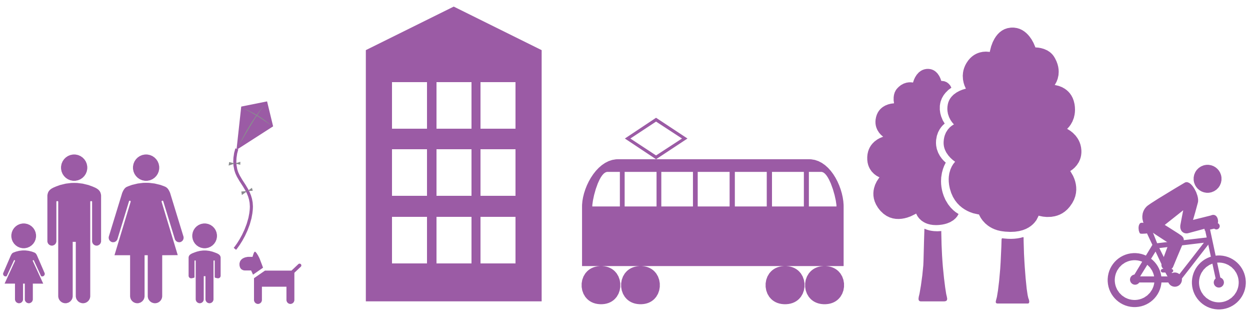
Castlelands

Masterplan

March 2021



Appendix 4
Surface Water Management Plan

Contents

Appendices

1 Introduction

1.1 Context

Arup was commissioned by Fingal County Council to prepare a Surface Water Management Plan (SWMP) for the Castlelands Masterplan, Balbriggan, Co. Dublin.

The main aim of the study is to inform the Masterplan of the area with respect to surface water management. The SWMP consists of two key integral parts;

i. Strategic Flood Risk Assessment (SFRA)

ii. Sustainable Drainage Strategy (SDS)

1.2 Scope

The scope of the study is as follows:

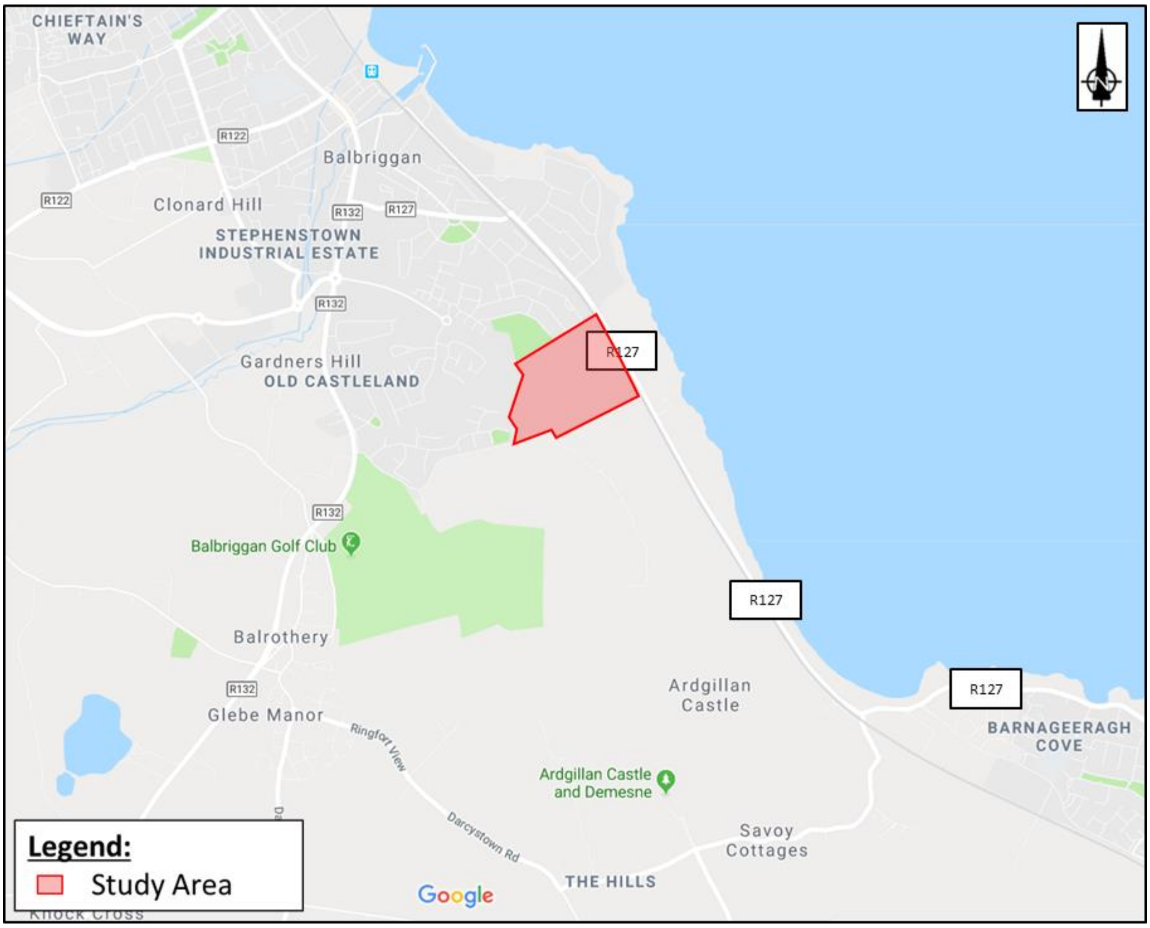
- Undertake a site visit to gain a thorough understanding of the flood risk at the site, and ground truth all topographical datasets and historic flood maps.
- Scope and procure any new topographic surveys of the site that may be required to facilitate the study.
- Undertake a hydrological assessment of the site including all relevant watercourses and an estimation of the contributing catchment.
- Develop a detailed 1D/2D hydraulic model of the river from source to sea in order to investigate fluvial, coastal and pluvial flood risk.
- Assessment of any existing flood defence infrastructure and the consequences of their subsequent failure.
- Determination of the predicted cause of flooding.
- Preparation of flood maps for the lands.
- Review of the existing drainage network servicing the lands.
- Review of Sustainable Drainage best practice in order to inform the SDS for the Masterplan lands.
- Review of the current Fingal County Council Development Plan.
- Consideration of the effects of climate change.
- Review of historical planning submissions to inform existing ground conditions.
- Preparation of Sustainable Drainage Maps including potential locations and approximate sizing of SuDS features.
- Recommendation for discharge rates for the site.

- Recommendations for future development on the site with respect to Flood Risk and Sustainable Drainage.
- Preparation of a SWMP Report that sets out key findings.

1.3 Study Area

The study area is located south of Balbriggan town adjacent to the R127 and the Dublin - Belfast railway line. Figure 1 presents the study area.

Figure 1: Study Area – Google Maps



2 Site Description & Development Proposal

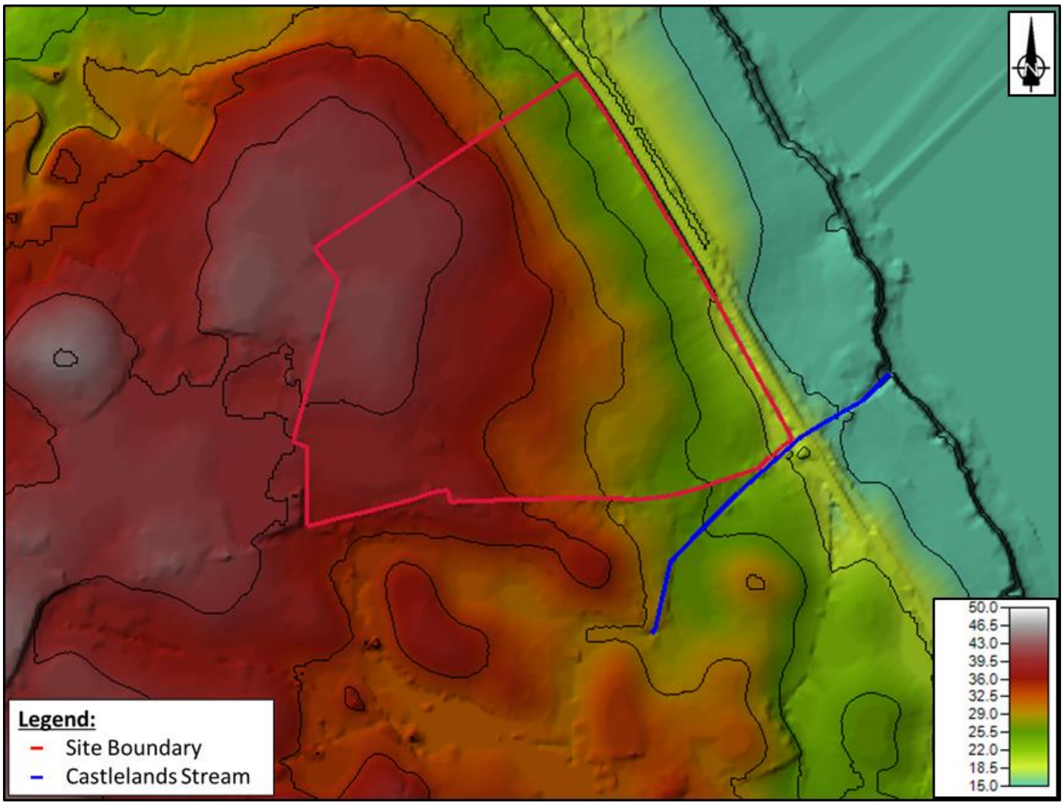
The Castlelands Masterplan lands are located south of Balbriggan town bounded by the Dublin – Belfast railway line on the eastern boundary and the Pinewood development to the north. The site is currently a greenfield site with residential developments in close proximity to the north and west.

An unnamed stream is located in the south-eastern corner of the site where it enters a culvert to underneath the railway line. For ease of reference throughout this report this stream will be referred to as the "Castlelands Stream." The location of the site and the Castlelands Stream can be seen in Figure 2 below.

Figure 2: Site Location – Bing Maps

The overall site is approximately 24.1 ha. The topography of the site varies significantly across the site with site levels ranging from approximately 41.5mOD (Malin Head) at the north-western corner of the site to 18.1m OD at the south-eastern corner of the site. Refer to Figure 3 below for terrain mapping illustrating site levels.

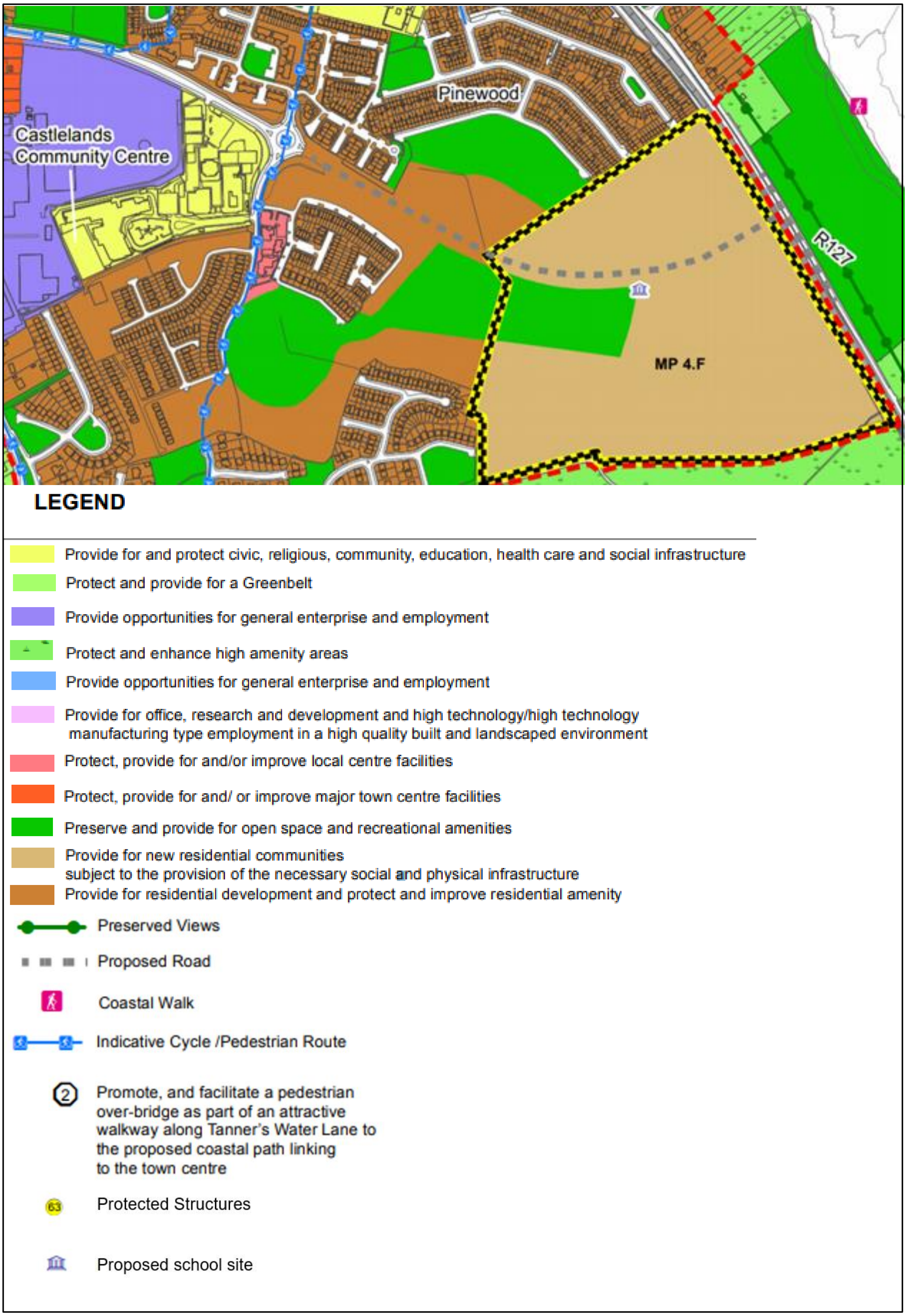
Figure 3: Existing Ground Levels (Malin Head)



Ground investigation for the site was not conducted however, this is recommended pre-construction in order to improve the assessment of the site-specific infiltration and/or run-off characteristics. Photographs of the existing ground conditions from the site walkover can be seen in Appendix A3. The photographs indicate rocky material as well as saturated clay material and thus for the purpose of this study, Soil Type 4 was used in all relevant calculations to represent the existing low permeability of the site-specific ground conditions.

Figure 4 below is an extract from the Fingal County Council Zoning Map which indicates that the majority of the lands are currently zoned as Residential Area (RA). The lands also contain a proposed road, a proposed primary school and an area of open space/recreational amenities.

Figure 4: Southern Environs Zoning Map (Extract)



3 Data Collection

A site walkover was carried out on 25 October 2018 to record the topographical features of the site and assess constraints and opportunities. Refer to Appendix A2 for photographs taken during the walkover.

River survey data was provided by Murphy Surveys Ltd (October 2018). The survey data consisted of a long section along the relevant watercourses, cross-sections and photographs along the watercourses as well as at any structures along the watercourses. Appendix A1 presents the topographic survey data and this was collected using the following equipment and accuracy:

- Trimble SPS850 Base - H +/-10mm+1ppm, V +/20mm+1ppm.
- Trimble R6 VRS Rover with TSC 3 loggers - H +/-15mm+1ppm, V+/20mm+1ppm.
- Trimble S6 Total Station - +/- 3mm+2ppm.

Terrain mapping was created using Civil 3D and the contour data provided by Fingal County Council (October 2018). This was used to define the surrounding ground elevations and subsequently the floodplain within the hydraulic model.

The following data was also collected and reviewed:

- Flooding history of the site from the OPW National Flood Hazard Mapping website (www.floodmaps.ie).
- Site geological data from the Geological Survey of Ireland website (www.gsi.ie).
- Fingal Development Plan 2017 – 2023.
- Ordnance Survey Ireland Discovery Series Map.
- Fingal East Meath Flood Risk Assessment and Management Study (FEM FRAMS).

All levels quoted in this report relate to Malin Head datum.

4 Planning Context

4.1 Introduction

The following planning policy documents are relevant to the preparation of this SWMP.

- The national planning guidelines published by the OPW and the Department of the Environment, Heritage and Local Government in November 2009 entitled 'The Planning System and Flood Risk Management: Guidelines for Planning Authorities'.
- In terms of planning policy context, the provisions of the Fingal Development Plan 2017 – 2023.

4.2 The Planning System and Flood Risk Management Guidelines

4.2.1 Introduction

In November 2009, the Department of Environment, Heritage and Local Government and the Office of Public works jointly published a Guidance Document for Planning Authorities entitled "The Planning System and Flood Risk Management".

The guidelines are issued under Section 28 of the Planning and Development Act 2000 and Planning Authorities and An Bord Pleanála are therefore required to implement these Guidelines in carrying out their functions under the Planning Acts.

The aim of the guidelines is to ensure that flood risk is neither created nor increased by inappropriate development.

The guidelines require the planning system to avoid development in areas at risk of flooding, unless they can be justified on wider sustainability grounds, where the risk can be reduced or managed to an acceptable level.

They require the adoption of a Sequential Approach (to Flood Risk Management) of Avoidance, Reduction, Justification and Mitigation and they require the incorporation of Flood Risk Assessment into the process of making decisions on planning applications and planning appeals.

Fundamental to the guidelines is the introduction of flood risk zoning and the classifications of different types of development having regard to their vulnerability.

The management of flood risk is now a key element of any development proposal in an area of potential flood risk and should therefore be addressed as early as possible in the site master planning stage.

4.2.2 Definition of flood zones

Flood Zones are geographical areas within which the likelihood of flooding is in a particular range.

There are three types of flood zones defined in the Guidelines. Refer Table 1 below.

Table 1: Flood zone definitions

Flood Zone A	Probability of flooding from rivers and the sea is highest (greater than 1% or 1 in 100 for river flooding or 0.5% or 1 in 200 for coastal flooding).
Flood Zone B	Probability of flooding from rivers and the sea is moderate (between 0.1% or 1 in 1000 year and 1% or 1 in 100 for river flooding and between 0.1% or 1 in 1000 year and 0.5% or 1 in 200 for coastal flooding); and
Flood Zone C	Probability of flooding from rivers and the sea is low (less than 0.1% or 1 in 1000 for both river and coastal flooding). Flood Zone C covers all areas of the plan which are not in zones A or B.

4.2.3 Definition of vulnerability classes

Table 2 summarises the Vulnerability Classes defined in the Guidelines and provides a sample of the most common type of development applicable to each.

Table 2: Vulnerability classes

Highly Vulnerable Development	Includes Garda, ambulance and fire stations, hospitals, schools, residential dwellings, residential institutions, essential infrastructure, such as primary transport and utilities distribution and SEVESO and IPPC sites, etc.
Less Vulnerable Development	Includes retail, leisure, warehousing, commercial, industrial and non-residential institutions, etc.
Water Compatible Development	Includes Flood Control Infrastructure, docks, marinas, wharves, navigation facilities, water-based recreation facilities, amenity open spaces and outdoor sport and recreation facilities

4.2.4 Types of vulnerability class appropriate to each zone

Table 3 illustrates the different types of Vulnerability Class appropriate to each Zone and indicates where a Justification Test will be required.

Table 3: Justification test applicability

	Flood Zone A	Flood Zone B	Flood Zone C
Highly Vulnerable	Justification Test	Justification Test	Appropriate
Less Vulnerable	Justification Test	Appropriate	Appropriate
Water Compatible	Appropriate	Appropriate	Appropriate

The flood risk management guidelines recognise that there is a need to reconcile the desire to avoid development in areas at risk of flooding while also ensuring sequential and compact urban development as several large urban centres are already located in areas that are at risk of flooding. Section 3.7 of the guidelines state the following;

"*Notwithstanding the need for future development to avoid areas at risk of flooding, it is recognised that the existing urban structure of the country contains many well-established cities and urban centres, which will continue to be at risk of flooding. At the same time such centres may also have been targeted for growth in the National Spatial Strategy, regional planning guidelines and the various city and county development plans taking account of historical patterns of development and their national and strategic value. In addition, development plans have identified various strategically located urban centres and particularly city and town centre areas whose continued growth and development is being encouraged in order to bring about compact and sustainable urban development and more balanced regional development. Furthermore, development plan guidelines, issued by the Minister for the Environment, Heritage and Local Government under Section 28 of the Planning and Development Act 2000, have underlined the importance of compact and sequential development of urban areas with a focus on town and city centre locations for major retailing and higher residential densities*".

4.3 Fingal Development Plan 2017 - 2023

Chapter 7.2 of the Fingal Development Plan outlines specific objectives for Surface Water and Flood Risk Management which have been developed in accordance with "The Planning System and Flood Risk Management Guidelines for Planning Authorities, 2009." These objectives ensure that surface water and flood risk management is fully integrated into the County Development Plan. The objectives outlined in Chapter 7.2 are presented below and are applicable to Castlelands.

- **Objective SW01**

  Protect and enhance the County's floodplains, wetlands and coastal areas subject to flooding as vital green infrastructure which provides space for storage and conveyance of floodwater, enabling flood risk to be more effectively managed and reducing the need to provide flood defences in the future and ensure that development does not impact on important wetland sites within river/stream catchments.

- **Objective SW02**

  Allow no new development within floodplains other than development which satisfies the justification test, as outlined in the Planning System and Flood Risk Management Guidelines 2009 for Planning Authorities (or any updated guidelines).

- **Objective SW03**

  Identify existing surface water drainage systems vulnerable to flooding and develop proposals to alleviate flooding in the areas served by these systems.

- **Objective SW04**

  Require the use of sustainable drainage systems (SuDS) to minimise and limit the extent of hard surfacing and paving and require the use of sustainable drainage techniques where appropriate, for new development or for extensions to existing developments, in order to reduce the potential impact of existing and predicted flooding risks.

- **Objective SW05**

  Discourage the use of hard non-porous surfacing and pavements within the boundaries of rural housing sites.

- **Objective SW06**

  Encourage the use of Green Roofs particularly on apartment, commercial, leisure and educational buildings.

- **Objective SW07**

  Implement the Planning System and Flood Risk Management-Guidelines for Planning Authorities (DoEHLG/OPW 2009) or any updated version of these guidelines. A site-specific Flood Risk Assessment to an appropriate level of detail, addressing all potential sources of flood risk, is required for lands identified in the SFRA, located in the following areas: Courtlough; Ballymadun; Rowlestown; Ballyboghil; Coolatrath; Milverton, Skerries; Channell Road, Rush; Blakescross; Lanestown/Turvey; Lissenhall, Swords; Balheary, Swords; Village/Marina Area, Malahide; Streamstown, Malahide; Balgriffin; Damastown, Macetown and Clonee, Blanchardstown; Mulhuddart, Blanchardstown; Portrane; Sutton; and Howth, demonstrating compliance with the aforementioned Guidelines or any updated version of these guidelines, paying particular attention to residual flood risks and any proposed site specific flood management measures.

- **Objective SW08**

  Implement the recommendations of the Fingal East Meath Flood Risk Assessment and Management Study (FEMFRAMS).

- **Objective SW09**

  Assess and implement the recommendations of the Eastern CFRAMS when complete.

- **Objective SW10**

  Require the provision of regional stormwater control facilities for all Local Area Plan lands and Strategic Development Zones with a view to also incorporating these control facilities in currently developed catchments prone to flooding.

- **Objective SW11**

  Ensure that where flood protection or alleviation works take place that the natural and cultural heritage of rivers, streams and watercourses are protected and enhanced to the greatest extent possible.

- **Objective SW12**

  Require an environmental assessment of all proposed flood protection or alleviation works.

- **Objective SW13**

  Provide for the schemes listed in Table SW01:

TABLE SW01: SURFACE WATER SCHEMES
1. Implementation of Fingal East Meath Flood Risk Assessment and Management Study (FEM-FRAMS), Measures – Flood Mitigation
2. Implementation of CFRAMS: Eastern CFRAMS Measures
3. Early Flood Warning System
4. Donabate Surface Water System
5. Garristown Surface Water System

Part A: Strategic Flood Risk Assessment

5 Definition of Flood Hazard & Flood Mechanisms

5.1 Potential Sources of Flooding

The potential sources of flooding considered for the proposed site can be categorised as:

Fluvial Flooding

Fluvial flooding occurs when rivers exceed their capacity due to sustained or heavy precipitation. The potential risk of fluvial flooding at the site is from the Castlelands Stream.

Coastal Flooding

Coastal flooding occurs when normally dry, low-lying land is flooded by sea water. The potential risk of coastal flooding is applicable at this site due its proximity to the coastline.

Pluvial flooding

Pluvial flooding occurs when the capacity of the local urban drainage network is exceeded during periods of intense rainfall. At these times, water can collect at low points in the topography and cause flooding. The potential risk of pluvial flooding is applicable at this site based on the existing topography of the site.

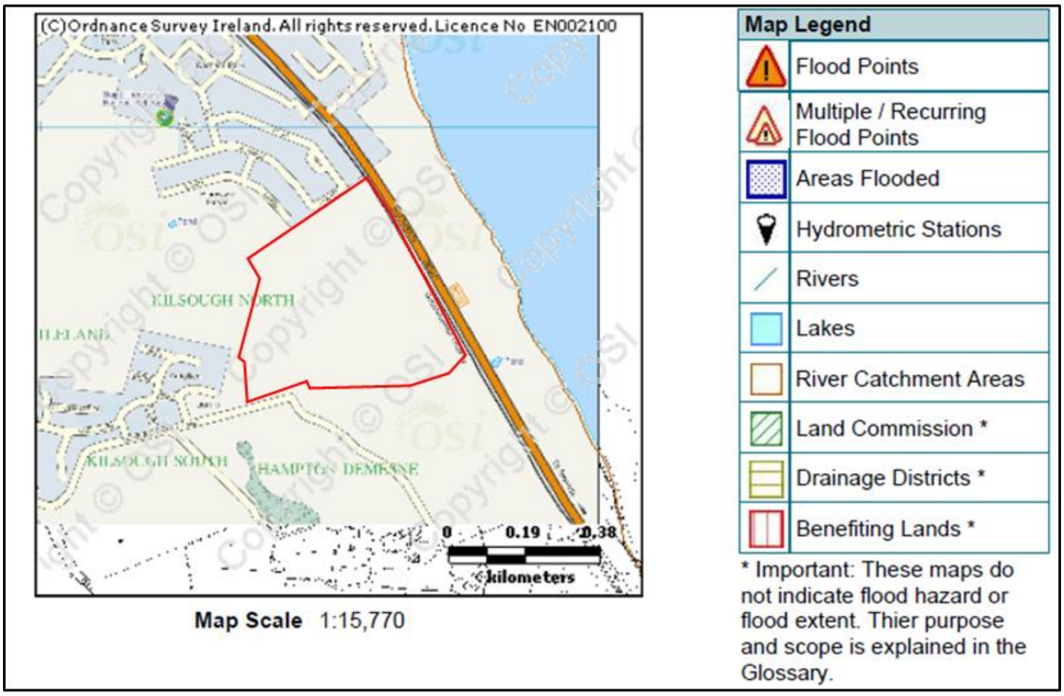
Groundwater flooding

Groundwater flooding can occur during lengthy periods of heavy rainfall, typically during late winter/early spring when the groundwater table is already high. If the groundwater level rises above ground level, it can pond at local low points and cause periods of flooding.

5.2 Historic Flooding

Reports and maps from the OPW Flood Hazard Mapping website (www.floodmaps.ie) have been examined as part of this flood risk assessment. No historic flood events are recorded within close proximity to the site, refer to Figure 5 below.

Figure 5: Historic Flood Events – Floodmaps.ie



It should be noted that while there is no record of historical flooding within the vicinity of the site, there is a possibility that unrecorded flooding has occurred in the past.

5.3 Summary of Flood Mechanisms

5.3.1 Fluvial Flooding

The Fingal East Meath Flood Risk Assessment and Management Study (FEM FRAMS) study was initially used to review the fluvial flood risk of the site and surrounding area. Figure 6 below taken from www.floodinfo.ie, shows flood extents from watercourses modelled as part of the FEM FRAMS.

Figure 6: FEM FRAMS Flood Extent Maps

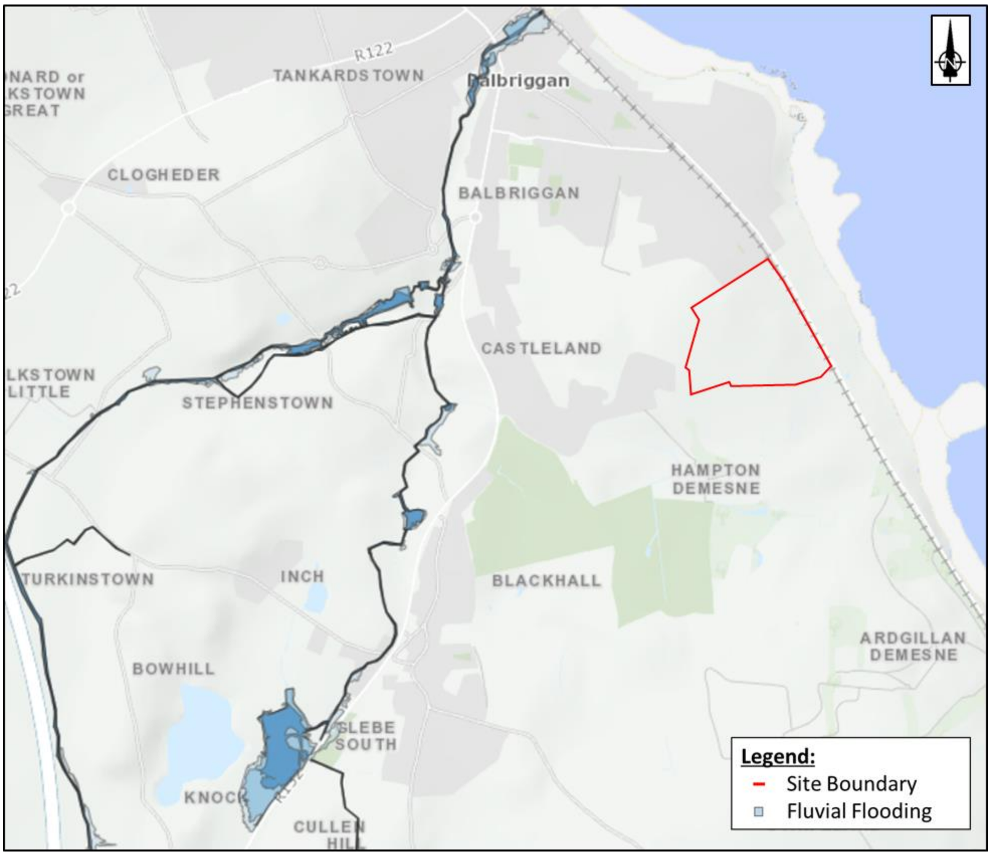


Figure 6 above shows no fluvial flood risk to the proposed lands; however, it should be noted that the Castlelands Stream was not included as part of the FEM FRAMS study and thus the fluvial flood risk will be discussed further in Section 7 of this report.

5.3.2 Coastal Flooding

The FEM FRAMS study was used to review the coastal flood risk of the site and surrounding area. Figure 7 below, taken from www.floodinfo.ie shows the flood extents within close proximity to the site boundary.

Figure 7: Coastal Flooding Location – floodinfo.ie

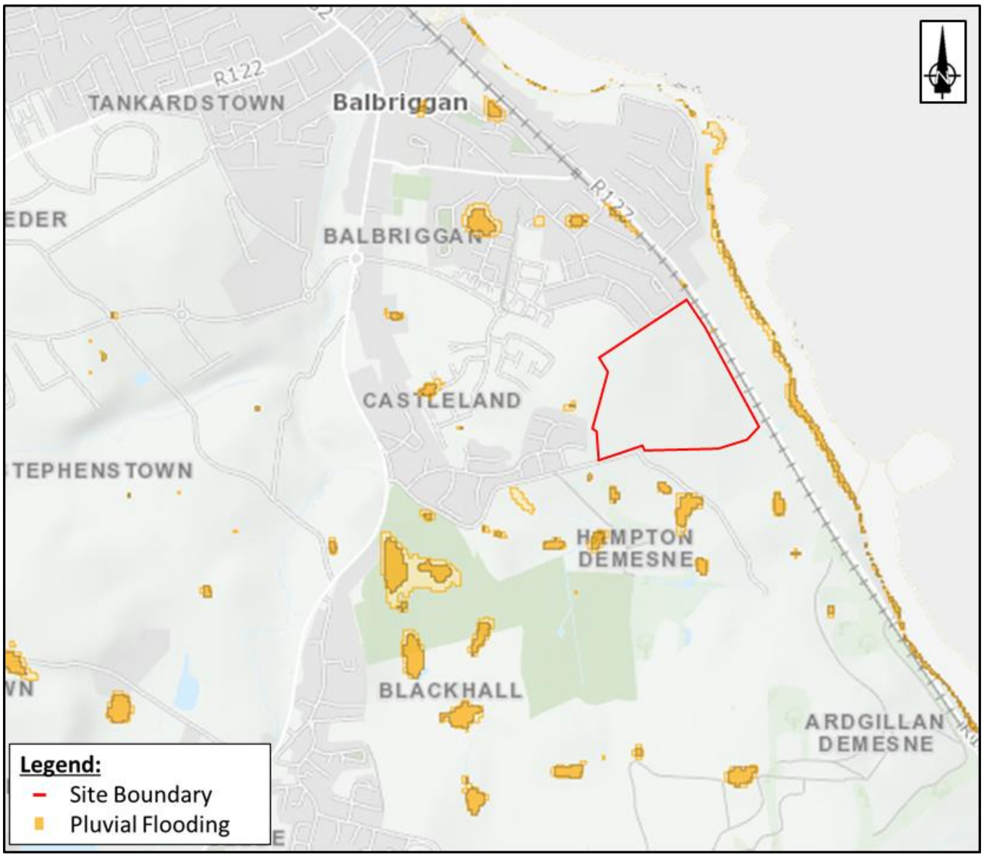
Due to the existing ground levels within the site boundary being in excess of 18m above sea level the site is not at risk of coastal flooding and thus coastal flooding will not be discussed further in this report.

5.3.3 Pluvial Flooding

Pluvial flooding occurs when extreme rainfall overwhelms drainage systems or soil infiltration capacity, causing excess rainwater to pond above ground at low points in the topography.

An extract from the OPW’s Preliminary Flood Risk Assessment (PFRA) mapping is illustrated in Figure 8 below.

Figure 8: Pluvial Flood Risk – OPW PFRA



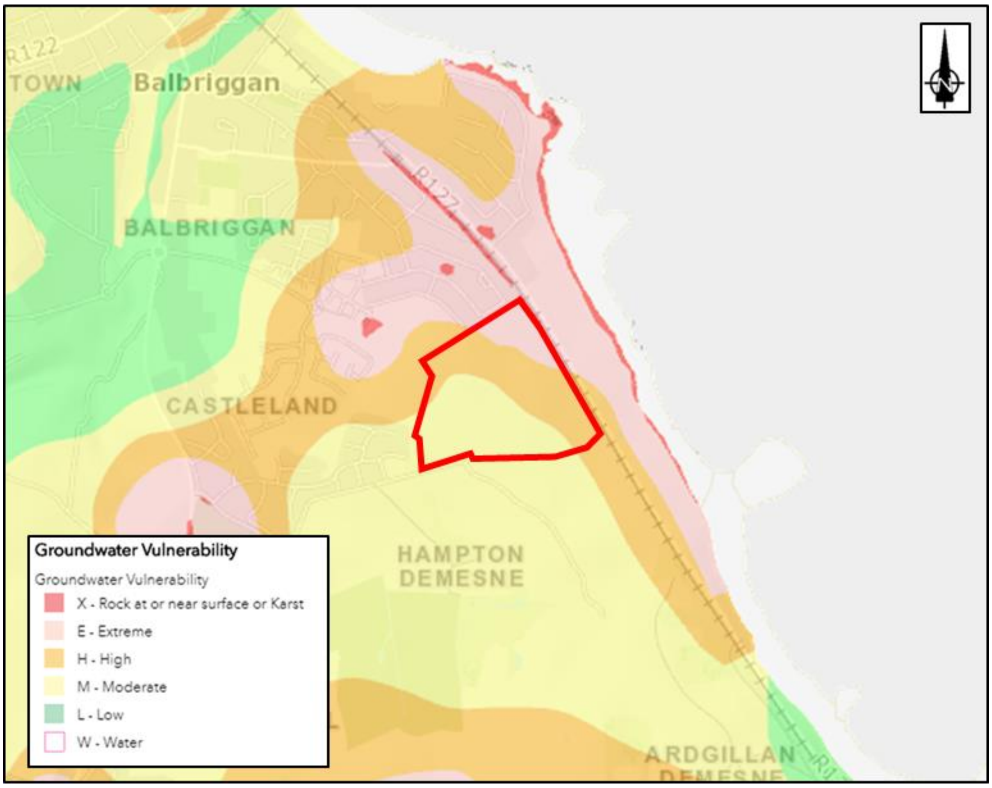
The mapping above shows no pluvial flood risk within the site boundary. However, given that this mapping was produced as part of a high level strategic study, completed at a national scale with a number of very coarse assumptions, it is not prudent to base a site-specific flood risk assessment on this PFRA mapping alone. Therefore, pluvial flood risk will be discussed further in Section 7 of this report.

5.3.4 Groundwater Flooding

Groundwater flooding can occur during lengthy periods of heavy rainfall, typically during late winter/early spring when the groundwater table is already high. If the groundwater level rises above ground level, it can pond at local low points and cause extended periods of flooding. Groundwater flooding is generally dependent on the geological setting.

The groundwater vulnerability varies across the site as can be seen in Figure 9 below.

Figure 9: GSI Groundwater Vulnerability Mapping



Most of the site falls into the "Moderate" groundwater vulnerability category with band of "High" groundwater vulnerability running from the north-western to south-eastern corners of the site. A portion of the site in the north-eastern corner falls into the "Rock at or near surface or Karst" category.

A search was done for historical planning applications on the site (FCC Planning Search) however, no ground investigation data relevant to the site was found therefore, further site investigation is recommended pre-construction to accurately assess the current groundwater conditions of the site.

6 Hydrology

6.1 Overview

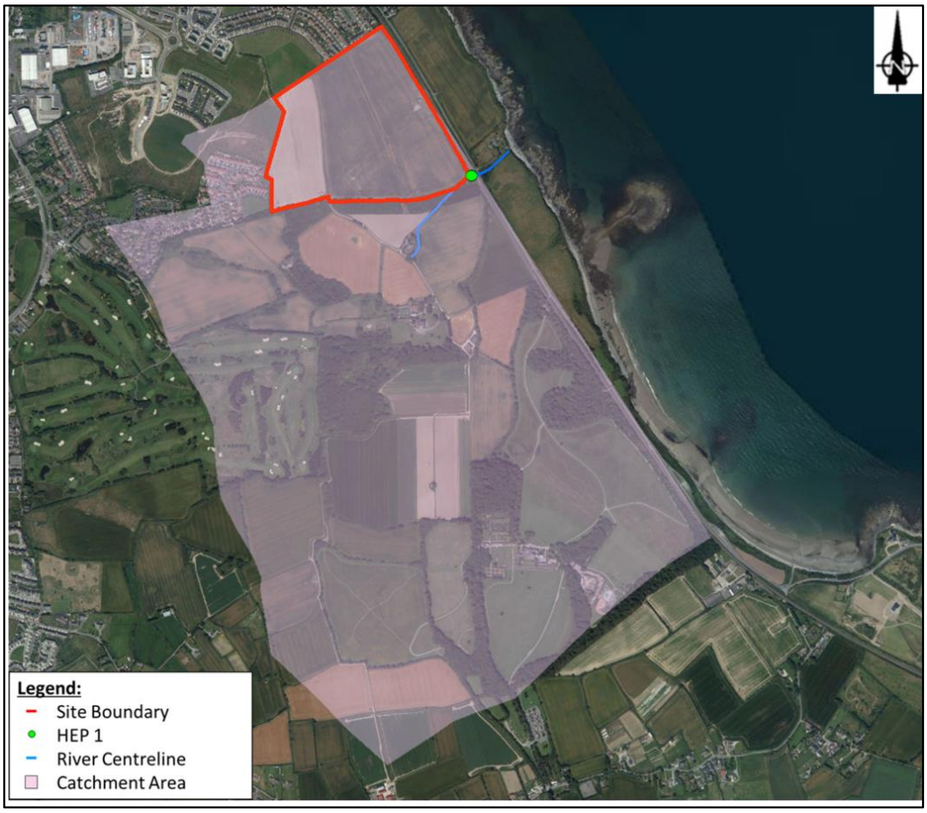
A hydrological assessment of the surrounding watercourses was carried out to produce estimates of peak flows and a hydrograph shape for use as input into the hydraulic model. This assessment included the derivation of peak flows using the following methodologies:

- Institute of Hydrology Report No. 124 (IH124) Method.
- The Flood Studies Update (FSU) Method.
- Flood Studies Report 6 Variable (FSR6) Method.
- Flood Studies Supplementary Report No. 16 (FSSR16) Unit Hydrograph Method.

The peak flows were estimated for a Hydrological Estimation Point (HEP 1) downstream of the subject site.

Figure 10 below indicates the proposed site boundary, surrounding watercourses, HEP and the respective catchment which covers a total area of 2.39km^2.

Figure 10: Catchment overview (Bing Maps)



The FSU Programme, commenced in 2005, and was undertaken by the OPW with a view to developing new flood estimation methods for Ireland, which would significantly improve the quality of flood estimation to aid flood risk management. The FSU is a substantial update of the FSR and the IH124.

The FSU was developed using revised datasets specific to Ireland and is now considered by OPW as the primary methodology for flood estimation in Ireland.

The OPW acknowledge that other methods should also be used; hence the FSR IH124 and FSR Unit Hydrograph methods were also employed in determining the peak flows for the river. All methods of hydrological estimation have limitations, particularly in relation to small catchments and these should be considered when reviewing flow estimations in this report.

6.2 Institute of Hydrology Report 124

The rural index flood, $Q_{bar\ rural}$, was calculated using the method outlined in the IH124 Report.

$Q_{bar} = 0.00108 \cdot AREA^{0.89} \cdot SOIL^{2.17} \cdot SAAR^{1.17}$

A factorial standard error of 1.65 applies to this method.

Table 4 below summarises the results from the above analysis for the un-factored scenario as well as the 68% and 95% confidence intervals.

Table 4: IH124 Method - $Q_{bar\ urban}$ results

	Q_{bar} urban (m^3/s)		
Site	Un-factored	68% Confidence	95% Confidence
HEP 1	0.95	1.57	2.6

6.3 Flood Studies Update (FSU)

The FSU adopts the median annual flood, Q_{med} as the index flood. FSU Work package 2.3 contains a method to estimate Q_{med} using a regression equation which uses seven different physical catchment descriptors (PCD's). The equation estimates Q_{med} for a rural catchment. However, it should be noted that the FSU Webportal does not recommend the use of this method for catchments smaller than 25km^2.

$$Qmed_{Rural} = 1.237\ x\ 10^{-5} AREA^{0.937} BFIsoils^{-0.922} SAAR^{1.306} FARL^{2.217} DRAIND^{0.341}\ S1085^{0.185} (1 + ARTDRAIN2)^{0.408}$$

The FSU 7-variable equation has a standard factorial error of approximately 1.37.

To determine the peak flows using the FSU method the Qmed value is first calculated for the subject site using Physical Catchment Descriptors (PCD); this is then calibrated to a hydrologically similar gauged catchment to determine the appropriate peak flows for a range of design storms.

Q_{med} (PCD) = $Q_{medrural}$ x Urban Adjustment Factor (UAF)

UAF = $(1 + URBEXT)^{1.482}$

The “Castlelands Stream” is not included in the FSU Webportal Database, thus the neighbouring catchment was used to derive the PCD’s. This was considered acceptable due to the proximity of the catchments as well as their similarity in area and urban extent.

Table 5: Physical Catchment Descriptors – Subject Site

Physical Catchment Descriptors	**Description**	**HEP 1**
Contributing Catchment (km^2)	Catchment area	2.39
BFISOIL	Base flow index derived from soil data	0.62
SAAR (mm)	Long-term mean annual rainfall amount in mm.	747
FARL	Flood attenuation by reservoir and lake	1
DRAIND (Km/km^2)	Drainage density	1.5
S1085 (m/km)	The slope of the main channel between 10% and 85% of its length measured from the downstream end of the catchment	31.3
ARTDRAIN2	Percentage of the catchment river network included in the Drainage Schemes	0
URBEXT	Urban Extent	0.04
UAF	Urban Adjustment Factor	1.06

The Q_{med} value calculated for a subject site is equivalent to having only one to two years gauged data at the site hence it is necessary to adjust the Q_{med} using a gauged “pivotal site”. The pivotal site is a hydrologically similar gauged site with a long-established record of flow. The pivotal site can be on the same watercourse or a different watercourse; hydrological similarity is based on AREA, SAAR and BFISOIL values.

Generally, sites with a hydrological similarity < 1.0 indicates a high similarity and a value of > 2.0 indicates a low similarity. In each case, where a pivotal site was available, the case of the lowest hydrological similarity was selected for the analysis.

The subject site adjustment factor (AdjFac) is calculated by estimating the $Q_{medrural}$ for the subject site using PCDs and comparing the resulting value with the gauged (pivotal site) Q_{med} value i.e.:

$AdjFac = Q_{medrural(gauged)}/Q_{medrural(PCD)}$

The adjustment is then partially or fully transferred to the subject site:

$Q_{medrura}l$, (adjusted) = (AdjFac)h x $Q_{medrural}$(PCD)

The typical procedure is to apply a full transfer by setting the exponent h to 1.0.

The Frankfort Station (9011) resulted in a hydrological similarity of 0.7 and was subsequently chosen as the pivotal site for this analysis. PCD values corresponding to the Frankfort Station can be seen in Table 6 below.

Table 6: FSU physical catchment descriptors – Pivotal Site

FSU Physical Catchment Descriptors	Description	HEP 1
Location Number	Identifier of ungauged location	9011
Contributing Catchment Area (km^2)	Catchment area	5.46
BFISOIL	Base flow index derived from soil data	0.56
SAAR (mm)	Long-term mean annual rainfall amount in mm.	773
FARL	Flood attenuation by reservoir and lake	1
DRAIND (Km/km^2)	Drainage density	1.4
S1085 (m/km)	The slope of the main channel between 10% and 85% of its length measured from the downstream end of the catchment	31.1
ARTDRAIN2	Percentage of the catchment river network included in the Drainage Schemes	0
URBEXT	Urban Extent	0.68
UAF	Urban Adjustment Factor	2.16
dhi	Hydrological Similarity	0.70

The annual flood flow Q_{med} was initially derived using the FSU Catchment Descriptor method. This estimate was reviewed following a pivotal site analysis. Table 7 summarises Q_{med} values calculated for the site.

Table 7: Q_{med} Estimation Results

Site	HEP 1
Sub. Q_{med} (m^3/s)	0.54
AdjFactor	1.12
Sub. $Q_{med\ adjusted}$ (m^3/s)	0.61

Table 8 below summarises the Q_{med} adjusted values for the un-factored scenario as well as the 68% and 95% confidence intervals adopting a standard factorial error of 1.2.

Table 8: Q_{med} adjusted

	Q_{med} adjusted (m^3/s)		
Site	Un-factored	68% Confidence	95% Confidence
HEP 1	0.61	0.73	0.88

6.4 Flood Studies Report - Six Variable Equation

The rural index flood, $Q_{barrural}$, was calculated using the equation below (Cunnane & Lynn, 1975).

$$Q_{barrural} = 0.00042 \cdot AREA^{0.95} \cdot Fs^{0.22} \cdot SOIL^{1.18} \cdot SAAR^{1.05} \cdot (1+LAKE)^{-0.85} \cdot S1085^{0.19}$$

A factorial standard error of 1.50 applies to this method.

Table 9 below summarises the results from the above analysis for the un-factored scenario as well as the 68% and 95% confidence intervals.

Table 9: FSR 6 Variable Method - $Q_{bar\ urban}$ results

	$Q_{bar\ urban}$ (m^3/s)		
Location	Un-factored	68% Confidence	95% Confidence
HEP 1	0.81	1.22	1.83

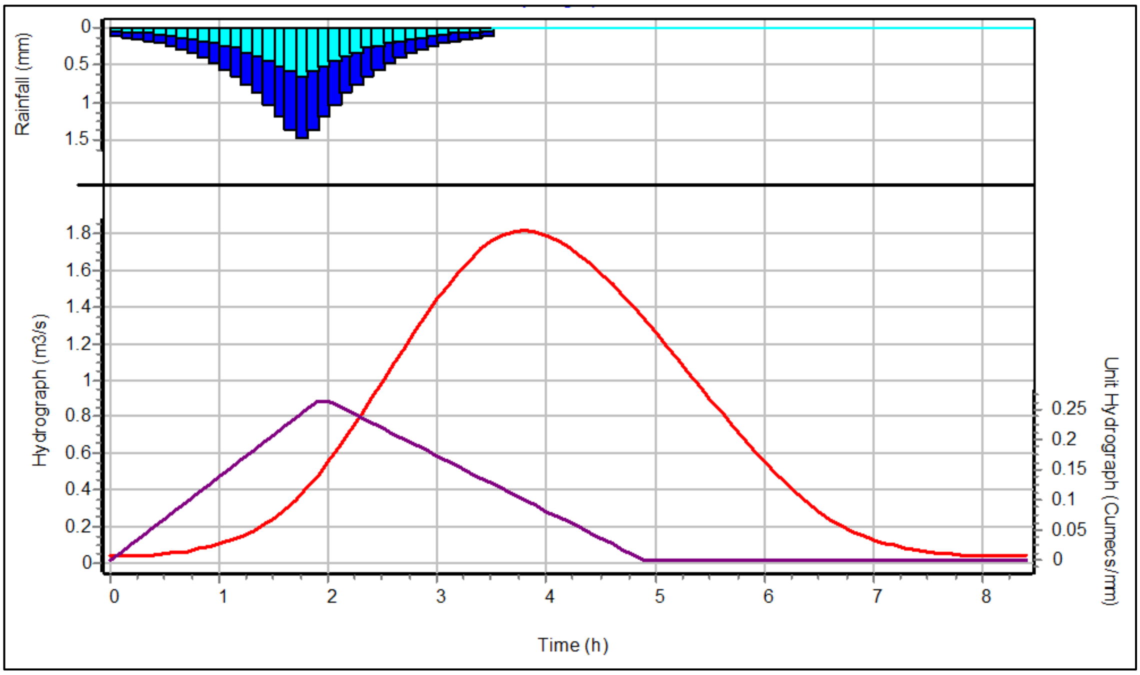
6.5 FSSR16 – Unit Hydrograph Method

The unit hydrograph method most widely used in Ireland for ungauged catchments is the FSR triangular unit hydrograph and design storm method. This method estimates the design flood hydrograph, describing the timing and magnitude of flood peak and flood volume (area beneath hydrograph). This method requires the catchment response characteristics (time to peak, tp), design rainstorm characteristics (return period, storm duration, rainfall depth and profile) and runoff/loss characteristics (percentage runoff and baseflow).

The FSSR16 Unit Hydrograph method is a rainfall-runoff model based on procedures set out in the Flood Studies Report (1975) and includes revisions contained in subsequent supplementary reports. The FSSR16 will generate flow hydrographs for design return period events or will simulate runoff during historic events using recorded rainfall and other input data.

A unit hydrograph was constructed using this method for the HEP downstream of the subject site, to determine the peak flow, time to peak and hydrograph shape. The subsequent flow hydrograph is shown in Figure 11.

Figure 11: HEP 1 FSSR16 Q_{bar} Hydrograph



A summary of the peak flow from the FSSR16 Unit Hydrograph method can be seen in Table 10.

Table 10: Q_{bar} results

	Q_{bar} (m^3/s)
HEP 1	1.82

6.6 Flow Comparison

Table 11 below shows a summary of the results for Q_{med} or Q_{bar} for the different flow estimation methods used.

Table 11: Q_{med}/Q_{bar} results

	Qmed /Qbar (m^3/s)
IH124	0.95
FSU	0.61
FSR6	0.81
FSSR16	*1.82*

The OPW Hydronet website advises that the FSU method is not deemed applicable for catchments smaller than $5km^2$ and therefore design flows estimated using this method were not selected as design flows. Furthermore, the FSSR Unit Hydrograph Method was predominantly used in order to derive a hydrograph profile for input into the hydraulic model.

As can be seen in the table above the design flows estimated in the IH124 flow method are slightly higher than those estimated using the FSR6 method and thus the IH124 Method was selected in order to calculate final design flows.

6.7 Growth Factors

Design flows for the 1 in 100-year return period (Q_{100}) are calculated by multiplying the Q_{med} or Q_{bar} values by a growth factor. Growth curves from four different studies were considered when selecting the growth factor to be applied. The four selected growth curves are as follows;

i. Fingal East Meath Flood Risk and Management Study (FEM FRAMS)

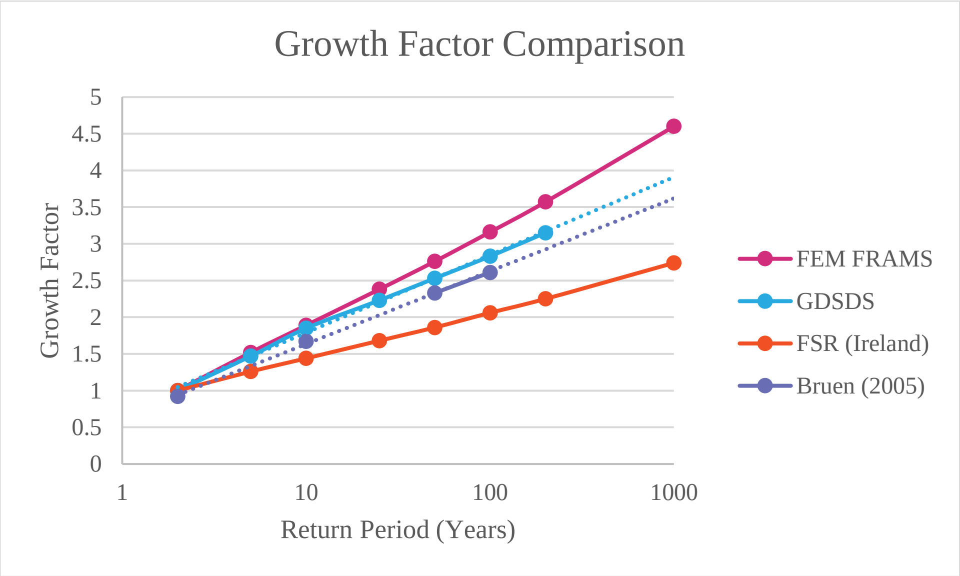
ii. Greater Dublin Strategic Drainage Strategy (GDSDS)

iii. Irish FSR Regional Growth Curve

iv. Dr. Michael Bruen (2005) – *"An investigation of the Flood Studies Report for ungauged catchment method for Mid-Eastern Ireland and Dublin"*

The growth curves can be seen in Figure 12 below.

Figure 12: Growth Curve Comparison



The Castlelands development falls within the catchment boundary of the Fingal East Meath Study (FEM FRAM) and thus the growth curve and subsequent growth factors from this study will be used in the calculation of design flows. It should be noted that the selection of this growth curve will result in the most conservative design flows when compared to the GDSDS, FSR (Ireland) and the Bruen (2005) curves. Table 12 below presents the growth factors used.

Table 12: FEM FRAMS Growth Factors

Return Period	2	5	10	25	50	100	200	1000
Growth Factor	1	1.52	1.89	2.38	2.76	3.16	3.57	4.6

6.8 Climate Change

OPW has produced a draft guidance document entitled "Assessment of Potential Future Scenarios for Flood Risk Management". The guidance addresses potential future climate change and presents two possible future scenarios - the Mid-Range Future Scenario (MRFS) and the High-End Future Scenario (HEFS), as described below:

- The MRFS is intended to represent a 'likely' future scenario, based on the wide range of predictions available and with the allowances for increased flow, sea level rise, etc. within the bounds of widely accepted projections.
- The HEFS is intended to represent a more extreme potential future scenario, but one that is nonetheless not significantly outside the range of accepted predictions available, and with the allowances for increased flow, sea level rise, etc. at the upper the bounds of widely accepted projections.

Figure 13: Extract from OPW Guidance on Potential Future Scenarios

Table 1: Allowances for Future Scenarios (100 year time horizon)

	MRFS	HEFS
Extreme Rainfall Depths	+ 20%	+ 30%
Flood Flows	+ 20%	+ 30%
Mean Sea Level Rise	+ 500 mm	+ 1000 mm
Land Movement	- 0.5 mm / year[1]	- 0.5 mm / year[1]
Urbanisation	*No General Allowance – Review on Case-by-Case Basis*	*No General Allowance – Review on Case-by-Case Basis*
Forestation	- 1/6 Tp[2]	- 1/3 Tp[2] + 10% SPR[3]

Note 1: Applicable to the southern part of the country only (Dublin – Galway and south of this)

Note 2: Reduce the time to peak (Tp) by a third: This allows for potential accelerated runoff that may arise as a result of drainage of afforested land

Note 3: Add 10% to the Standard Percentage Runoff (SPR) rate: This allows for increased runoff rates that may arise following felling of forestry.

Both the MRFS and HEFS are adopted to assess the potential impact of climate change at Castlelands. Please refer to Section 7.7 for further information.

6.9 Final Flows

Flows have been calculated by multiplying the estimates of Q_{bar} by the growth factors from the FEM FRAMS Study. Table 13 below presents the design flows for each of the four flow estimation methods.

Table 13: Final Flows

	Q_{bar}	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{1000}
Flow Rate (m^3/s)	0.95	0.95	1.44	1.80	2.26	2.62	3.00	3.39	4.37

The above flows were used for input into the hydraulic model and flows for Section 50 requirements are presented in Table 14.

Table 14: Final Flows (95% Confidence and Climate Change)

	Q_{bar}	Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}	Q_{200}	Q_{1000}
Flow Rate (m^3/s)	3.10	3.10	4.72	5.87	7.39	8.57	9.81	11.08	14.28

7 Hydraulic Model Development

A detailed one-dimensional (1D) and two-dimensional (2D) unsteady flow hydraulic model of the Castlelands Stream was constructed in order to accurately simulate flooding across the site including both fluvial and pluvial sources. The model was developed using HEC-RAS 5.0.4 software.

7.1 Data Acquisition

As stated in Section 3 above, survey data was provided by Murphy Surveys Ltd. The survey data was used in order to construct the 1D element of the model. A 3D Terrain was also constructed using 1m contours supplied by FCC in order to construct the 2D element of the model.

7.2 Model Geometry

7.2.1 Model Extents

The Castlelands Stream reach extends upstream of the site as well as downstream towards the Irish Sea. The Irish Transverse Mercator (ITM) coordinates of the extent of the model are presented in Table 15 and Figure 14 shows the location of the model extents.

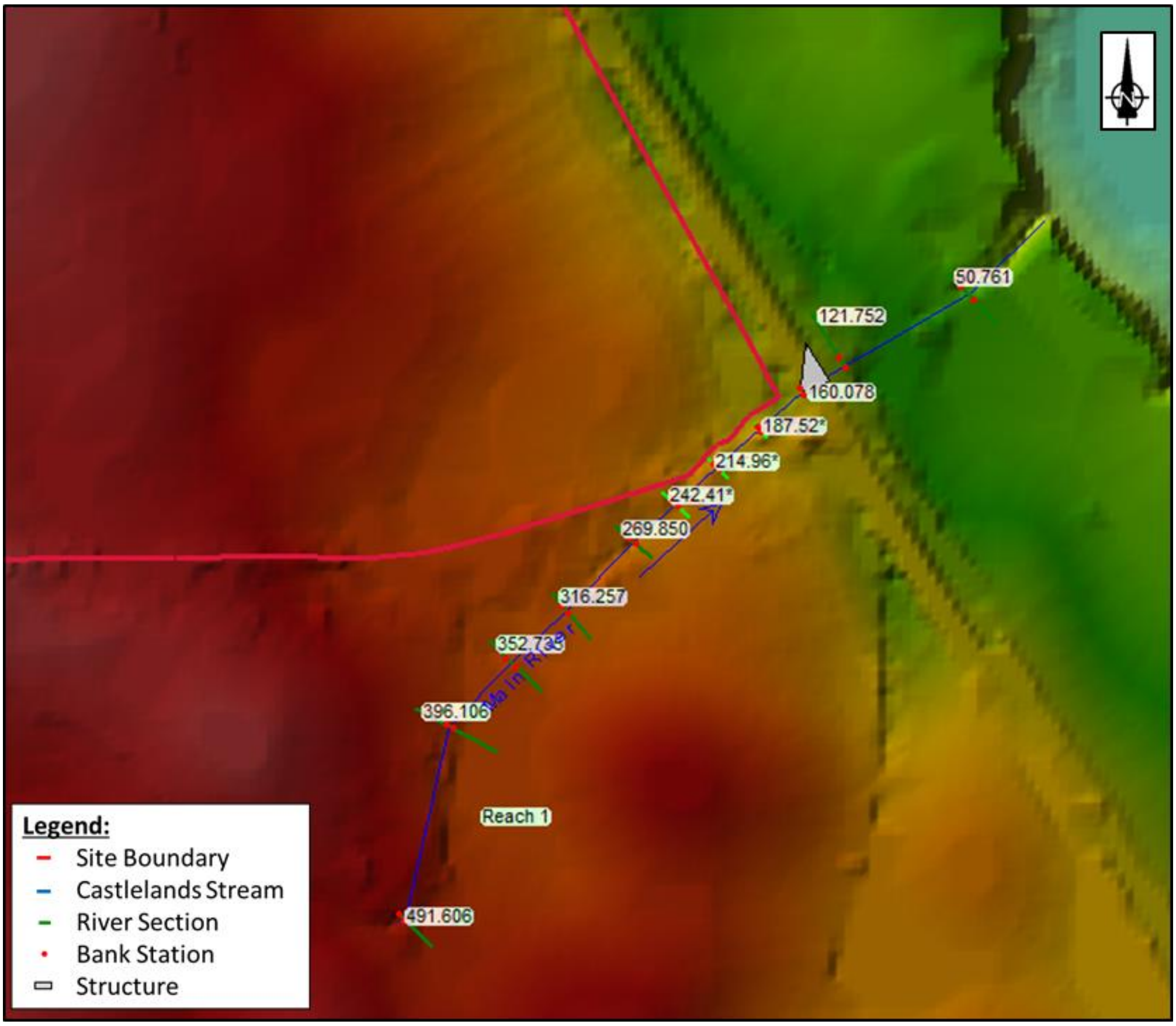
Table 15: Model extent coordinates

Watercourse	Upstream Extent		Downstream Extent	
	Easting	Northing	Easting	Northing
Castlelands Stream	321500	262131	321811	262468

Figure 14: Model extents & river reaches

Figure 15 on the following page illustrates the numbering of River Sections within the model.

Figure 15: Model Schematic



7.2.2 Channel Geometry

The channel geometry for the model was imported into the model directly from the survey by Murphy Surveys Ltd. The accuracy of the imported geometry was validated using the photographs provided, the existing contour data as well as the site walkovers.

The cross-section labelling system adopted in the model is consistent with the "ISIS Chainage" given in the survey data. Appendix A3 presents the model cross-section.

7.2.3 Hydraulic Roughness Coefficients

The roughness values of the 1D model have been defined for three separate sections of each cross section: (1) The left bank, (2) The main channel, and (3) The right bank. These sections of each cross section in the model are defined by panel markers.

The Manning's n roughness values of the 1D model were selected based on a detailed analysis and following review of survey photographs and site visits undertaken by Arup.

The Castlelands Stream main channel consists of overgrown weeds & stones with banks consisting of relatively thick vegetation. Selected Manning's values fall within the corresponding typical ranges as presented in Table 16 and 17. Please refer to Appendix A3 for specific Manning's values used at each cross section.

Table 16: Typical Manning's n values for river channel

Channel Characteristics	Manning's n value
Main Channel	
Clean, straight	0.030
Clean, meandering	0.035
Stones & weeds, meandering	0.045
Banks	
Weeds & vegetation	0.040
Heavy weeds & vegetation	0.050
Mature trees and thick vegetation	0.060

Table 17: Typical Manning's n values for floodplain

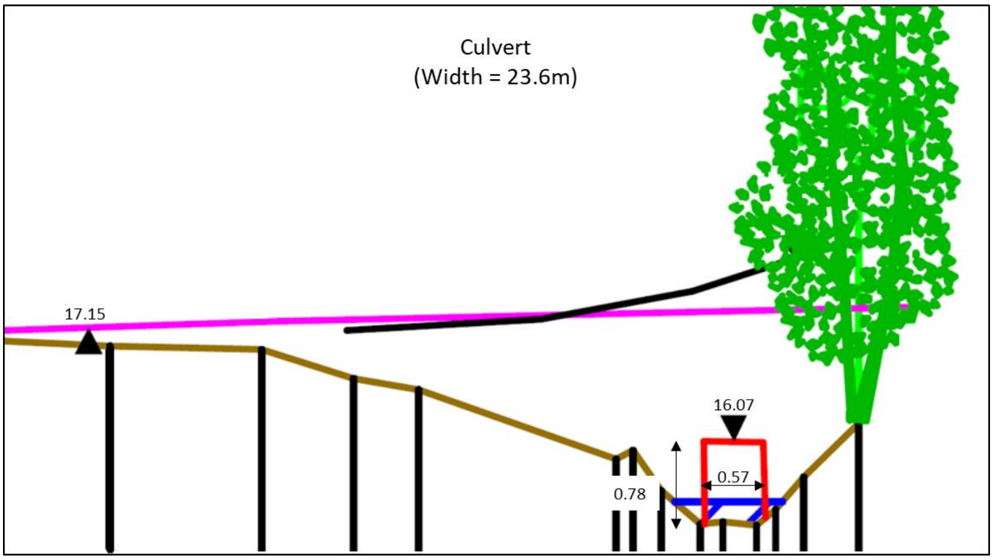
Land Use	Manning's n value
Roads	0.020
Buildings	0.100
Parkland	0.030
Open space	0.035
Forestry	0.06

Based on the findings of the site walkover and survey data received as well as the table above, a Manning's n value of 0.06 was for the floodplain within the hydraulic model.

7.2.4 Hydraulic Structures

Within the model extents, there is one existing culvert running underneath the railway line at River Station 160.078. Opening dimensions of the culvert at the upstream and downstream ends differ significantly and subsequently the smallest opening dimensions were used in the model, producing the most conservative result. Figure 16 below shows the cross-section used to model the culvert.

Figure 16: Culvert Downstream Cross-Section



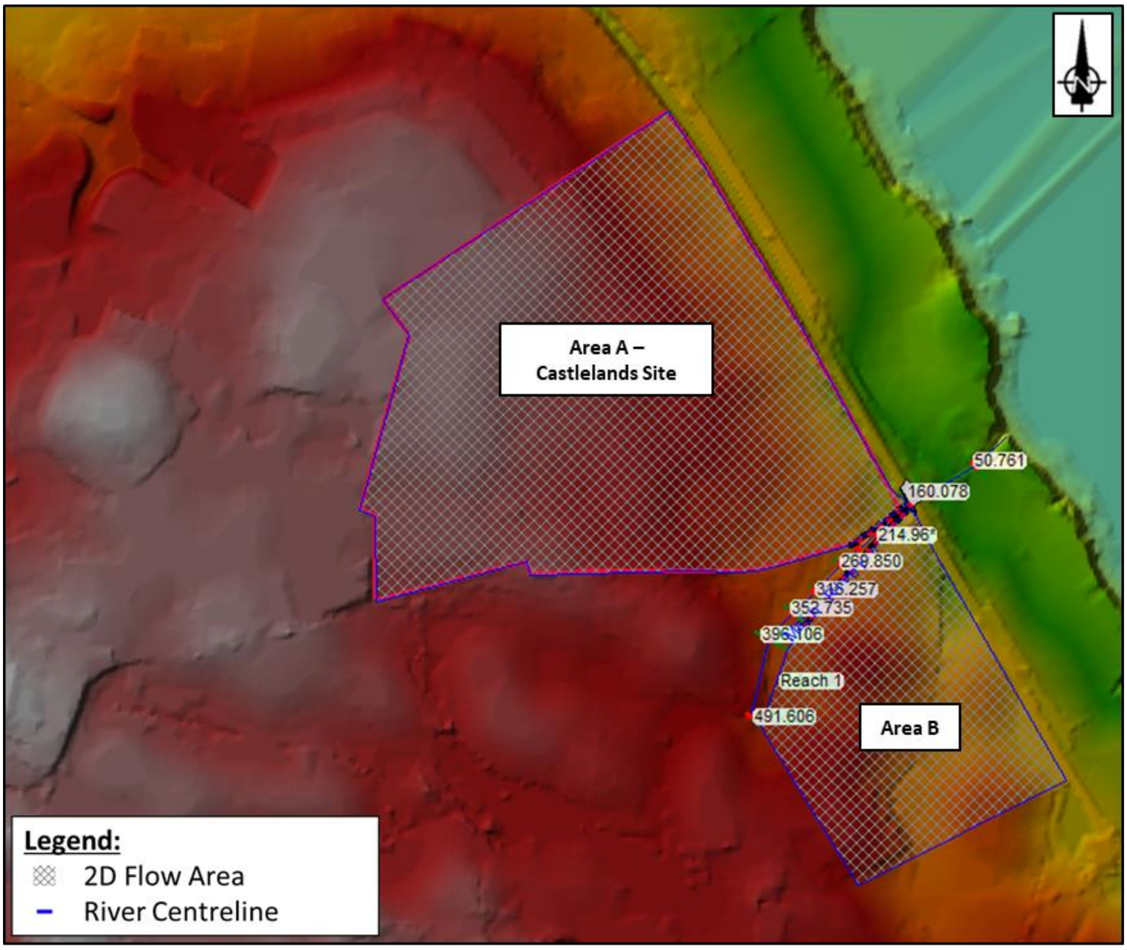
7.2.5 Two-dimensional Flow Area

In order to model the two-dimensional flood extents within the floodplain, two 2D Flow Areas were modelled.

These 2D Flow Areas were modelled using a 4m x 4m computational mesh with each cell covering an average area of approximately 16m^2, providing an accurate representation of the undeveloped subject site.

Refer to Figure 17 below for a graphical representation of the 2D Flow Areas within the model.

Figure 17: 2D Flow Areas



7.2.6 Lateral Structure

The 2D Flow Area forms the two-dimensional extents of the model and is connected to the one-dimensional extent of the model by means of lateral structures within the model.

All lateral weirs were modelled in an identical manner using the following weir data assumptions;

- Weir width: 0.5m.
- Weir computation: Standard Weir Equation.
- Weir Coefficient: 1.1.
- Weir Crest Shape: Broad Crested.

Tailwater connections for the lateral embankment weirs were set to their relevant 2D Flow Areas within the system, thus linking the 1D and 2D aspects of the model.

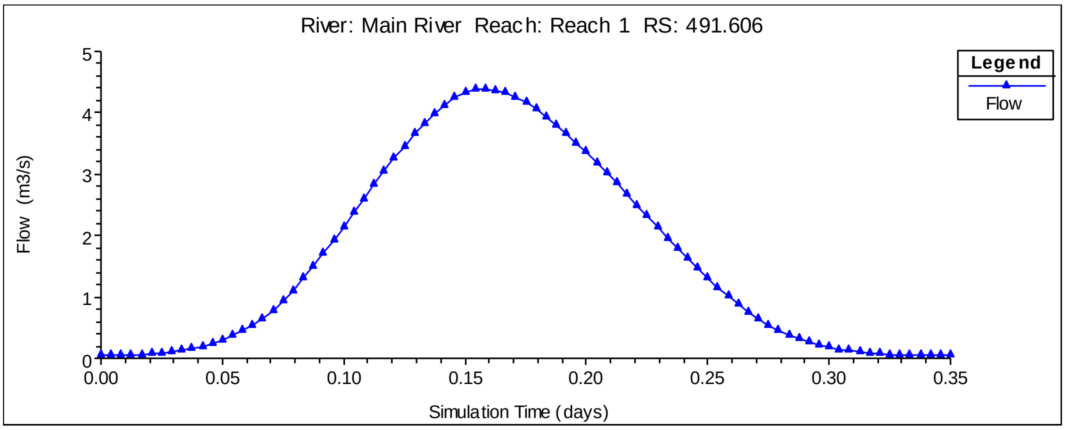
7.3 Unsteady Flow Data

7.3.1 Boundary Conditions

In order to simulate the unsteady flow within the model, two boundary conditions were included. An inflow hydrograph at the upstream extents of the model and one downstream normal depth.

The FSSR 16 hydrograph shape, as detailed in Section 6.5 was adopted with the hydrograph being scaled to match the relevant peak flow estimates. Figure 18 presents the inflow hydrograph shape used before scaling.

Figure 18: Typical inflow hydrograph Castlelands Stream



Furthermore, the model contains a downstream boundary modelled as a normal depth equal to the bed slope at the downstream extent of the watercourse.

7.3.2 Initial Flows

Initial flows were specified to ensure hydraulic model stability at the start of the run.

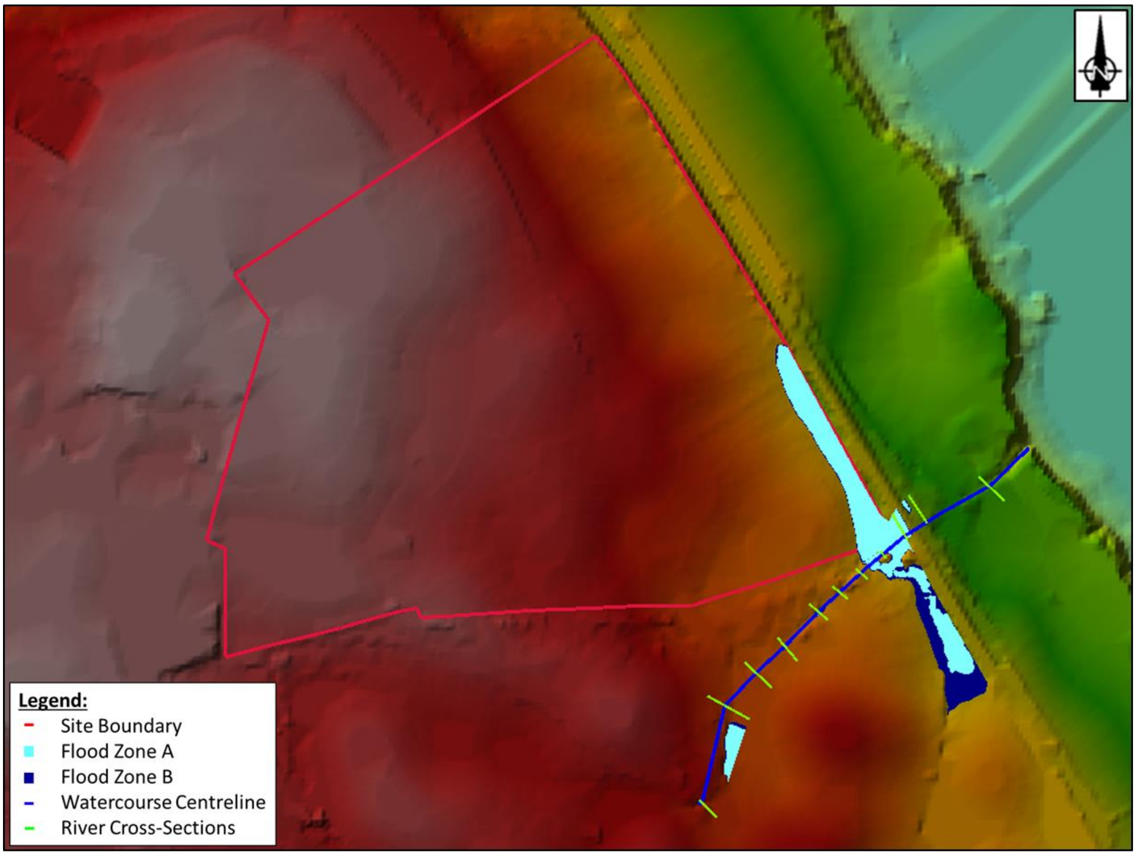
7.3.3 Minimum Flows in Hydrograph

Minimum flows were set to ensure hydraulic model stability throughout the run. In the case of the addition of a minimum flow, the flow added was circa 10% of the peak flow of the relevant hydrograph.

7.4 Flood Zone Mapping

Flood zone maps for the area of interest and surrounding lands is presented in Figure 19. This is based on our site-specific model but ignores any existing defences, as per the Flood Risk Planning Guidelines (OPW, 2009).

Figure 19: Flood Zone Map



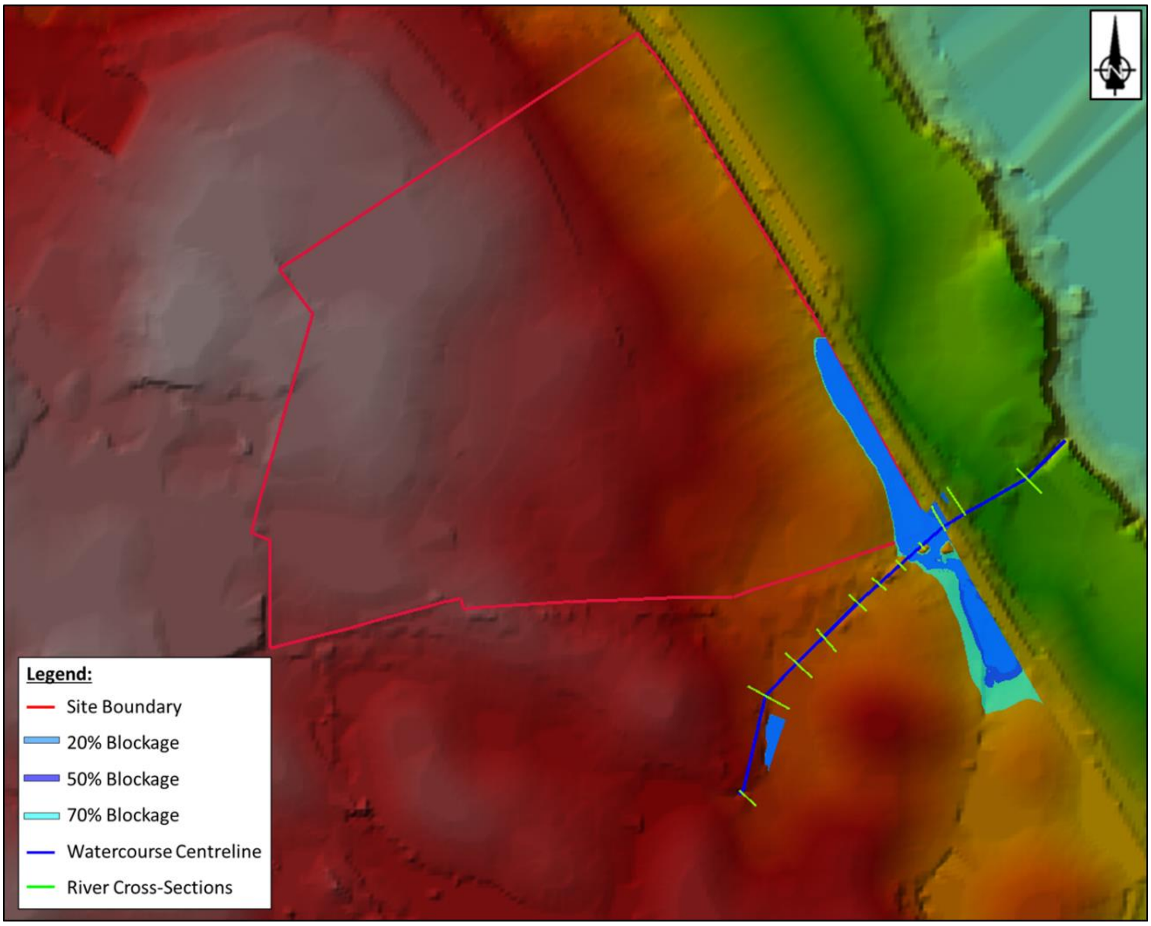
As can be seen in the above figure, the flood extents for Flood Zone A (Q_{100} Flows) and Flood Zone B (Q_{1000} Flows) do not differ significantly within the Castlelands site boundary. Within Flood Zone A, flood depths range up to 2m with a typical depth of 0.9m. Similarly, for Flood Zone B flood depths range up to 2.2m with a typical depth of 1.05m.

Refer to Appendix A4 for full Flood Zone Maps.

7.5 Culvert Blockage Analysis

A risk of a blockage within the culvert underneath the railway line has been identified as a potential cause of flooding. Thus, a blockage analysis was modelled in order to establish the risk. The blockage analysis was done considering 20%, 50% and 70% blockage combined with Q_{100} flows. Figure 20 below presents the results of this analysis.

Figure 20: Blockage Analysis – Flood Extents



Similarly, to the flood zones above, the flood extents for the 20%, 50% and 70% scenarios do not vary significantly within the Castlelands site boundary due to the existing topography of the site.

7.6 Fluvial Flood Depths

The flood depth for the 70% blockage scenario produces marginally larger flood extents than those found for Flood Zone B above and thus these will be used in order to establish the fluvial flood depths within the site. Figure 21 below shows the final fluvial flood depth mapped onto a Bing Maps aerial background.

Figure 21: Final Flood Depth Map

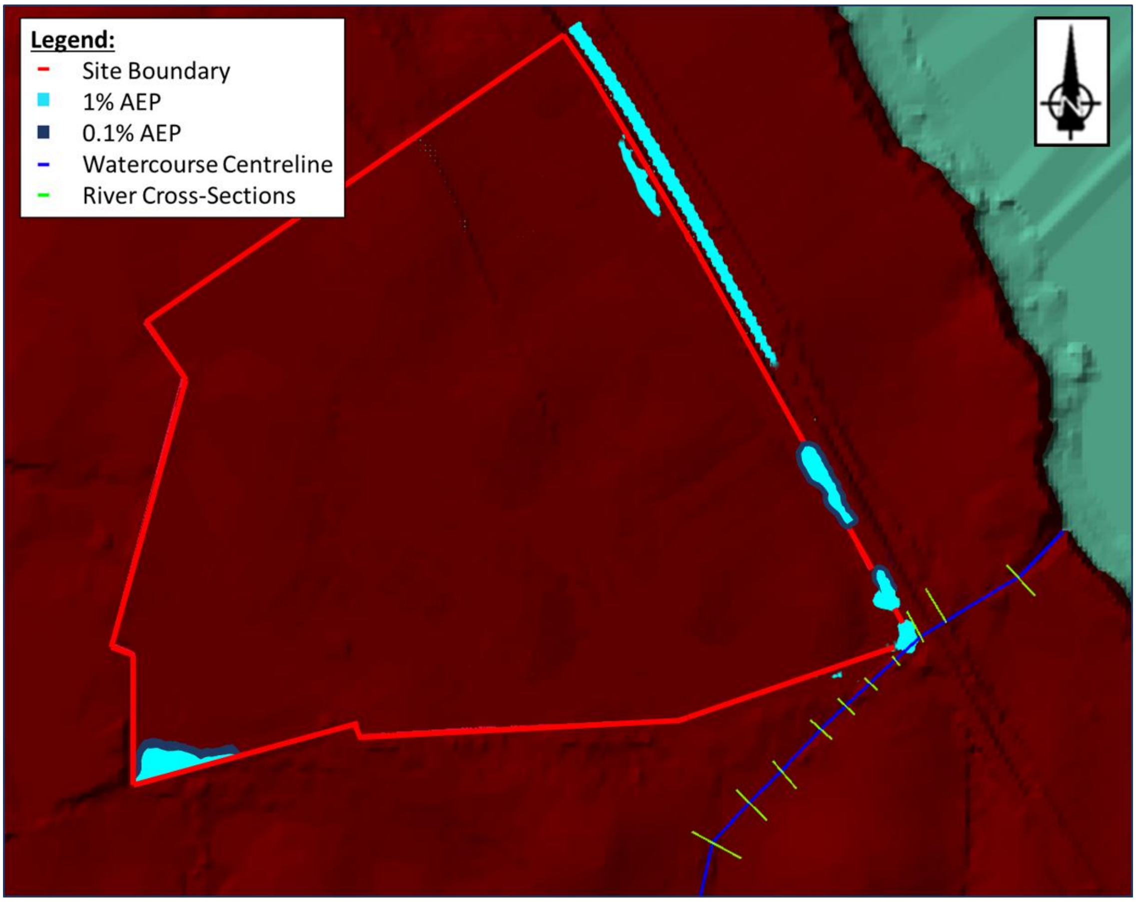
7.7 Flood Extent Maps

Flood extent maps were produced for the Castlelands site illustrating the extents for the existing scenarios as well as climate change scenarios (MRFS & HEFS) as detailed in Section 6.8 above. Refer to Appendix A4 for Flood Extent Maps.

7.8 Pluvial Flooding

In order to accurately assess the pluvial flood risk within the site a pluvial model was run within HEC-RAS considering a number of storm durations and return periods. The model was found to not be sensitive to these changes and thus the final pluvial flood extents correspond to the 1-hour storm duration with both the 100-year (1% AEP) and 1000-year (0.1% AEP) return periods. Figure 22 below shows the pluvial flood extents for the site.

Figure 22: Pluvial Flood Extents



As can be seen in the figure above, there are some areas of pluvial flooding within the Castlelands site boundary. These localised areas correspond with areas of low ground levels. However, the flood depth is shallow, thus adequate stormwater drainage systems will reduce pluvial flood risk.

7.9 Recommendations

The following summarises the recommendations from this FRA for Castlelands:

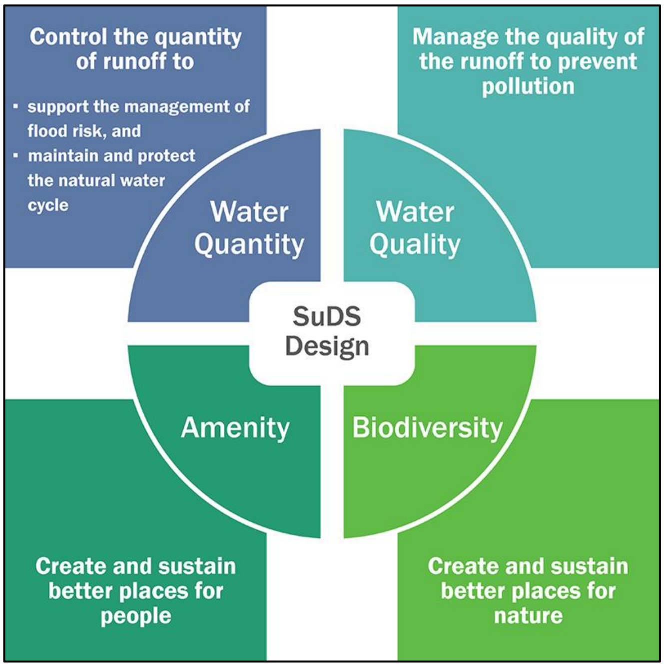
- Protect and enhance the identified floodplains as presented in Appendix A4 as vital green infrastructure which provides space for storage and conveyance of floodwater.
- Allow no new development within the floodplains as presented in Appendix A4 other than development which satisfies the justification test, as outlined in the Planning System and Flood Risk Management Guidelines 2009 for Planning Authorities (or any updated guidelines).
- It is recommended that the watercourse and fluvial floodplain within the area of the masterplan boundary be maintained and protected by the riparian land owners (both public and private).
- It is also recommended that the existing culvert be maintained and protected by Irish Rail.

Part B: Sustainable Drainage Strategy

8 Overview

The following section will outline the Sustainable Drainage Strategy (SDS) for the Castlelands Masterplan lands. Surface water is a valuable resource within any development and thus this should be reflected in the way it is collected, managed and used with the development. Sustainable Drainage Systems (SuDS) aim to maximise the benefits and minimize the negative impacts of surface water runoff from developed areas. This is done by slowing down and reducing the runoff in order to manage flood risk as well as reducing the risk of pollution caused by runoff by harvesting, infiltrating, storing, conveying and treating on the surface rather than in underground tanks. This makes water much more visible and tangible within a development and thus can be enjoyed and/or appreciated more. Figure 23 below outlines the 4 key pillars of the SuDS design philosophy namely; Water Quantity, Water Quality, Amenity and Biodiversity.

Figure 23: The four pillars of SuDS design (CIRIA SuDS Manual 2015)



With consideration of the above, it is proposed to discharge all surface water by gravity from the lands to the Castlelands Stream. The surface water runoff from the lands will be designed in accordance with the FCC Development Plan and thus the Greater Dublin Strategic Drainage Strategy (GDSDS) and the CIRIA SuDS Manual C753.

9 Design Criteria

In order to fulfil the four pillars of SuDS design as presented in Figure 23 above, a number of design aspects need to be considered. The CIRIA SuDS Manual (2015) outlines the following design criteria;

	Design Criteria
Water Quantity	1. Use surface water as a resource 2. Support the management of flood risk in the receiving environment 3. Protect morphology and ecology in receiving surface waters 4. Preserve and protect natural hydrological systems on the site 5. Drain the site effectively 6. Manage on-site flood risk 7. Design system flexibility/ adaptability to cope with future change
Water Quality	1. Support the management of water quality in the receiving waters and groundwaters 2. Design system resilience to cope with future change
Amenity	1. Maximise multi-functionality 2. Enhance visual character 3. Deliver safe surface water management systems 4. Support development resilience/ adaptability to future change 5. Maximise legibility 6. Support community environmental learning
Biodiversity	1. Support and protect natural local habitats and species 2. Contribute to the delivery of local biodiversity objectives 3. Contribute to habitat connectivity 4. Create diverse, self-sustaining and resilient ecosystems

These design criteria should be applied in the design of SuDS within the Castlelands Masterplan lands. Furthermore, a 20% allowance for climate change should be applied to all SuDS components within the development as per the MRFS detailed in Section 6.8.

Each of the above design criteria is discussed in more detail below.

9.1 Water Quantity

Due to the introduction of impermeable areas such as roads, houses, pavements etc. when developing a greenfield site, both the runoff volume and rate is likely to increase. Therefore, these two parameters are the most important components in analysing the performance of drainage systems.

The GDSDS Regional Policy, Volume 2 (New Development) details the methods and equations to be used to enable the determination of flow rates and volumes for Greenfield and post development conditions to enable calculation of the throttle rates and storage volumes. In summary the procedure is as follows;

- Assess the Greenfield peak runoff rate.
- Assess the Development runoff rate.
- Assess the Development runoff volumes.
- Determine the volume of storage for the development runoff.

For the Castlelands development the above procedure is to be followed to account for the 1:100-year event, discharging to the receiving watercourse at a rate of 2 l/s/ha or the average annual peak flow rate (QBAR), whichever is greater.

Furthermore, the following recommendations stated in the GDSDS Regional Policy, Volume 3 (Environmental Management) should be taken into consideration;

- Emergency overflows should be built in to SuDS to cater for extreme events.
- Hydrograph methods are to be used in the design of SuDS.
- In addition, a range of drainage components should be considered to enable effective hydraulic design.
- A precautionary approach is recommended for the design of SuDS for hydraulic performance, especially when selecting infiltration rates for soils.

9.2 Water Quality

Runoff from greenfield sites is generally unpolluted. In contrast, runoff from urban areas is likely to contain more pollutants and thus this increase in pollution must be accounted for when designing appropriate infrastructure for new developments. As outlined in Section 10.1, the SuDS Treatment Train approach is recommended in order to effectively treat runoff from proposed developments.

There are several methods of determining the treatment volume requirement for SuDS. Both the GDSDS and CIRIA SuDS Manuals adopt the Wallingford Procedure variables:

$$\mathrm{Vt}\left(\frac{m^3}{\mathrm{Total}}\mathrm{Area, ha}\right) = 9\mathrm{D}\left(\frac{SOIL}{2} + \left(\frac{1 - SOIL}{2}\right)\mathrm{I}\right)$$

Where:

V_t Treatment volume (m^3/ ha)

I Fraction of the area which is impervious (30% impermeable area = 0.3)

D M5-60 rainfall depth, Volume 3 Wallingford Procedure (60-minute, 5-year return period)

SOIL WRAP Soil Classification

To compute the total design treatment volume, multiply V_t by the catchment area in hectares, that drains to it. The application of the design treatment volume to various types of treatment controls are described below. Retention ponds should generally have a minimum permanent pool volume of 4 x Vt. Whereas wetlands, due to the increased amount of vegetation, the minimum permanent pool volume required would be 3 x Vt.

The Pollution Indices (PI) and Pollution Mitigation Indices (PMI) outlined in CIRIA C753 Part E, Chapter 26 in Tables 18 and 19 below should be accounted for when designing for water quality of SuDS options. SuDS systems within the Castlelands development should aim to provide sufficient pollution mitigation. In order to ensure adequate pollution mitigation, the following should be provided;

$$PI < PMI$$

Where the mitigation of an individual component is insufficient, two (or more) components may be used in series. The Total PMI can be calculated as follows;

$$PMI_{total} = PMI_1 + 0.5PMI_2 \ldots + 0.5PMI_n$$

A factor of 0.5 is used to account for the reduced performance of secondary or tertiary components associated with already reduced inflow concentrations.

Table 18: Pollution indices for different land use classifications (CIRIA C753 Part E Chapter 26(hi)-V3, Table 26.2)

Landuse	Pollution Hazard Level	TSS	Metals	Hydrocarbons
Residential Roofs	Very low	0.2	0.2	0.05
Other roofs (commercial, industrial)	Low	0.3	0.2	0.05
Individual property driveways, residential car parks, low traffic roads (e.g. cul de sacs, homezones and general access roads) and non-residential car parking with infrequent change (e.g. schools, offices) i.e. < 300 traffic movements per day	Low	0.5	0.4	0.4

Landuse	Pollution Hazard Level	TSS	Metals	Hydrocarbons
Commercial yard and delivery area, non-residential car parking with frequent change (e.g. hospitals, retail) all roads except low traffic roads and trunk roads/motorways	Medium	0.7	0.6	0.7
Sites with heavy pollution (e.g. haulage yards, truck parks), sites where chemicals and fuels (other than domestic fuel) are to be delivered, handled, stored, used or manufactured, industrial sites, trunk roads and motorways.	High	0.8	0.8	0.9

Table 19: Indicative SuDS mitigation indices for discharges to surface waters (CIRIA C753 Part E Chapter 26(hi)-V3, Table 26.2)

Type of SUDS Component	TSS	Metals	Hydrocarbons
Filter Strip	0.4	0.4	0.5
Filter drain	0.4	0.4	0.4
Swale	0.5	0.6	0.6
Bioretention System	0.8	0.8	0.8
Permeable paving	0.7	0.6	0.7
Detention Basin	0.5	0.5	0.6
Pond	0.7	0.7	0.5
Wetland	0.8	0.8	0.8

Furthermore, the following recommendations stated in the GDSDS Regional Policy, Volume 3 (Environmental Management) should be taken into consideration;

- The calculation of water quality treatment volume for SuDS facility should be based upon capturing 90% of storms in a year. At this level, the first flush of large storms as well as most smaller storms are captured and treated.
- The design process and parameters for stormwater control as contained in the Regional Policy for New Development should be adopted.

9.3 Amenity

Water is a valuable resource and can be used to form a key part of an urban development, enriching aesthetic and recreational value, promoting health and well-being whilst supporting and implementing green infrastructure. Water managed on the surface rather, than underground, can act as a resource to raise local environmental awareness and provide habitat for fauna and flora. SuDS can provide multiple opportunities for water to be visible and audible as it travels through a development.

Table 20 below, outlines the amenity design criteria from The CIRIA SuDS Manual (2015) as well as example indicators that should be considered in the design of SuDS within the Castlelands site.

Table 20: Amenity Design Criteria and Example Indicators (CIRIA C753 Part B Chapter 5(hi), Table 5.2)

Amenity Design Criteria	Example Indicators
Maximise multi-functionality	The number, variety and quality of additional and multi-functional uses for SuDS, such as recreational areas, car parking or traffic management.
Enhance visual character	The proportion of the drainage system that is designed to be visually attractive, adds visual value to the development, supports local heritage and landscape character and integrates appropriately with the surrounding area.
Deliver safe surface water management systems	The consideration of public safety within the design of each SuDS component.
Support development resilience/ adaptability to future change	The proportion of the drainage system that is designed with allowance for future climate change or development change. The proportion of the drainage system that will contribute to the developments climate resilience, such as reducing the heating/cooling needs of buildings or through shade provision.
Maximise legibility	The proportion of the system that is visible.
Support community environmental learning	The extent of community awareness strategies, school involvement, community education strategies, visitor provision etc.

Further information as to how these criteria can be implemented can be found in The CIRIA SuDS Manual (2015) - C753 Part B Chapter 5(hi).

9.4 Biodiversity

Designing SuDS for biodiversity can help connect the community with the surrounding natural environment. This serves as an important contribution to both ecosystem services as well as improved community living space.

Table 21 below, outlines the biodiversity design criteria from The CIRIA SuDS Manual (2015) as well as example indicators that should be considered in the design of SuDS within the Castlelands site.

Table 21: Biodiversity Design Criteria and Example Indicators (CIRIA C753 Part B Chapter 6(hi), Table 6.1)

Amenity Design Criteria	Example Indicators
Support and protect natural local habitats and species	The extent, quality and significance of local habitats supported or enhanced by the SuDS design.
Contribute to the delivery of local biodiversity objectives	The habitats delivered by the SuDS design that meet objectives set out in local biodiversity frameworks/strategies.
Contribute to habitat connectivity	The extent to which the SuDS scheme is integrated into the wider green infrastructure strategies, or is helping to support connecting habitats.
Create diverse, self-sustaining and resilient ecosystems	The range and diversity of habitat types delivered or supported by the SuDS design, and the likely resilience of these habitats and the ecosystems they support to potential future change.

Further information as to how these criteria can be implemented can be found in The CIRIA SuDS Manual (2015) - C753 Part B Chapter 6(hi).

9.5 SuDS Types

SuDS are a flexible series of options which allow the designer to reduce runoff and/or pollution based on site specific constraints. To maximise the efficiency of these options, a treatment train approach which combines multiple SuDS options in sequence is recommended. This is described further in Section 10.1 below. Table 22 below taken from the GDSDS Regional Policy, Volume 3 (Environmental Management) shows the different types of SuDS and their primary functions.

Table 22: Functions of different SuDS types (GDSDS)

Type of System	Device	Primary Function	Primary Characteristics
Water Conservation & Re-use (Source Control)	Water Butts, Rain Tanks, Greywater Re-use, Rooftop Greening	Collection and reuse of surface water.	Provides offline attenuation of stormwater.
Infiltration Systems (Source Control)	Infiltration Trenches, Infiltration Basins, Permeable Paving	Encourage stormwater to soak into the ground while filtering pollutants.	Permeable features allowing infiltration.
Filtration Systems (Source Control)	Swales, Bioretention Systems, Filter Strips	Capture heavy metals, grease, oil, nutrients and sediment.	Grassed or planted features such as channels.
Retention Systems (Site/Regional Control)	Retention Ponds	Primarily designed to retain pollutants.	Artificial lake with fringing vegetation.

Type of System	Device	Primary Function	Primary Characteristics
Detention Systems (Site/Regional Control)	Detention Basins, Filter Drains	Primarily designed to reduce runoff rate.	Vegetated depressions.
Constructed Wetlands (Regional Control)	Stormwater Wetlands	Filter stormwater and reduce runoff rate while providing a wildlife habitat.	Heavily vegetated hydrologically charged area.

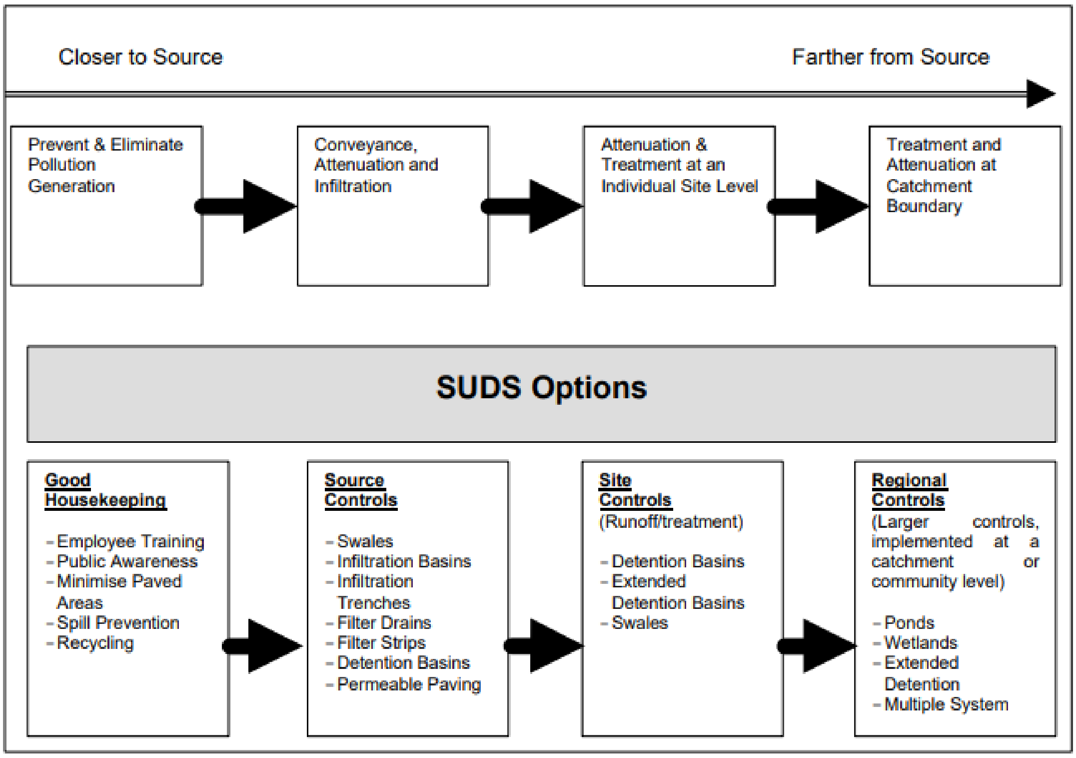
10 SuDS Strategy

Effective stormwater management is best attained using a management systems approach, rather than focusing on discrete practices. Some individual practices may not be very effective alone, but in combination with others, may provide a key function in highly effective systems. The SuDS Management/Treatment Train as outline below advocates such an approach.

10.1 SuDS Management/Treatment Train

The stormwater management or treatment train in Figure 24 below ensures that water quantity and quality is addressed.

Figure 24: The Stormwater Treatment Train Concept (GDSDS)



As can be seen in the figure above there are four main objectives of the treatment train concept namely;

i. Pollution prevention: spill prevention, recycling, public awareness and participation.

ii. Source control: conveyance and infiltration of runoff;

iii. Site Control: reduction in volume and rate of surface runoff, with some additional treatment provided; and

iv. Regional Control: Interception of runoff downstream of all source and on-site controls to provide follow–up flow management and water quality treatment.

10.2 SuDS Selection

These objectives provide an integrated and balanced approach to ensure that changes in stormwater quality and quantity runoff from subsequent development of lands is mitigated and provision of amenity value and biodiversity is maximised.

The proposed development will include a distributor road linking the R132 and Skerries Road, c. 850 residential units, a school and small-scale retail / local facilities, all of which were included to size the regional attenuation feature.

Based on the above design recommendations, the following SuDS types are proposed for use within the Castlelands site;

- **Green Roofs** – To be provided on all flat roof areas greater than 300m^2. Where required, a Green Roof, shall cover a minimum of 60% of the roof area. For design guidance refer to CIRIA C753, Part D, Chapter 12.
- **Rainwater Harvesting** – To be provided on large roof areas (>300m^2) where a green roof has not been provided. For design guidance refer to CIRIA C753, Part D, Chapter 11.
- **Permeable Pavements** – To be provided for all residential driveways and parking areas within the development. For design guidance refer to with CIRIA C753, Part D, Chapter 20.
- **Porous Pavements** – To be provided for on all access roads and public car parking spaces within the development. For design guidance refer to with CIRIA C753, Part D, Chapter 20.
- **Bioretention Tree Pits** – To be provided in areas surrounded by hardstanding ground e.g. adjacent to roads and/or pavements. For design guidance refer to CIRIA C753, Part D, Chapter 19.
- **Filter Drains** – To be provided adjacent to all roads where swales cannot be provided. For design guidance refer to CIRIA C753, Part D, Chapter 16.

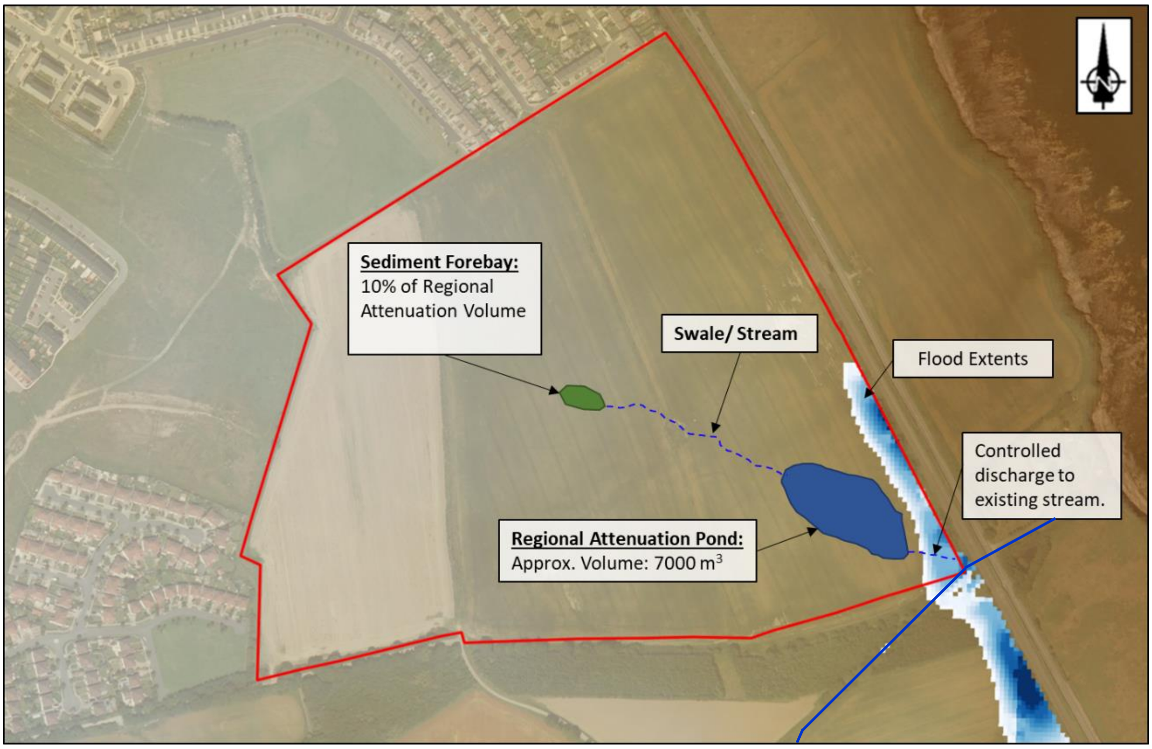
  Petrol Interceptor - As per the Greater Dublin Regional Code of Practice, all surface car parks with the provision for 10 spaces or more must be fitted with a Class I Light Liquid Separator, in accordance with latest version of European Standards EN858: Parts 1 & 2.
- **Swales** – To be provided along all roads and pathways where suitable space is available. For design guidance refer to CIRIA C753, Part D, Chapter 17. Furthermore, a swale/stream is to be provided within green belt area connecting the sediment forebay to attenuation pond as well from the pond to the existing Castlelands Stream, see Figure 24 below. Due to the steep gradient of the existing ground levels, scour protection should be provided where necessary. All scour protection should add to the natural amenity of the open space e.g. gabions, rock lining, vegetation etc. For further design guidance refer to CIRIA C551; NRA HD 107/15 and/or NRA HD119/15
- **Attenuation Pond** – To be provided within low-lying area, outside flood extents to facilitate drainage from the entire development.

The pond should provide for interception, attenuation, treatment and long-term storage of approximately 7000m^3, of which at least 10% should be provided within the sediment forebay.

This includes an allowance of 20% for climate change. Discharge from the pond should be limited to 2 l/s/ha or Q_{bar}, whichever is greater. Appendix A5 provides detailed output from the storage analysis that was carried out using Microdrainage Software. This is based on an initial development layout covering 14.9ha impervious area, which is subject to change. The attenuation feature could be increased if required.

For design guidance refer to CIRIA C753, Part D, Chapter 23. Figure 25 below illustrates the proposed attenuation features. The location of these features is indicative only and will depend on the actual site layout. Appendix A4 includes the following figure in A3 size with OS Background.

Figure 25: Regional Attenuation – Approximate Location & Sizing



11 Summary & Conclusion

Arup was commissioned by Fingal County Council to prepare a Surface Water Management Plan (SWMP) for the Castlelands Masterplan, Balbriggan, Co. Dublin. The following section outlines the summary and conclusion for the two key parts of the SWMP.

11.1 Strategic Flood Risk Assessment

In order to inform the Masterplan of the area with respect to flood risk, a Strategic Flood Risk Assessment (SFRA) for the site was conducted. The SFRA consisted of a review of existing site conditions by undertaking a site visit as well as topographic survey of the lands and relevant watercourses. Furthermore, the SFRA consisted of an assessment of the existing hydrology and historic flooding to inform a detailed 1D/2D hydraulic model of the site. This was developed to assess the fluvial and pluvial flood risk to the site with further investigation into the possible blockage of the culvert immediately downstream of the site underneath the railway line as well as climate change effects.

Fluvial Flood Zone Maps were produced using the Q_{100} and Q_{1000} design flows for Flood Zone A and B respectively. Due to the existing site topography, the flood extents for Flood Zone A and B do not differ significantly within the Castlelands site. Furthermore, the blockage analysis produced similar flood extents with the 70% blockage producing a marginally larger flood extent. Due to the likeliness of this blockage occurring it was decided to adopt this flood extent for the final fluvial flood extents for the site.

The pluvial model was found to not be sensitive to changes in return periods and/ or storm durations and thus the final pluvial flood extents correspond to the 1-hour storm duration with both the 100-year (1% AEP) and 1000-year (0.1% AEP) return periods. The results of the model showed there are some areas of pluvial flooding within the Castlelands site boundary however, these localised areas correspond with areas of low ground levels. The provision of adequate stormwater drainage systems will however mitigate this flood risk within the site.

11.2 Sustainable Drainage Strategy

In order to inform the Masterplan of the area with respect to SuDS, a Sustainable Drainage Strategy for the site was produced. The SDS included a review of existing site conditions by undertaking a site visit as well as topographic survey of the lands. Ground investigation was not conducted however, this is recommended pre-construction to improve the assessment of the site-specific infiltration and/or run-off characteristics.

Recommendations based on best practice have been provided with regards to Design Criteria, SuDS Types, the SuDS Management/ Treatment Train, Water Quantity and Water Quality. Based on these recommendations a SuDS Strategy for the Castlelands site was proposed.

This strategy includes recommendation for the use of green roofs, rainwater harvesting, permeable paving, bioretention trees, filter drains, attenuation ponds, swales and a petrol interceptor to ensure that surface water within the site is adequately managed.

Furthermore, the proposed development will include a distributor road linking the R132 and Skerries Road, c. 850 residential units, a school and small-scale retail / local facilities, all of which were included to size the regional attenuation feature of c. 7000m^3 and serving an impervious area of 14.9ha.

The approximate sizing, location and discharge rate for the regional attenuation features are proposed in order to make use of the surface water as a focal point of the development to better enhance public amenity and habitat growth.

Appendix A1

Survey Data

Head Office
Global House
Kilcullen Business Campus
Kilcullen
Co. Kildare
Ireland
Phone: (+353) 045 484040
Fax: (+353) 045 484004
Email: info@murphysurveys.ie

Cork
Douglas, Cork
Phone: (+353) 021 4895704
Fax: (+353) 021 4368230
cork@murphysurveys.ie

Belfast
The Gasworks
Phone: (+44) 028 9044 7606
Fax: (+44) 028 9044 7645
belfast@murphysurveys.co.uk

London Head Office
9 Devonshire Square, London, EC2M 4YF
Phone: (+44) 0203 1786644
Fax: (+44) 0203 1786642
london@murphysurveys.co.uk

Bedfordshire Office
Unit 721 1st Floor
Capability Green Business Park
Bedfordshire, LU1 3LU
Phone: (+44) 01582 405058
Fax: (+44) 01582 723403
london@murphysurveys.co.uk

www.murphysurveys.ie

LEGEND

section plan details

- Surveyed Section Lines with References & Section Orientation (at Open channel)
- Surveyed Section Lines with References & Section Orientation (at Structures)
- Surveyed Section Lines with References & Section Orientation (at Additional items)

Surveyed by : MSL — Date: OCTOBER 2018
Drawn by : CE — Date: OCTOBER 2018
Checked by : KC — Date: 24.10.2018

Revisions

No.	Date	Description
0	24.10.18	First Drawing
1	07.11.18	Additional Sections

murphy SURVEYS
GLOBAL CONSULTING SURVEYORS

Topographic surveys, Measured Building Surveys, Setting-Out, As-Built Surveys, Hydrographic Surveys, Legal Mapping, Pipeline Surveys, Services Location, Ground Penetrating Radar, Laser Scanning, Rectified Photography

Kildare Cork Belfast London

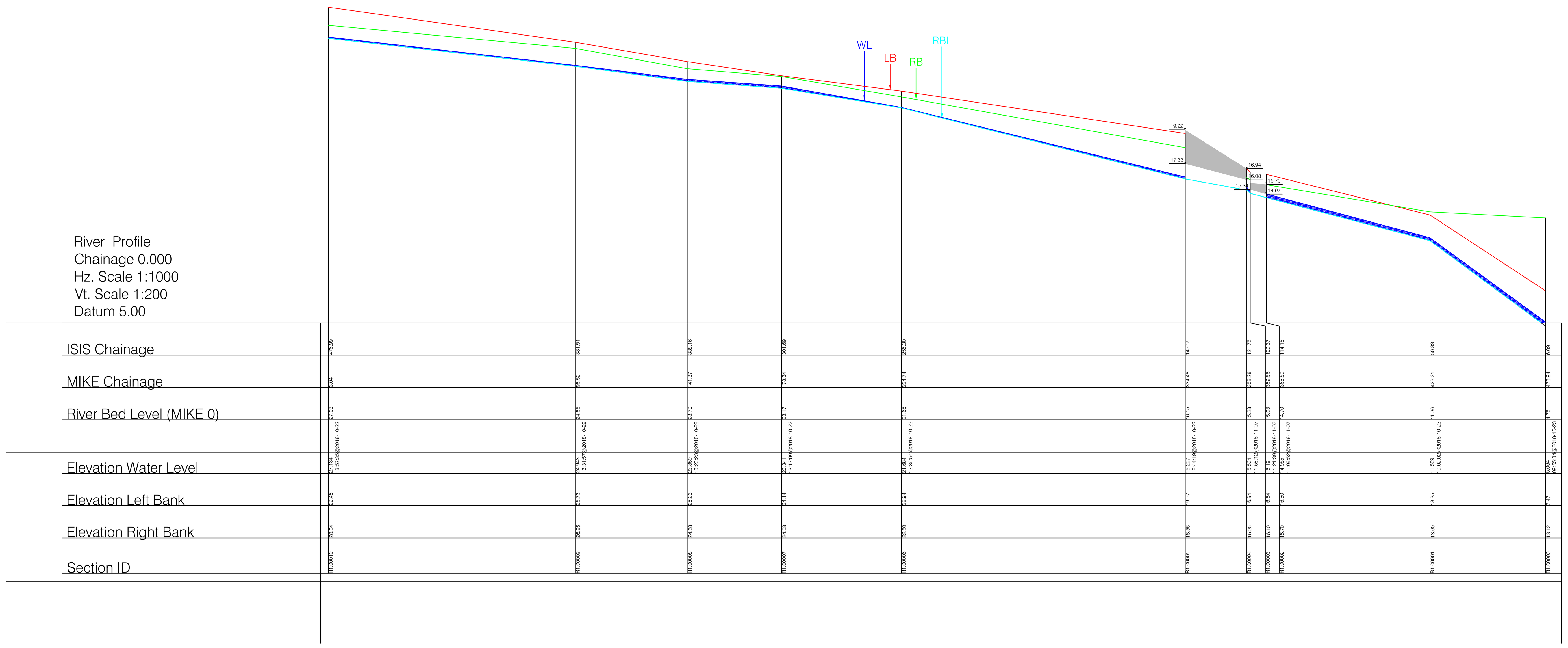
Client : Arup Consulting Engineers Dublin

Project : 27682_River Cross Sections_Castlelands Fingal County Council

Date : 24.10.2018 **Scale :** AS SHOWN

Description : SECTIONS PLAN

Drawing Number : MSL27682_CASTLELANDS_R1_PLAN_V1



Head Office
Global House
Kilcullen Business Campus
Kilcullen
Co. Kildare
Ireland
Phone: (+353) 045 484040
Fax: (+353) 045 484004
Email: info@murphysurveys.ie

Cork
Douglas, Cork
Phone: (+353) 021 4895704
Fax: (+353) 021 4368230
cork@murphysurveys.ie

Belfast
The Gasworks
Phone: (+44) 028 9044 7606
Fax: (+44) 028 9044 7645
belfast@murphysurveys.co.uk

London Head Office
9 Devonshire Square, London,
EC2M 4YF
Phone: (+44) 0203 1786644
Fax: (+44) 0203 1786642
london@murphysurveys.co.uk

Bedfordshire Office
Unit 721 1st Floor
Capability Green Business Park
Bedfordshire, LU1 3LU
Phone: (+44) 01582 405058
Fax: (+44) 01582 723403
london@murphysurveys.co.uk

www.murphysurveys.ie

LEGEND

long section details

Water Profile	
Water Level	LB Left Bank Level
Left Bank Level	RB Right Bank Level
Right Bank Level	WL Water Level
River Bed Level	RBL River Bed Level
Road Level	
Structure Level	

North

murphy SURVEYS
GLOBAL CONSULTING SURVEYORS
Kildare Cork Belfast London

Client : Arup Consulting Engineers Dublin

Project : 27682_River Cross Sections_Castlelands Fingal County Council

Date : 24.10.2018 **Scale :** AS SHOWN

Description : LONG SECTION

Drawing Number : MSL27682_CASTLELANDS_R1_LS_V1

Head Office
Global House
Kilcullen Business Campus
Kilcullen
Co. Kildare
Ireland
Phone: (+353) 045 484040
Fax: (+353) 045 484004
Email: info@murphysurveys.ie

Cork
Douglas, Cork
Phone: (+353) 021 4895704
Fax: (+353) 021 4368230
cork@murphysurveys.ie

Belfast
The Gasworks
Phone: (+44) 028 9044 7606
Fax: (+44) 028 9044 7645
belfast@murphysurveys.co.uk

London Head Office
9 Devonshire Square, London, EC2M 4YF
Phone: (+44) 0203 1786644
Fax: (+44) 0203 1786642
london@murphysurveys.co.uk

Bedfordshire Office
Unit 721 1st Floor
Capability Green Business Park
Bedfordshire, LU1 3LU
Phone: (+44) 01582 405058
Fax: (+44) 01582 723403
london@murphysurveys.co.uk

www.murphysurveys.ie

LEGEND

cross section details

River Profile	LB Left Bank
Water Level	RB Right Bank
Ground Level	Building Line
Road Line	Wall Line
Wall Line	Fence Line
Bridge Line	Pipe Profile

Surveyed by : MSL	Date: OCTOBER 2018
Drawn by : CE	Date: OCTOBER 2018
Checked by : KC	Date: 24.10.2018

Revisions

No.	Date	Description
0	24.10.18	First Drawing
1	07.11.18	Additional Sections

murphy SURVEYS
GLOBAL CONSULTING SURVEYORS
Topographic surveys, Measured Building Surveys, Setting-Out, As-Built Surveys, Hydrographic Surveys, Legal Mapping, Pipeline Surveys, Services Location, Ground Penetrating Radar, Laser Scanning, Rectified Photography
Kildare Cork Belfast London

Client : Arup Consulting Engineers Dublin
Project : 27682_River Cross Sections_Castlelands Fingal County Council
Date : 24.10.2018 **Scale :** AS SHOWN
Description : CROSS SECTIONS
Drawing Number : MSL27682_CASTLELANDS_R1_XS_V1

Appendix A2

Site Photos

Figure 26: Site walkover photo locations

Photo 1: Location A – Site topography south-east facing

Photo 2: Location A – Site topography south facing

Photo 3: Location A – Site topography south-west facing

Photo 4: Location A – Site topography west facing

Photo 5: Location B – Site topography north facing

Photo 6: Location B – Existing ground conditions

Photo 7: Location B – Existing on-site ponding

Photo 8: Location C – Existing topography west facing

Photo 9: Location C – Existing ground conditions

Photo 10: Location D – Opening in existing stone wall

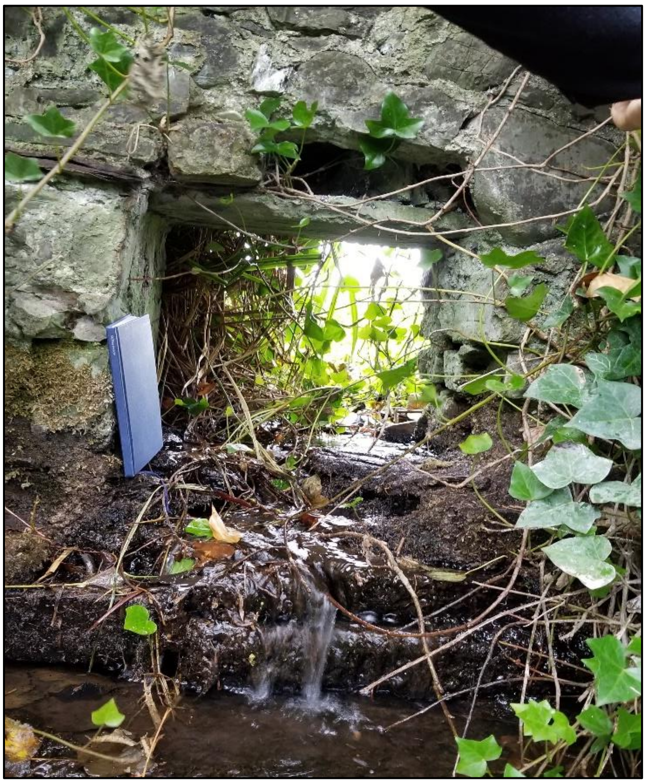


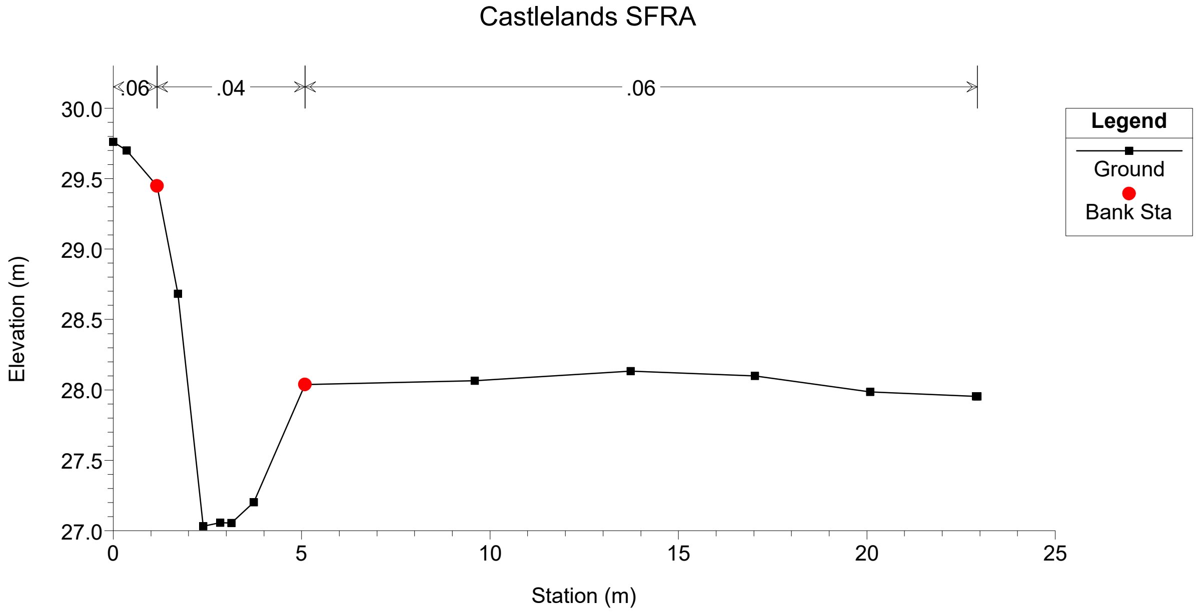
Photo 11: Location D – Existing culvert (upstream)

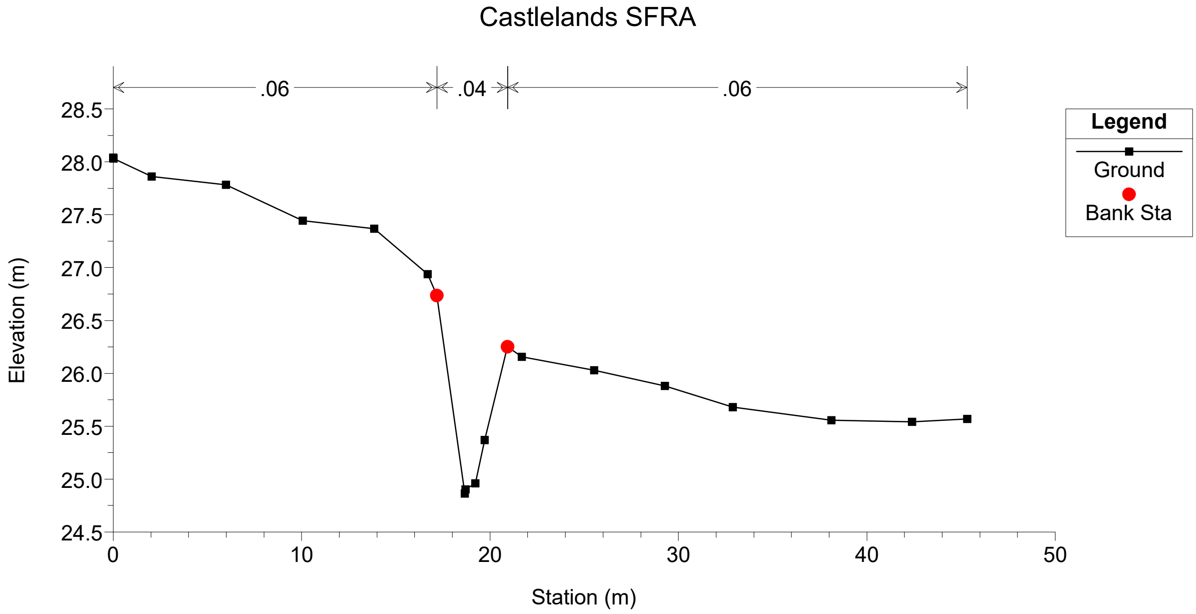
Photo 12: Location D – Culvert facing downstream

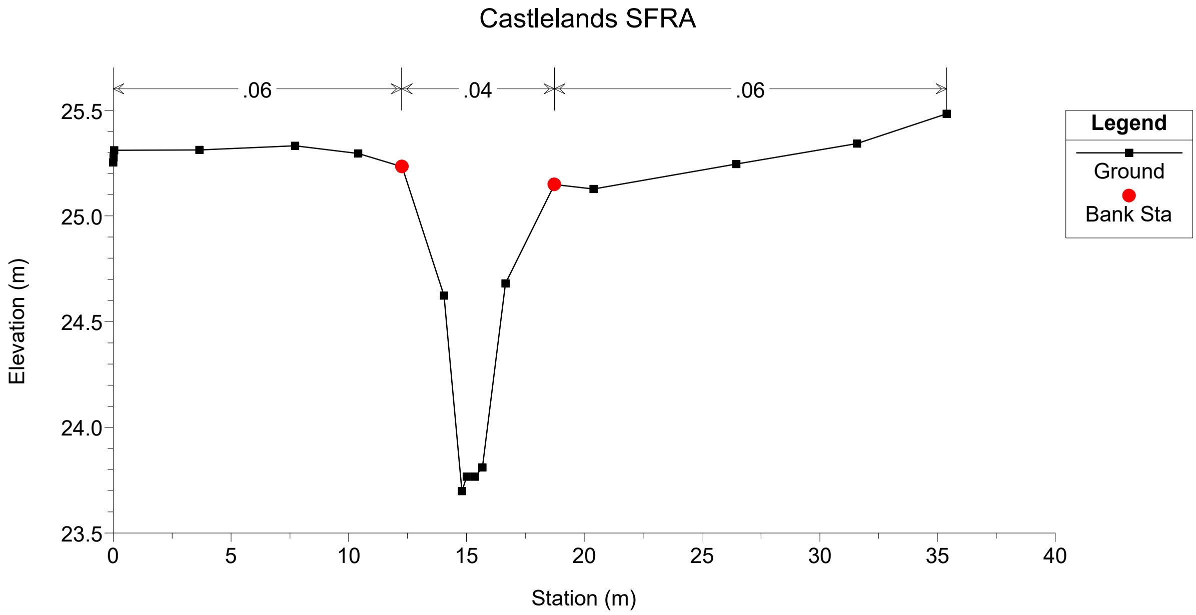
Photo 13: Location E – Site topography facing south

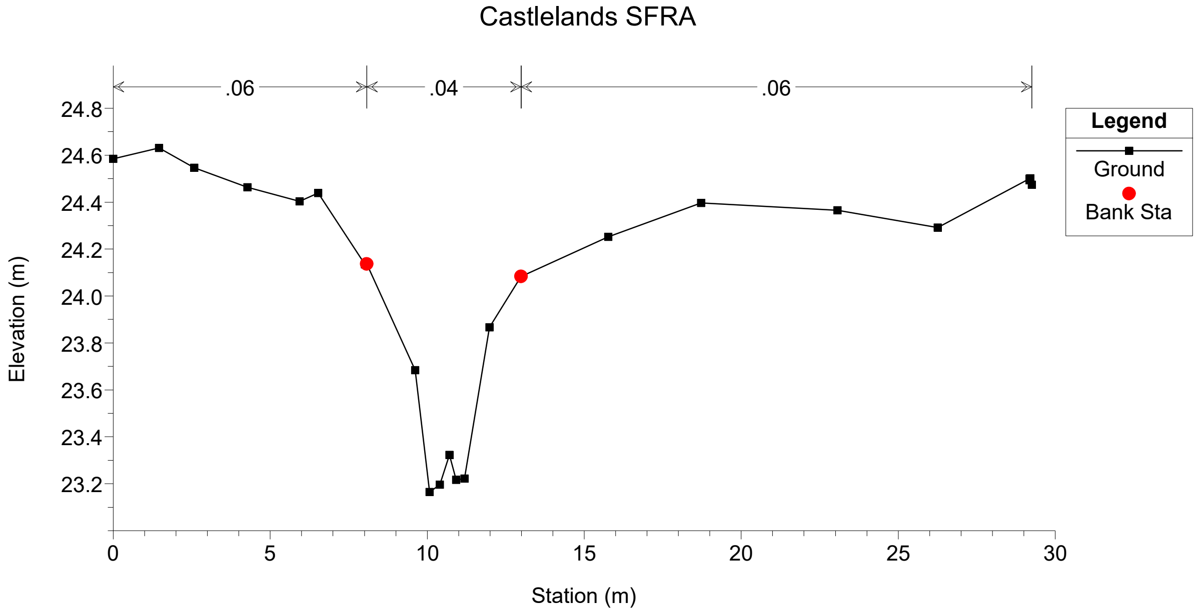
Appendix A3

Hydraulic Model Cross Sections

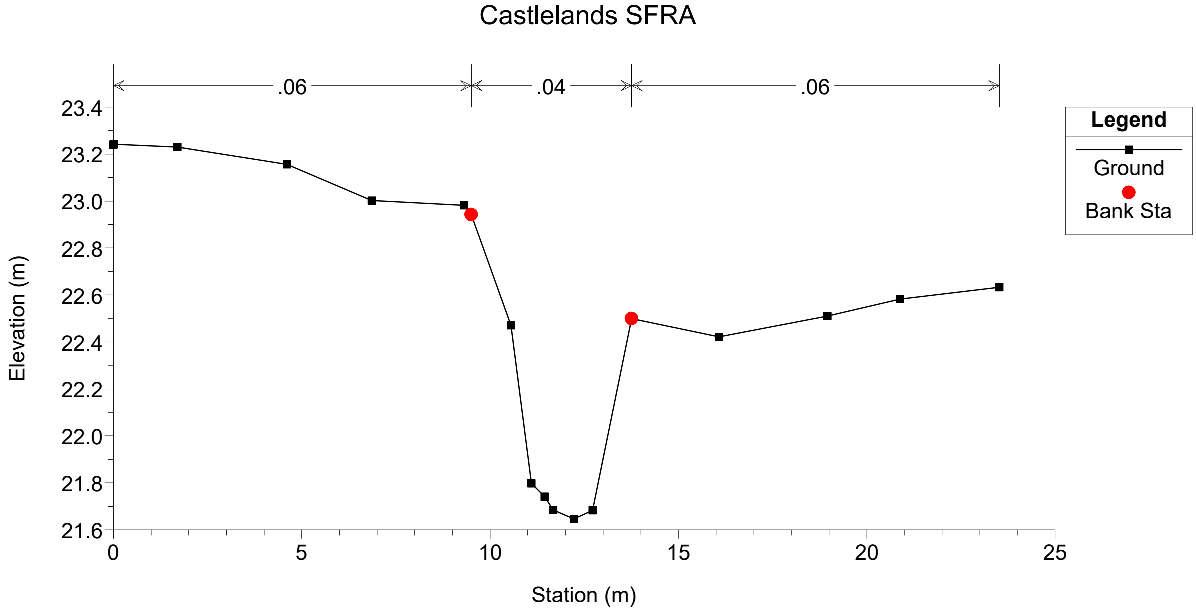

Castlelands SFRA
.06
.04
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)
30.0
29.5
29.0
28.5
28.0
27.5
27.0
0
5
10
15
20
25


Castlelands SFRA
.06
.04
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)
28.5
28.0
27.5
27.0
26.5
26.0
25.5
25.0
24.5
0
10
20
30
40
50

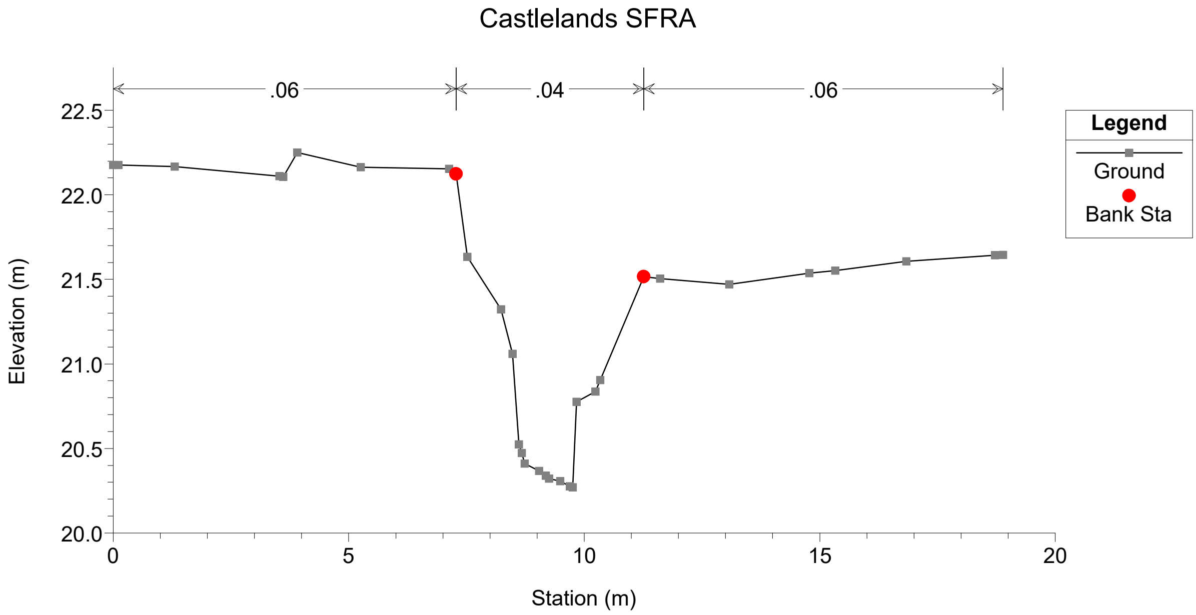

Castlelands SFRA
.06
.04
.06
Legend
Ground
Bank Sta
Elevation (m)
Station (m)
25.5
25.0
24.5
24.0
23.5
0
5
10
15
20
25
30
35
40



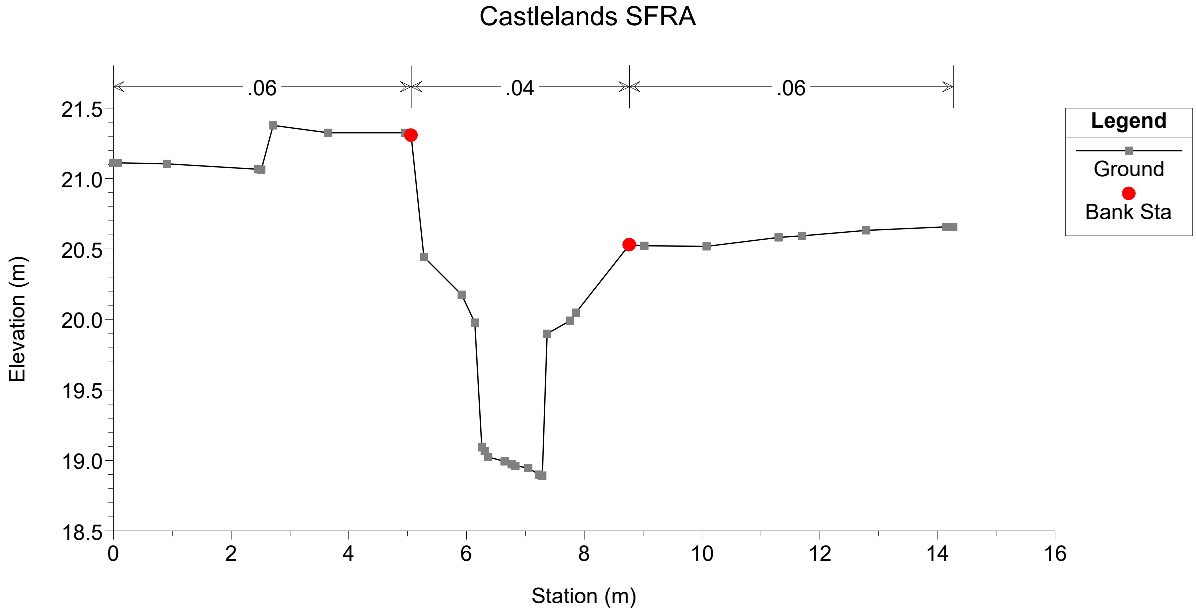
Castlelands SFRA
.06
.04
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

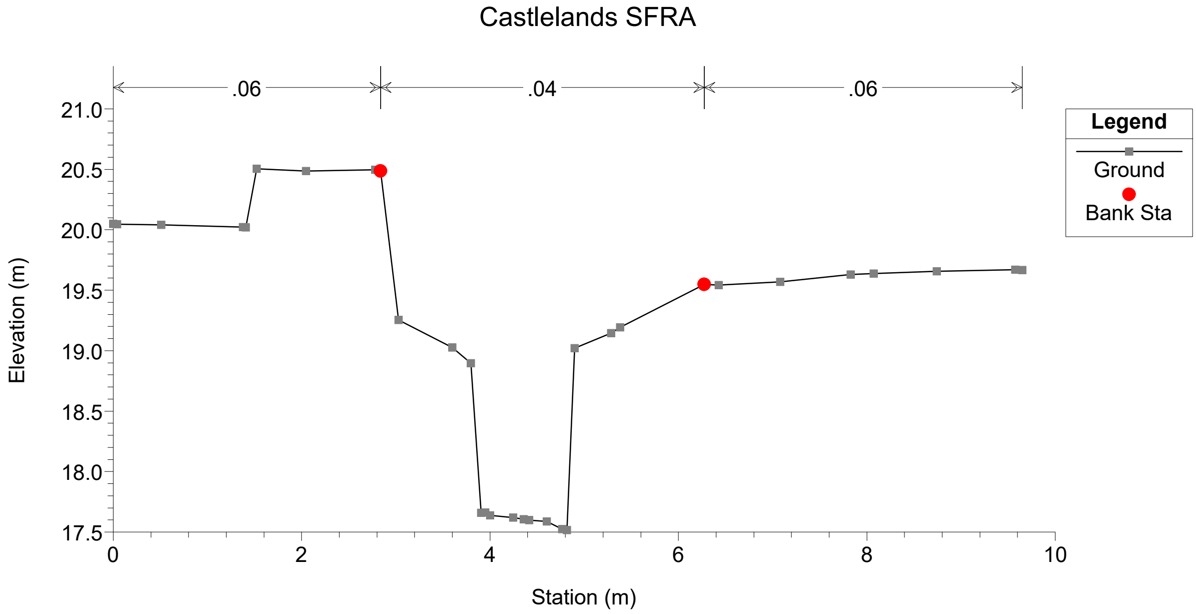


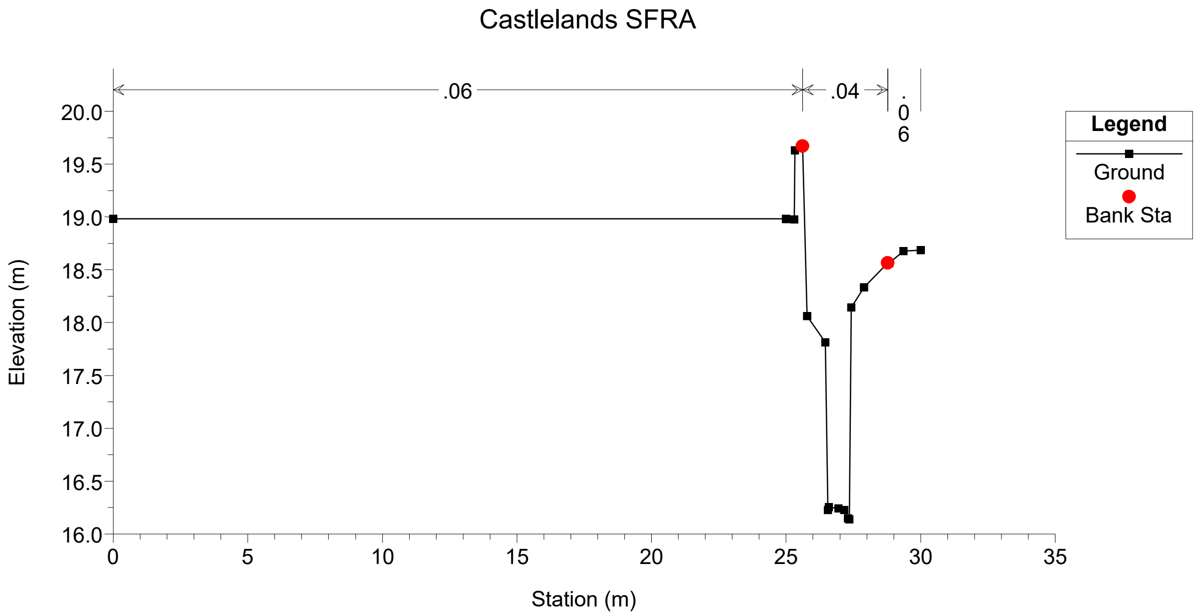
Castlelands SFRA
.06
.04
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

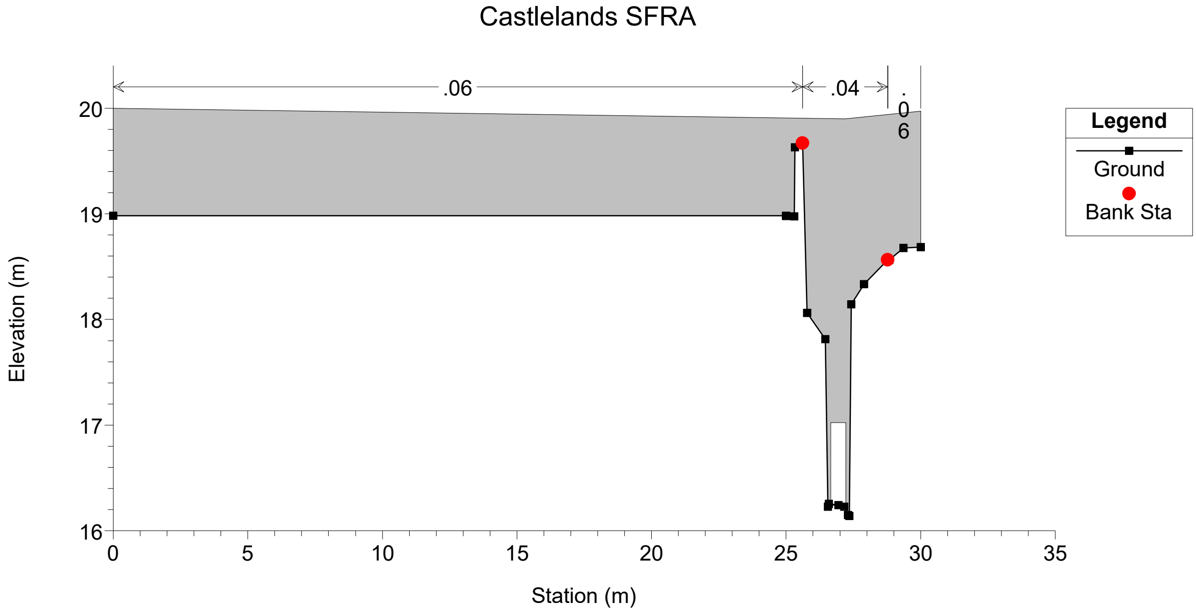


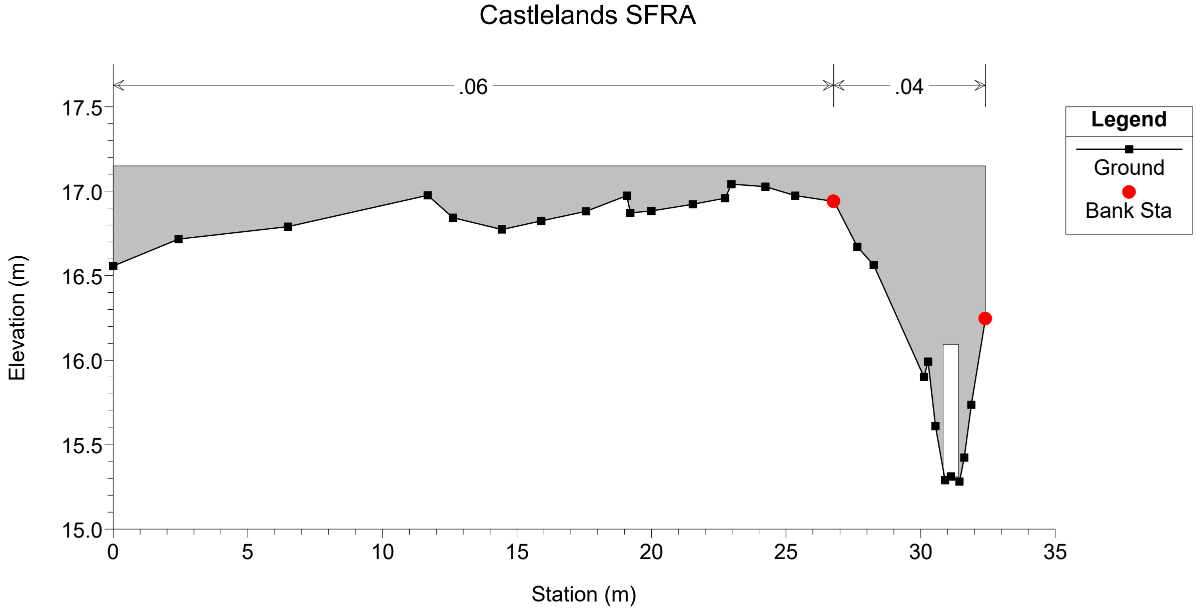
Castlelands SFRA
.06
.04
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

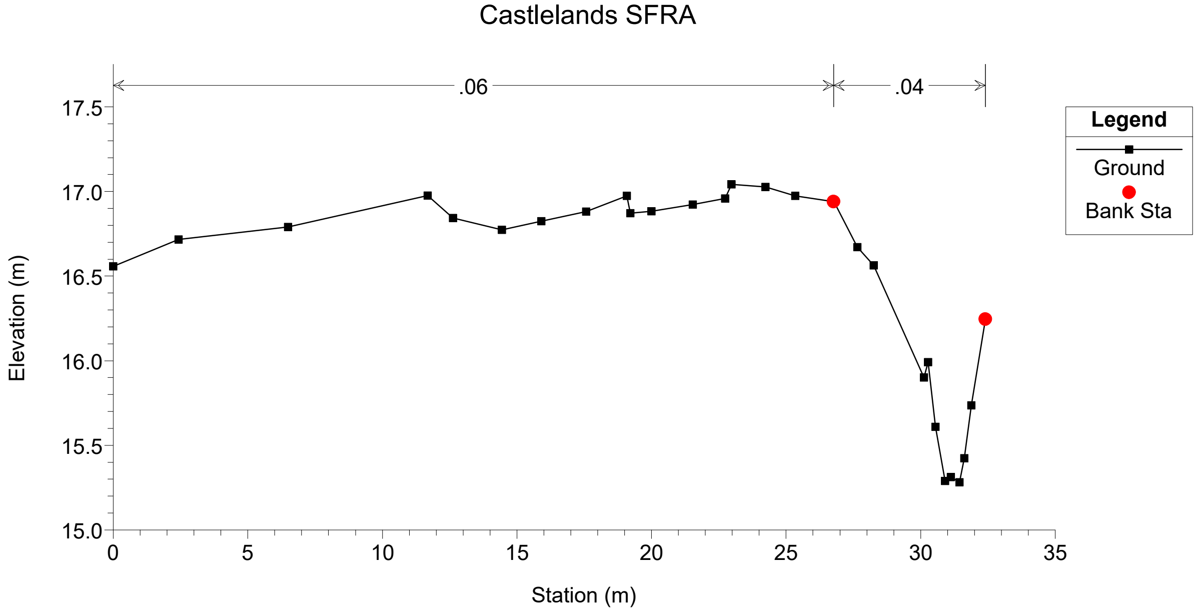

Castlelands SFRA
.06
.04
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
21.5
21.0
20.5
20.0
19.5
19.0
18.5
0
2
4
6
8
10
12
14
16

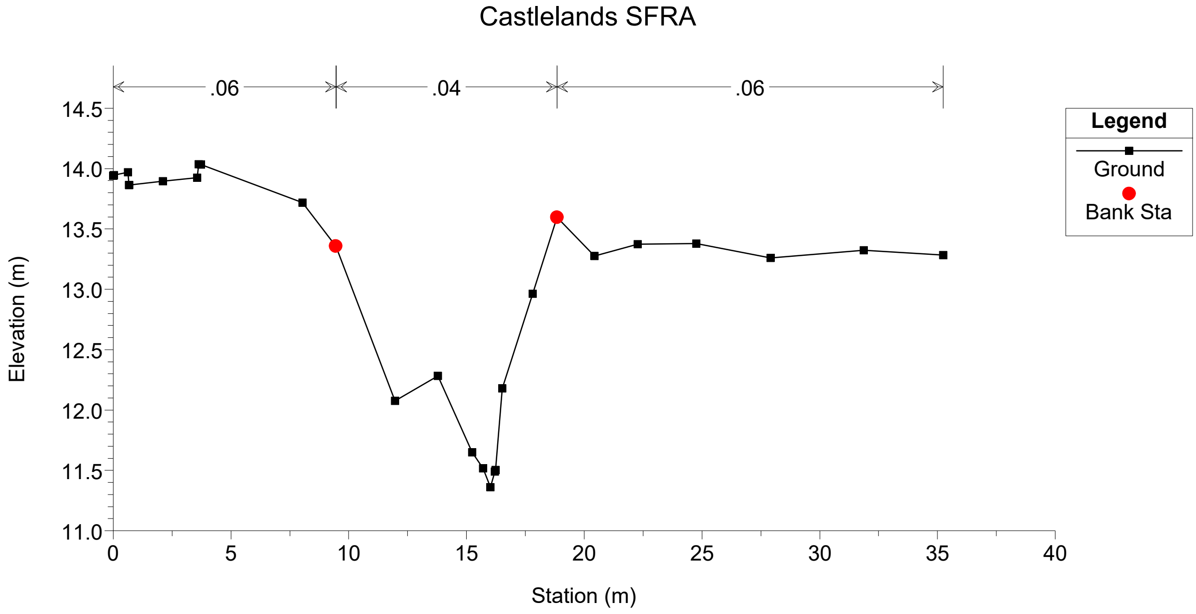

Castlelands SFRA
.06
.04
.06
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
0
2
4
6
8
10


Castlelands SFRA
.06
.04
.
0
6
Elevation (m)
Station (m)
Legend
Ground
Bank Sta
20.0
19.5
19.0
18.5
18.0
17.5
17.0
16.5
16.0
0
5
10
15
20
25
30
35


Castlelands SFRA
.06
.04
.
0
6
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


Castlelands SFRA
.06
.04
Elevation (m)
Station (m)
Legend
Ground
Bank Sta

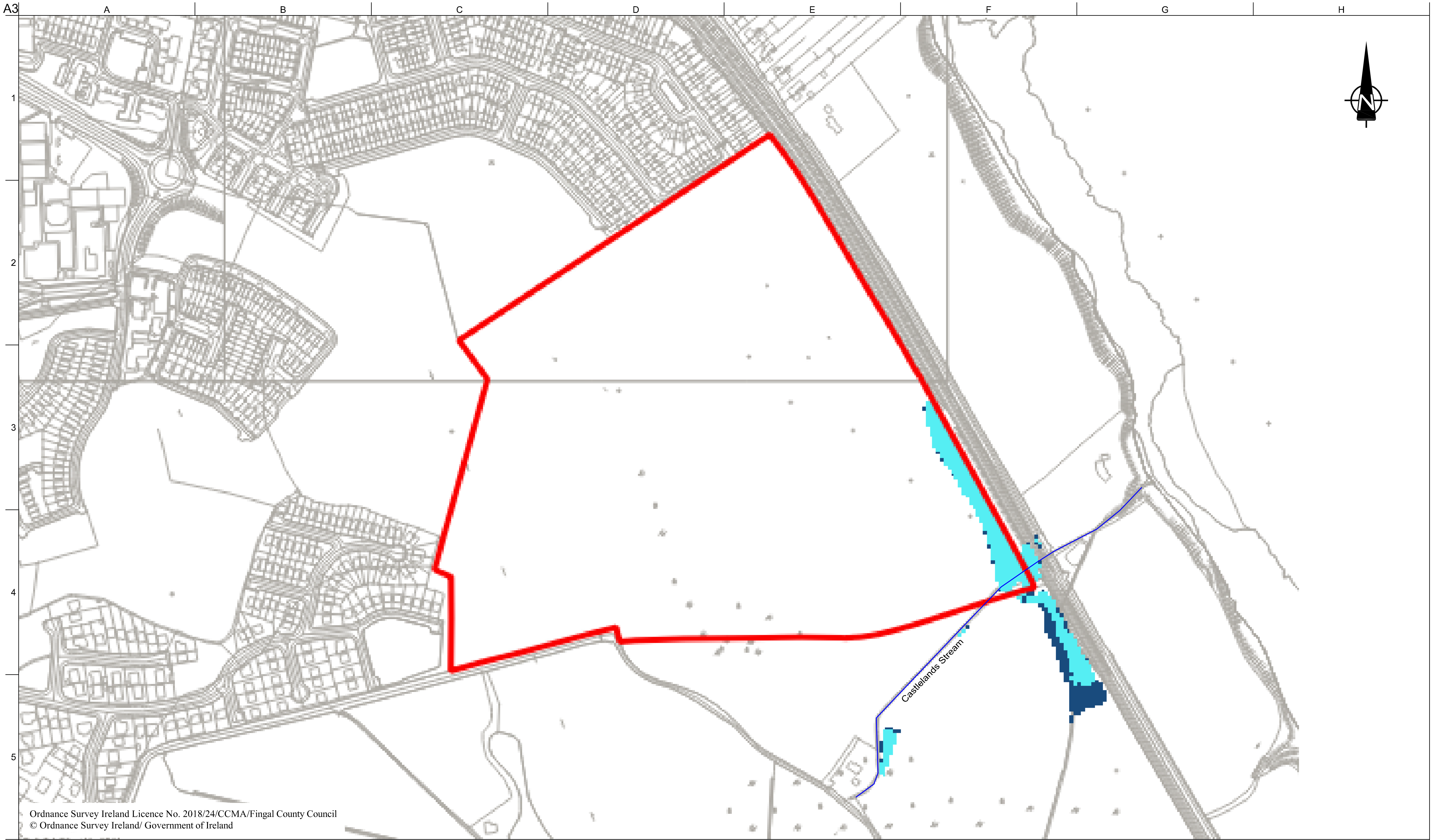

Castlelands SFRA
.06
.04
Elevation (m)
Station (m)
Legend
Ground
Bank Sta


Castlelands SFRA
.06
.04
.06
Legend
Ground
Bank Sta
Elevation (m)
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0
0
5
10
15
20
25
30
35
40
Station (m)

Appendix A4

Flood Maps

A3



\\GLOBAL\EUROPE\DUBLIN\JOBS\264000\264616-00\4. INTERNAL\4-02 DRAWINGS\4-02-1 ISSUE DRAWINGS\ISSUE 3\CL-001-00.DWG

LEGEND:

- Site Boundary
- Flood Zone A
- Flood Zone B

Issue	Date	By	Chkd	Appd
3	15/03/19	AG	TD	WS

Client
Fingal County Council

Job Title
Castlelands
Surface Water Management Plan

Scale at A3 1:4000

Discipline Infrastructure

ARUP

Arup, 50 Ringsend Road
Dublin 4
Tel +353(0)1 233 4455 Fax +353(0)1 668 3169
www.arup.ie

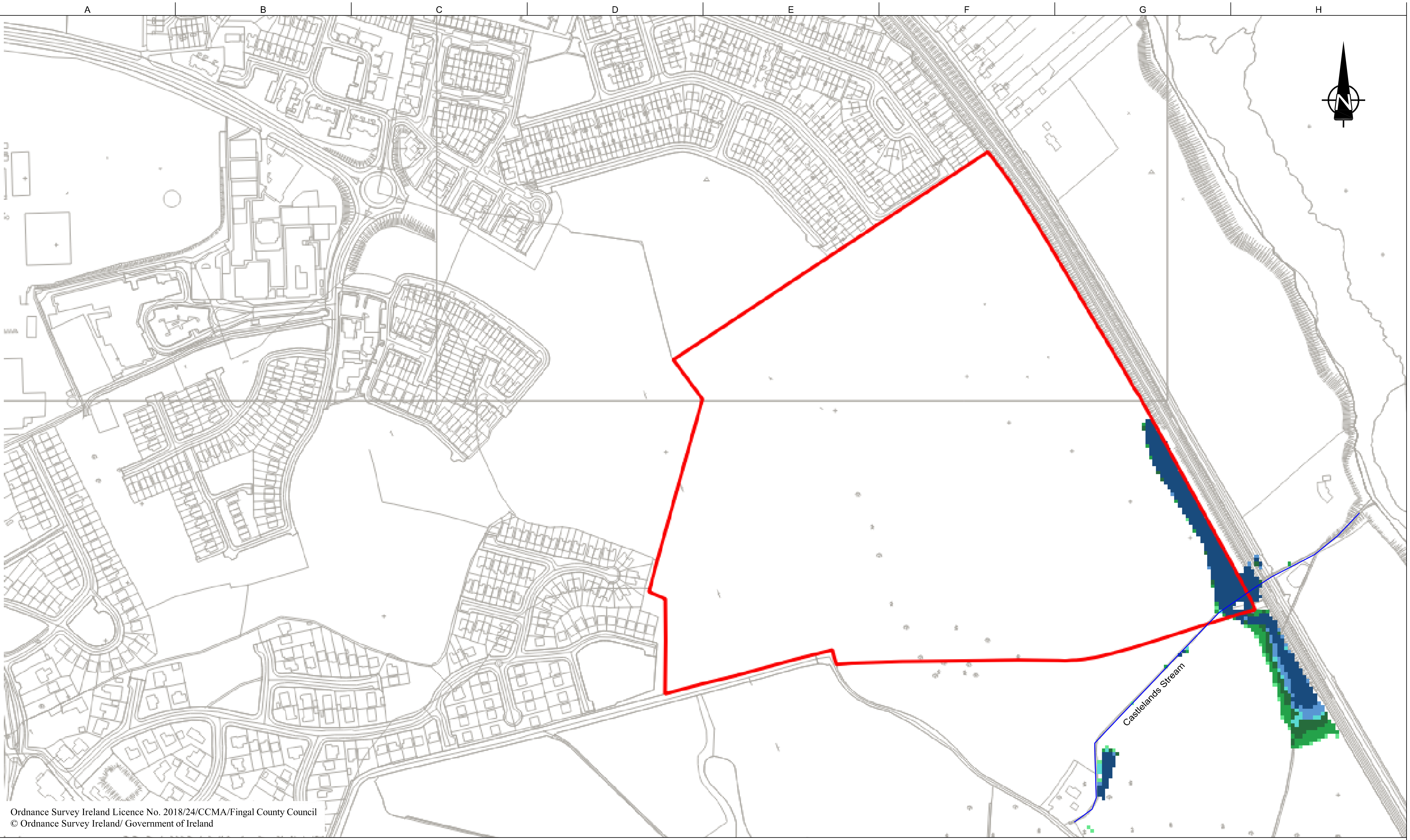
Drawing Title
Flood Zone Map

Drawing Status
For Information

Job No	Drawing No	Issue
264616-00	CL-001-00	01

Do not scale

A3



\\GLOBAL\EUROPE\DUBLIN\JOBS\264000\264616-00\4. INTERNAL\4-02 DRAWINGS\4-02-1 ISSUE DRAWINGS\ISSUE 3\CL-002-00.DWG

LEGEND:

- Site Boundary
- 1% AEP Existing
- 1% AEP MRFS
- 1% AEP HEFS
- 0.1% AEP Existing
- 0.1% AEP MRFS
- 0.1% AEP HEFS

Issue	Date	By	Chkd	Appd
03	15/03/19	MP	TD	WS

Client
Fingal County Council

Job Title
Castlelands
Surface Water Management Plan

Scale at A3 1:2000

Discipline Infrastructure

ARUP

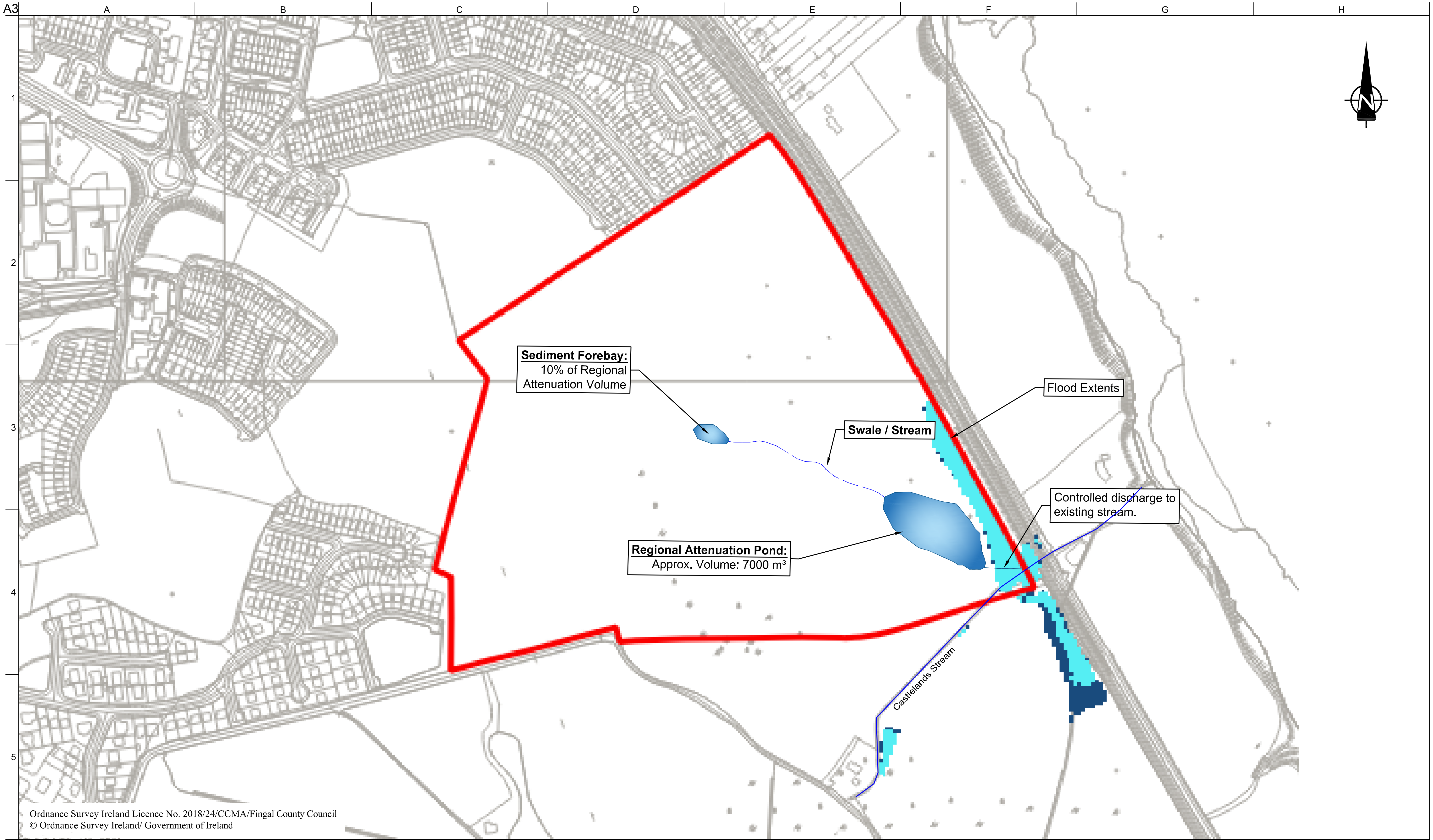
Arup, 50 Ringsend Road
Dublin 4
Tel +353(0)1 233 4455 Fax +353(0)1 668 3169
www.arup.ie

Drawing Title
Flood Extents

Drawing Status
For Information

Job No	Drawing No	Issue
264616-00	CL-002-00	01

Do not scale



LEGEND:

- Site Boundary
- Flood Zone A
- Flood Zone B

Issue	Date	By	Chkd	Appd
03	15/03/19	AG	TD	WS

Client
Fingal County Council

Job Title
Castlelands
Surface Water Management Plan

Scale at A3
1:4000

Discipline
Infrastructure

ARUP

Arup, 50 Ringsend Road
Dublin 4
Tel +353(0)1 233 4455 Fax +353(0)1 668 3169
www.arup.ie

Drawing Title
Flood Zone Map & SuDS Features

Drawing Status
For Information

Job No	Drawing No	Issue
264616-00	**CL-003-00**	**01**

Do not scale

\\GLOBAL\EUROPE\DUBLIN\JOBS\264000\264616-00\4. INTERNAL\4-02 DRAWINGS\4-02-1 ISSUE DRAWINGS\ISSUE 3\CL-003-00.DWG

Appendix A5

Storage Volume Analysis
(Microdrainage Output)

Summary of Results for 100 year Return Period (+20%)

Storm Event	Max Level (m)	Max Depth (m)	Max Control (l/s)	Max Volume (m³)	Status
15 min Summer	0.860	0.360	91.0	1942.3	O K
30 min Summer	0.995	0.495	96.8	2671.9	O K
60 min Summer	1.145	0.645	97.6	3484.8	O K
120 min Summer	1.308	0.808	97.6	4363.8	O K
180 min Summer	1.402	0.902	97.6	4870.2	O K
240 min Summer	1.463	0.963	97.6	5199.8	O K
360 min Summer	1.532	1.032	97.6	5570.3	O K
480 min Summer	1.559	1.059	97.6	5719.1	O K
600 min Summer	1.570	1.070	97.6	5775.3	O K

Storm Event	Rain (mm/hr)	Flooded Volume (m³)	Discharge Volume (m³)	Time-Peak (mins)
15 min Summer	71.795	0.0	1723.3	26
30 min Summer	50.004	0.0	2482.6	40
60 min Summer	33.236	0.0	3552.3	68
120 min Summer	21.518	0.0	4633.4	126
180 min Summer	16.513	0.0	5348.6	186
240 min Summer	13.617	0.0	5889.4	244
360 min Summer	10.292	0.0	6684.9	362
480 min Summer	8.379	0.0	7257.7	462
600 min Summer	7.113	0.0	7699.4	518

Summary of Results for 100 year Return Period (+20%)

Storm Event	Max Level (m)	Max Depth (m)	Max Control (l/s)	Max Volume (m³)	Status
720 min Summer	1.577	1.077	97.6	5815.6	O K
960 min Summer	1.578	1.078	97.6	5822.1	O K
1440 min Summer	1.550	1.050	97.6	5667.9	O K
2160 min Summer	1.473	0.973	97.6	5254.8	O K
2880 min Summer	1.386	0.886	97.6	4783.9	O K
4320 min Summer	1.221	0.721	97.6	3892.2	O K
5760 min Summer	1.087	0.587	97.6	3169.4	O K
7200 min Summer	0.987	0.487	96.7	2627.8	O K
8640 min Summer	0.916	0.416	95.0	2245.7	O K

Storm Event	Rain (mm/hr)	Flooded Volume (m³)	Discharge Volume (m³)	Time-Peak (mins)
720 min Summer	6.233	0.0	8091.3	580
960 min Summer	5.055	0.0	8734.3	710
1440 min Summer	3.754	0.0	9676.8	980
2160 min Summer	2.781	0.0	11067.7	1384
2880 min Summer	2.244	0.0	11901.8	1784
4320 min Summer	1.655	0.0	13099.4	2520
5760 min Summer	1.331	0.0	14216.8	3232
7200 min Summer	1.123	0.0	14981.7	3904
8640 min Summer	0.977	0.0	15611.6	4584

Summary of Results for 100 year Return Period (+20%)

Storm Event	Max Level (m)	Max Depth (m)	Max Control (l/s)	Max Volume (m³)	Status
10080 min Summer	0.870	0.370	93.3	1995.8	O K
15 min Winter	0.903	0.403	94.6	2176.7	O K
30 min Winter	1.056	0.556	97.5	3003.1	O K
60 min Winter	1.227	0.727	97.6	3925.5	O K
120 min Winter	1.413	0.913	97.6	4931.1	O K
180 min Winter	1.523	1.023	97.6	5523.3	O K
240 min Winter	1.596	1.096	97.6	5920.1	O K
360 min Winter	1.683	1.183	97.6	6390.4	O K
480 min Winter	1.721	1.221	97.6	6593.1	O K

Storm Event	Rain (mm/hr)	Flooded Volume (m³)	Discharge Volume (m³)	Time-Peak (mins)
10080 min Summer	0.868	0.0	16115.6	5248
15 min Winter	71.795	0.0	1956.1	25
30 min Winter	50.004	0.0	2804.7	40
60 min Winter	33.236	0.0	3993.3	68
120 min Winter	21.518	0.0	5203.1	126
180 min Winter	16.513	0.0	6003.0	182
240 min Winter	13.617	0.0	6607.3	240
360 min Winter	10.292	0.0	7495.2	354
480 min Winter	8.379	0.0	8134.5	466

Summary of Results for 100 year Return Period (+20%)

Storm Event	Max Level (m)	Max Depth (m)	Max Control (l/s)	Max Volume (m³)	Status
600 min Winter	1.732	1.232	97.6	6651.3	O K
720 min Winter	1.733	1.233	97.6	6660.0	O K
960 min Winter	1.725	1.225	97.6	6614.3	O K
1440 min Winter	1.678	1.178	97.6	6359.0	O K
2160 min Winter	1.548	1.048	97.6	5656.9	O K
2880 min Winter	1.403	0.903	97.6	4877.7	O K
4320 min Winter	1.148	0.648	97.6	3501.3	O K
5760 min Winter	0.969	0.469	96.4	2532.3	O K
7200 min Winter	0.868	0.368	93.3	1989.4	O K

Storm Event	Rain (mm/hr)	Flooded Volume (m³)	Discharge Volume (m³)	Time-Peak (mins)
600 min Winter	7.113	0.0	8627.1	574
720 min Winter	6.233	0.0	9063.4	674
960 min Winter	5.055	0.0	9776.4	762
1440 min Winter	3.754	0.0	10804.2	1074
2160 min Winter	2.781	0.0	12404.3	1516
2880 min Winter	2.244	0.0	13341.2	1912
4320 min Winter	1.655	0.0	14698.6	2644
5760 min Winter	1.331	0.0	15931.2	3296
7200 min Winter	1.123	0.0	16790.6	3832

Summary of Results for 100 year Return Period (+20%)

Storm Event	Max Level (m)	Max Depth (m)	Max Control (l/s)	Max Volume (m^3)	Status
8640 min Winter	0.831	0.331	82.8	1787.7	O K
10080 min Winter	0.805	0.305	74.5	1644.4	O K

Storm Event	Rain (mm/hr)	Flooded Volume (m^3)	Discharge Volume (m^3)	Time-Peak (mins)
8640 min Winter	0.977	0.0	17501.6	4576
10080 min Winter	0.868	0.0	18080.4	5248

Rainfall Details

Rainfall Model	FSR	Ratio R	0.300	Cv (Winter)	0.840
Return Period (years)	100	Summer Storms	Yes	Shortest Storm (mins)	15
Region	England and Wales	Winter Storms	Yes	Longest Storm (mins)	10080
M5-60 (mm)	14.000	Cv (Summer)	0.750	Climate Change %	+20

Time Area Diagram

Total Area (ha) 14.900

Time From:	**(mins) To:**	**Area (ha)**	**Time From:**	**(mins) To:**	**Area (ha)**	**Time From:**	**(mins) To:**	**Area (ha)**
0	4	5.000	4	8	5.000	8	12	4.900

Model Details

Storage is Online Cover Level (m) 3.000

Tank or Pond Structure

Invert Level (m) 0.500

Depth (m)	Area (m²)	Depth (m)	Area (m²)	Depth (m)	Area (m²)
0.000	5400.0	1.500	5400.0	1.501	0.0

Hydro-Brake® Optimum Outflow Control

Unit Reference	MD-SHE-0384-9760-1500-9760
Design Head (m)	1.500
Design Flow (l/s)	97.6
Flush-Flo™	Calculated
Objective	Minimise upstream storage
Application	Surface
Sump Available	Yes
Diameter (mm)	384
Invert Level (m)	0.500
Minimum Outlet Pipe Diameter (mm)	450
Suggested Manhole Diameter (mm)	Site Specific Design (Contact Hydro International)

Control Points	Head (m)	Flow (l/s)	Control Points	Head (m)	Flow (l/s)
Design Point (Calculated)	1.500	97.6	Kick-Flo®	1.136	85.3
Flush-Flo™	0.606	97.6	Mean Flow over Head Range	-	80.1

Hydro-Brake® Optimum Outflow Control

The hydrological calculations have been based on the Head/Discharge relationship for the Hydro-Brake® Optimum as specified. Should another type of control device other than a Hydro-Brake Optimum® be utilised then these storage routing calculations will be invalidated

Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)
0.100	10.7	0.600	97.6	1.600	100.7	2.600	127.5	5.000	175.5	7.500	214.1
0.200	38.2	0.800	96.1	1.800	106.6	3.000	136.7	5.500	183.9	8.000	220.9
0.300	72.9	1.000	91.8	2.000	112.2	3.500	147.4	6.000	191.9	8.500	227.6
0.400	94.5	1.200	87.6	2.200	117.6	4.000	157.4	6.500	199.6	9.000	234.1
0.500	96.9	1.400	94.4	2.400	122.6	4.500	166.7	7.000	206.9	9.500	240.4