approved: DH



PROJECT

Arklow Substation, Avoca River Park - FRA

CLIENT

SSE

Legend

Upstream extent of model

Site boundary

0.1% AEP event

Depth (m)

0 - 0.5

0.5 - 1

1 - 1.5

1.5 - 2

2 - 3

3 - 4

4 - 4.25

* River levels are not shown depth varied

Scale 1:10,000

PROJECT NUMBER

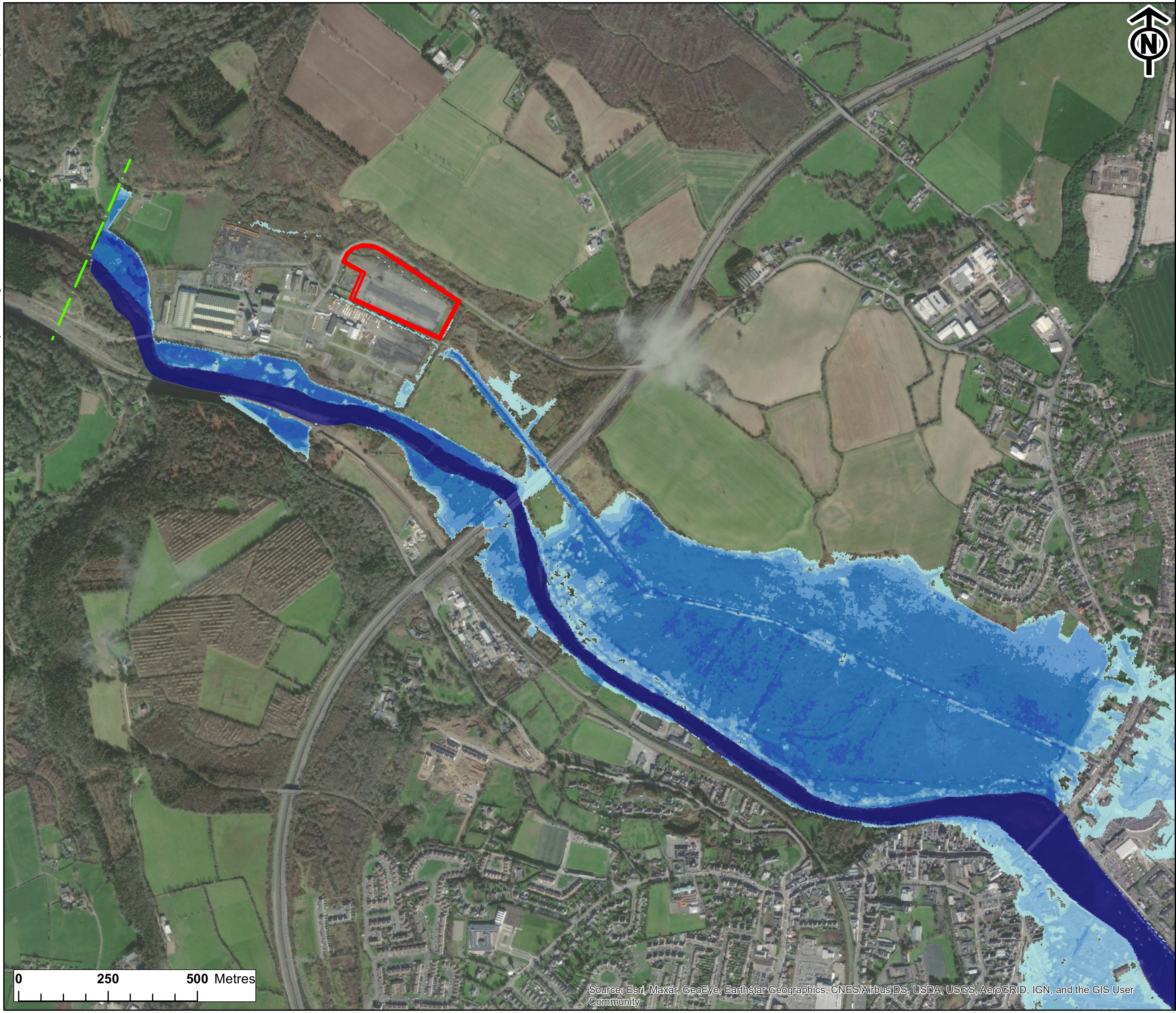
60605933

SHEET TITLE

Figure 2: 0.1% AEP event

SHEET NUMBER

Sheet 2 of 7



Project Management Initials SH Designer: MH Checked: SH Approved: DH

PROJECT

Arklow Substation, Avoca River Park - FRA

CLIENT

SSE

Legend

Upstream extent of model

Site boundary

1% AEP event +CC

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4.05

* River levels are not shown depth varied

Scale 1:10,000

PROJECT NUMBER

60605933

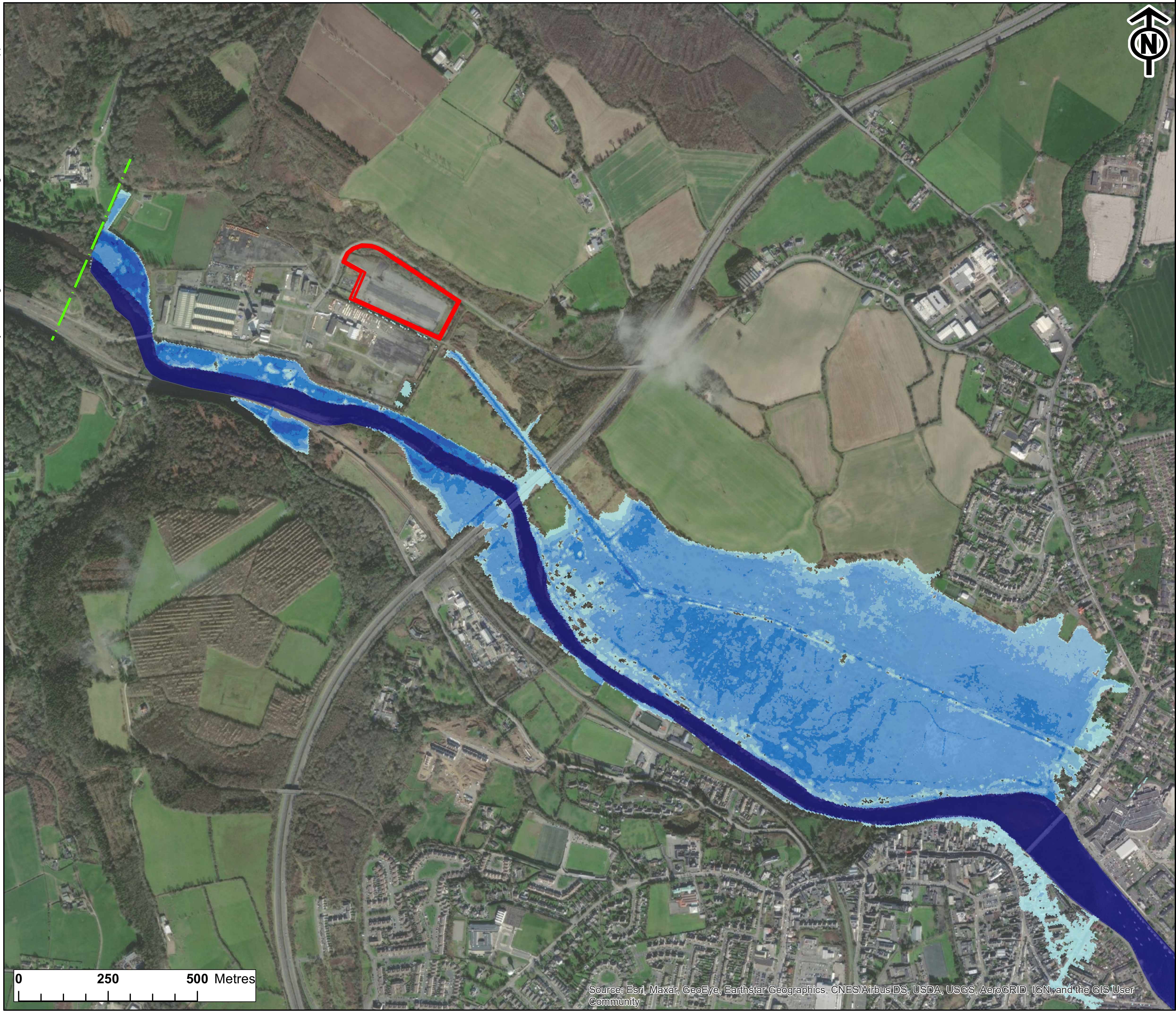
SHEET TITLE

Figure 3: 1% AEP +CC event

SHEET NUMBER

Sheet 3 of 7

Project Management Initials SH Designer: MH Checked: SH Approved: DH



PROJECT

Arklow Substation, Avoca River Park - FRA

CLIENT

SSE

Legend

Upstream extent of model

Site boundary

1% AEP event

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 3.74

* River levels are not shown depth varied

Scale 1:10,000

PROJECT NUMBER

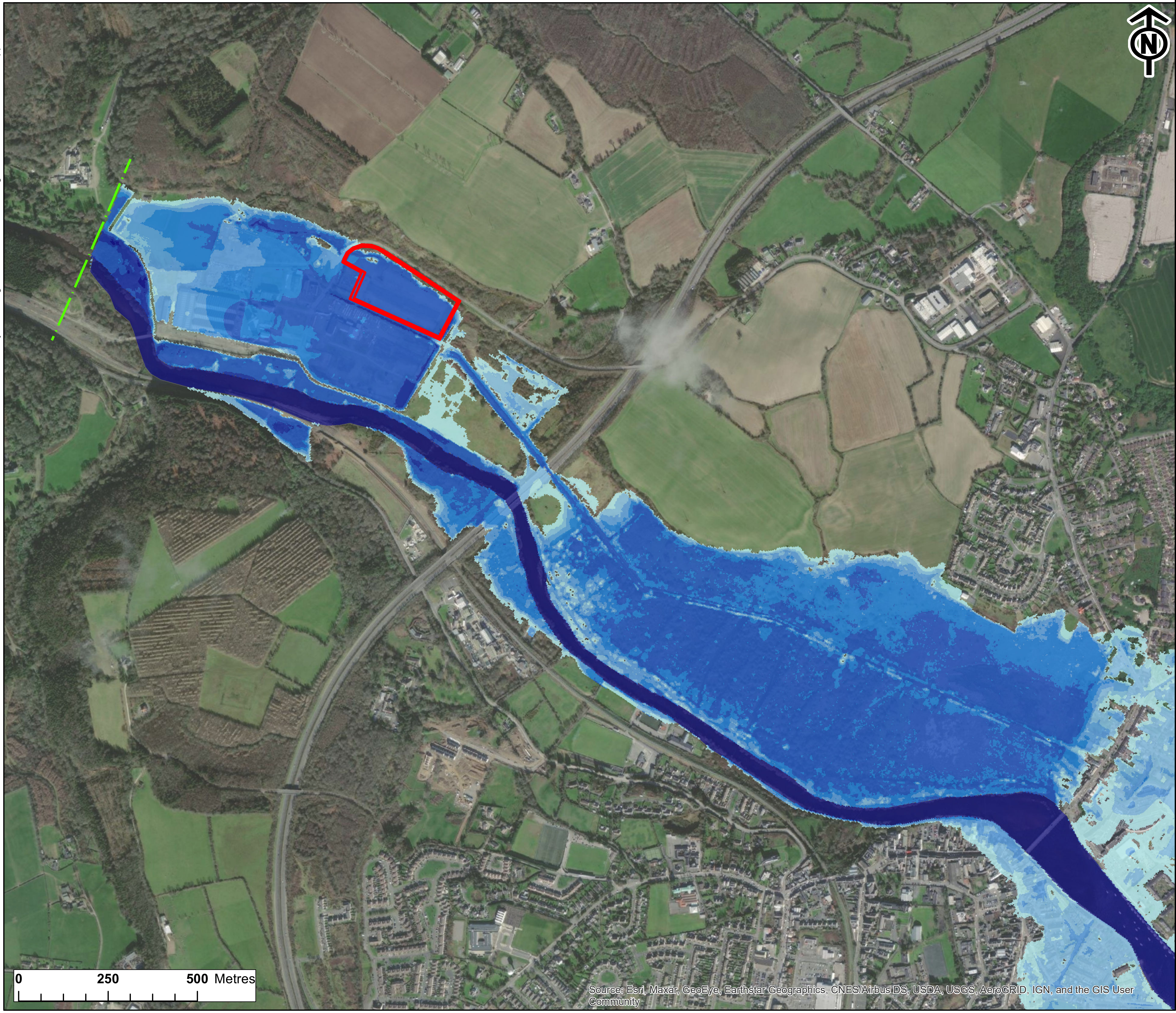
60605933

SHEET TITLE

Figure 4: 1% AEP event

SHEET NUMBER

Sheet 4 of 7



PROJECT

Arklow Substation, Avoca River Park - FRA

CLIENT

SSE

Legend

Upstream extent of model

Site boundary

0.1% AEP +CC event - Scheme

Depth (m)

0 - 0.5

0.5 - 1

1 - 1.5

1.5 - 2

2 - 3

3 - 4

4 - 4.60

* River levels are not shown depth varied

Scale 1:10,000

PROJECT NUMBER

60605933

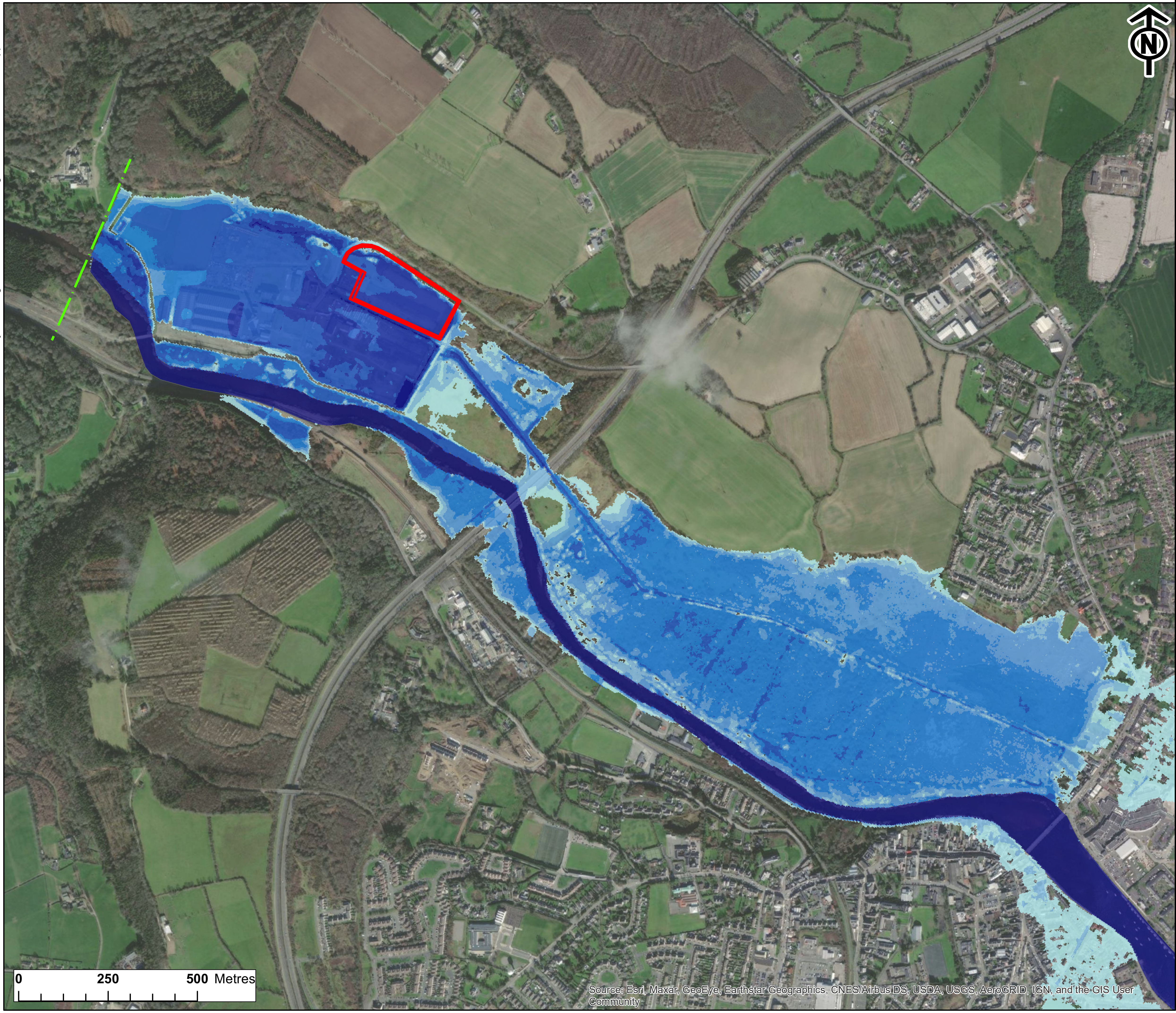
SHEET TITLE

Figure 5: 0.1% AEP +CC event - Arklow Scheme debris catcher

SHEET NUMBER

Sheet 5 of 7

Project Management Initials SH Designer: MH Checked: SH Approved: DH



PROJECT

Arklow Substation, Avoca River Park - FRA

CLIENT

SSE

Legend

- Upstream extent of model
- Site boundary

0.1% AEP event - breach

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4
- 4 - 4.35

* River levels are not shown depth varied

Scale 1:10,000

PROJECT NUMBER

60605933

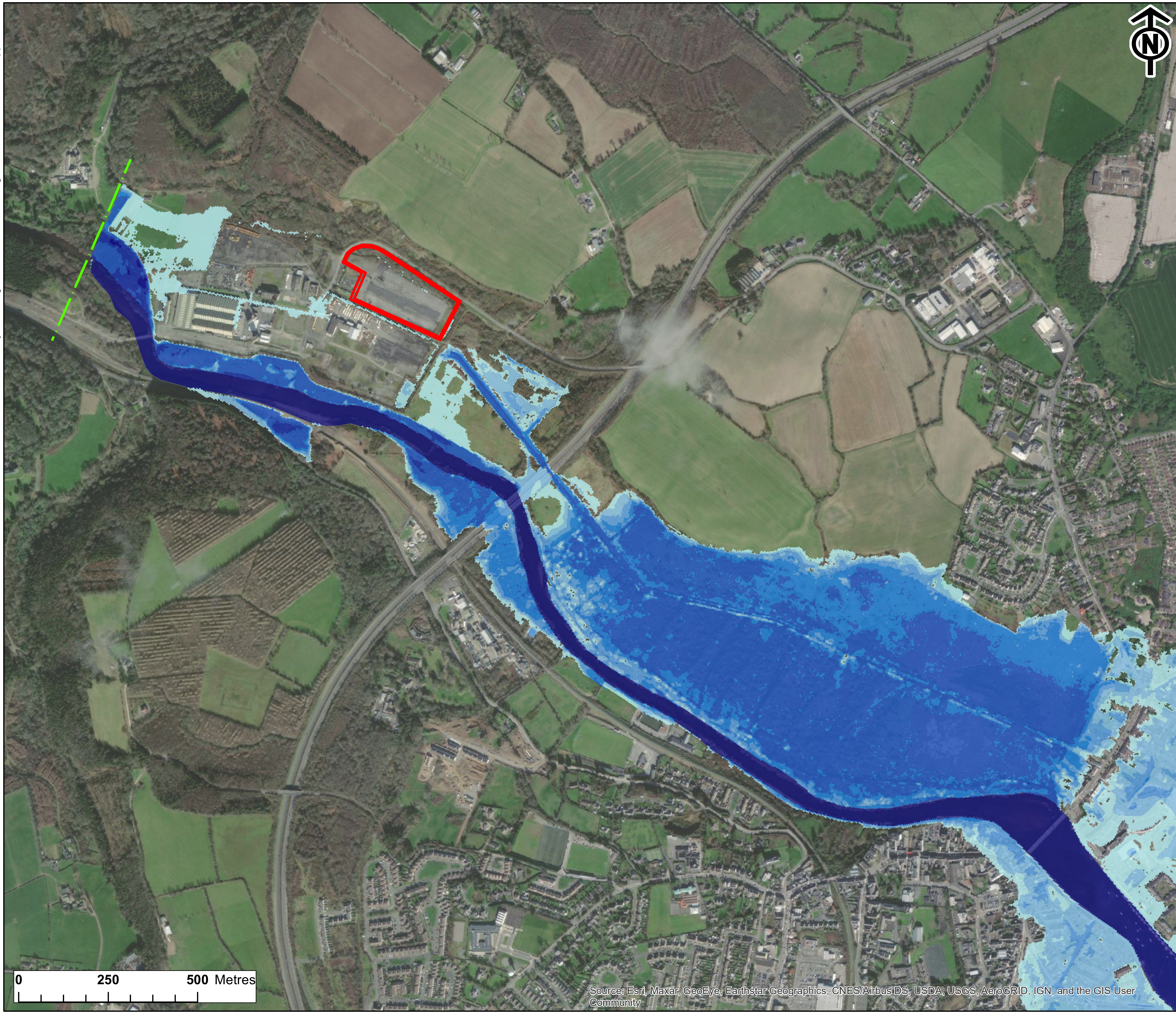
SHEET TITLE

Figure 6: 0.1% AEP event - Breach scenario

SHEET NUMBER

Sheet 6 of 7

Project Management Initials SH Designer: MH Checked: SH Approved: DH



PROJECT

Arklow Substation, Avoca River Park - FRA

CLIENT

SSE

Legend

Upstream extent of model

Site boundary

0.1% AEP event +CC - Option

Depth (m)

- 0 - 0.5
- 0.5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 3
- 3 - 4
- 4 - 4.65

* River levels are not shown depth varied

Scale 1:10,000

PROJECT NUMBER

60605933

SHEET TITLE

Figure 7: 0.1% AEP event - Development option

SHEET NUMBER

Sheet 7 of 7