

Holly Street Flood Consequence Assessment

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Revision history

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23 rd January 2019	Updated site layout Section 2.3	Paul Markey
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Contract

This report describes work commissioned by Paul Markey, on behalf of Bluefield Land, by an email dated 2nd October 2018. Amy Evans, Tim Luck and Steffan Howley of JBA Consulting carried out this work.

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Purpose

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1 Introduction

1.1 Terms of reference

JBA Consulting were commissioned by Bluefield Land Ltd. in October 2018 to prepare a Flood Consequence Assessment (FCA) in support of a planning application for a proposed residential development, adjacent to Holly Street and Arthur Terrace in Pontardawe, South Wales.

1.2 FCA requirements

The FCA follows Welsh Government guidance on development and flood risk set out in Technical Advice Note 15: Development and Flood Risk (TAN-15). Where appropriate, the following aspects of flood risk are to be addressed in all planning applications over the development's expected lifetime in flood risk areas:

- The likely mechanisms of flooding
- The likely source of flooding
- The depths of flooding through the site
- The speed of inundation of the site
- The rate of rise of flood water through the site
- Velocities of floodwater across the site
- Overland flow routes
- The effect of access and egress and infrastructure, for example public sewer outfalls, combine sewer outflows, surface water sewers and effluent discharge pipes from waste water treatment works
- The impacts of the development in terms of flood risk on neighbouring properties and elsewhere on the flood plain

2 Site description

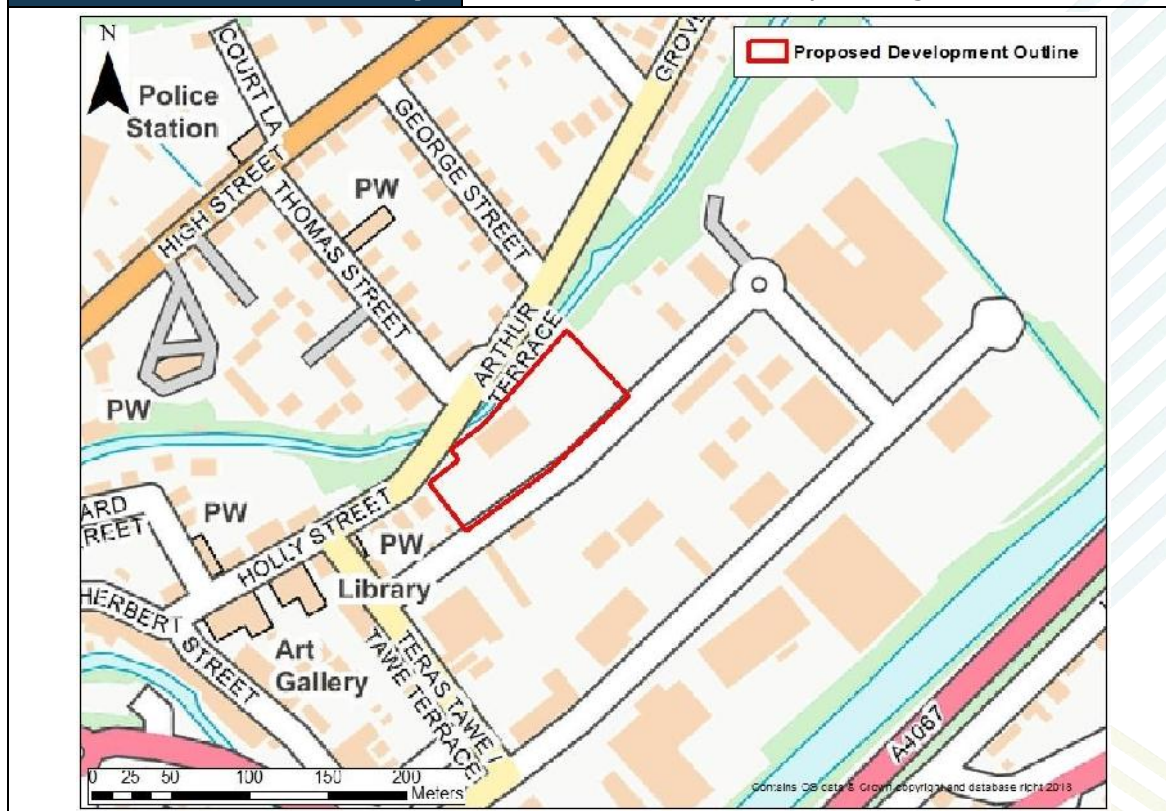
The Holly Street site is 0.7 hectares in area and brownfield in nature. The site is surrounded by residential developments to the north and west and industrial developments to the south and east as shown in Table 2-1.

Swansea canal runs along the site's north-western boundary and the River Tawe is located approximately 240 metres south-east of the site's south-eastern boundary.

Arthur Terrace, a residential road, runs parallel to the site's north-western boundary crossing over the Swansea canal. This road is at a significantly higher elevation than the site. Old Foundry Road runs parallel and immediately adjacent to the site's south-eastern boundary; this road forms the access to the nearby industrial estate.

Table 2-1 Site summary

Site name	Holly Street
Site area	0.7 Hectares
Existing land use	Brownfield site
Purpose of development	Residential
Existing land use	Brownfield ground which has been dormant for 10 years
OS NGR	272495E 204091N
Local Planning Authorities	Neath Port Talbot County Borough Council
Lead Local Flood Authority	Neath Port Talbot County Borough Council



2.1 Existing land use and site topography

The site was previously used for industrial purposes but has been derelict for over 10 years. The previous buildings across the site have been demolished, however the site is still largely impermeable in nature as shown by aerial photography in Figure 2-1.



Figure 2-1: Image of current land use and the proposed site

Ground levels generally rises from the south-east towards the north-western boundary. The elevation of the site ranges from 31.8m AOD in the south-east to 34m AOD in the north-west. There are areas of raised ground in the east and north of the site where buildings previously stood. Ground level in this area are approximately 36.7m AOD. The canal tow path north of the site is at a level of 36.5-37m AOD and the area north of the Swansea Canal is significantly higher at over 40m AOD. The industrial area to the south is at an elevation similar to that of the proposed site.

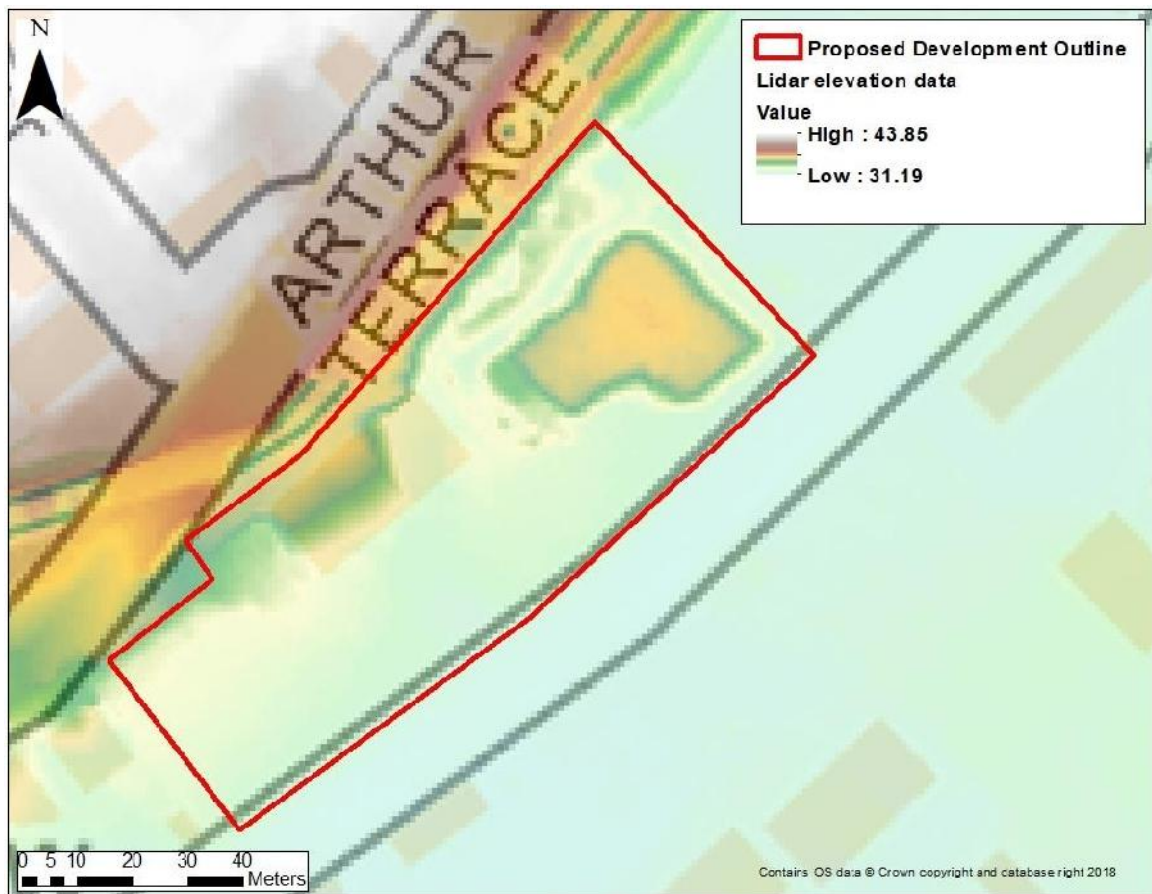


Figure 2-2 LiDAR elevation data

2.2 Soils and geology

The proposed development site is largely 'made ground' as a result of previous development. However, the underlying soils are described as loamy, freely draining and slightly acidic according to the Cranfield University Soilscales tool¹. The geology of the site is sedimentary sandstone from the Rhondda Member formed approximately 308 to 315 million years ago in the Carboniferous Period, with the area previously dominated by rivers. The proposed development should aim to utilise the sites infiltration potential as much as possible to manage surface water flood risk.

2.3 Development proposal

The proposal is for a 36-unit residential development consisting of houses and apartments. The main access is from the Foundry Road to the south, however emergency vehicle access is included in the site layout from Holly Street to the north.

The proposed site layout is shown in Figure 2-3. A number of different site layout and level variations have been considered and assessed with regards to their impact on flood risk.

¹ Cranfield University Soilscape viewer <http://www.landis.org.uk/soilscales/>



Figure 2-3: Development proposal for Holly Street (Spring Design)

2.4 Review of existing flood risk data

The latest available information of flood risk at the site, published by Natural Resources Wales (NRW) is summarised in Table 2-2.

Table 2-2: Summary of flood risk

Source of Flooding	Onsite Presence	Description
Fluvial	✓ (section 2.5)	The south-western half of the site, and a few other isolated areas near the site's boundary are located in Flood Zone 3, while much of the remainder is located in Flood Zone 2. A small area of raised ground in the north-east of the site is located within Flood Zone 1.
Tidal	✗	The site is not at risk of tidal flooding
Surface Water	✓ (section 2.6)	A small area in the north of the site is at a high risk of surface water flooding. The remainder of the site is considered to be at a very low risk of flooding from surface water.
Reservoirs	✗	The site is not at risk of flooding as a result of reservoir failure
Groundwater	✗	The site is not considered to be at risk from groundwater flooding.
Sewers	✗	There is no evidence to suggest that the site is at risk of flooding from sewers

2.5 Existing flood zone mapping (fluvial risk)

The NRW Flood Zone mapping shown in Figure 2-4 shows that the majority of the site is located within either Flood Zones 2 or 3. Flood Zone 3 describes areas at risk of flooding from events more frequent than the 1% AEP (1 in 100 year) fluvial flood event. Flood Zone 2 describes areas at risk of flooding in events more frequent than 0.1% AEP (1 in 1000 year) and less frequent than 1% AEP event (1 in 100 year). The area of raised ground in the north-east is located within Flood Zone 1, which describes areas not at risk of flooding in the 0.1% AEP design event.

It should be noted that the Flood Zone mapping does not consider the impact of flood defences, including the defences along the River Tawe to the south, as shown within Figure 2-4.

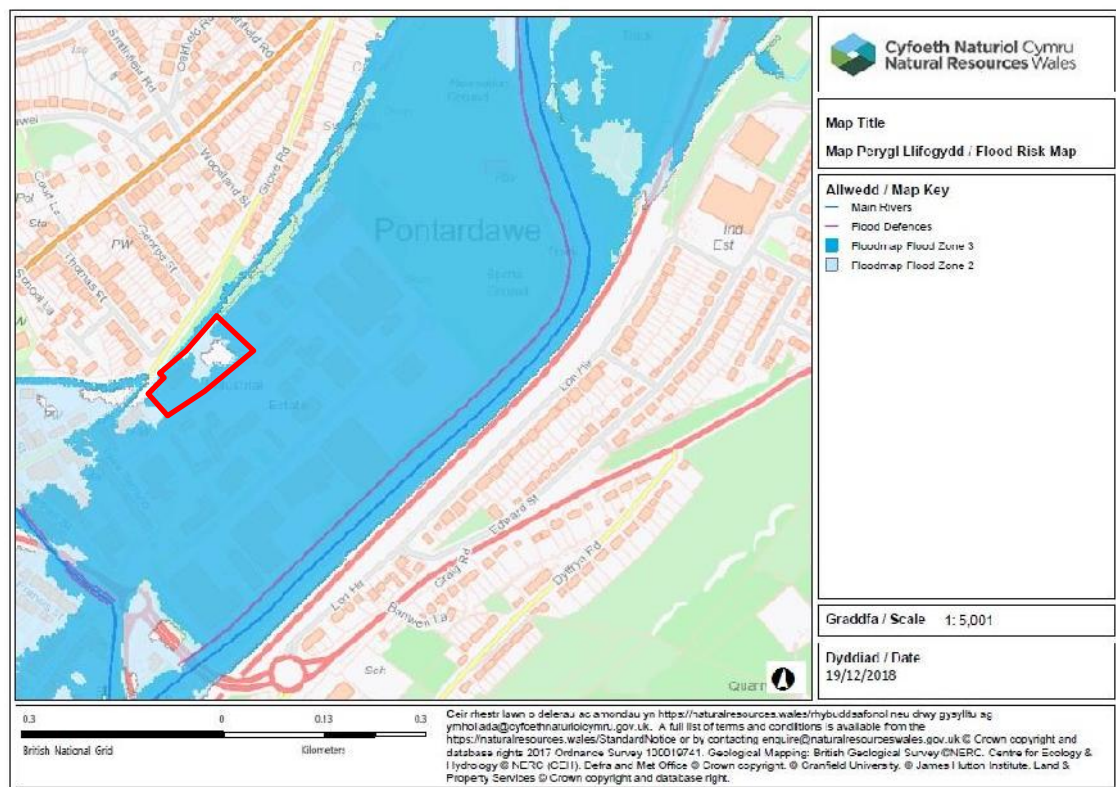
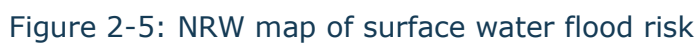


Figure 2-4: NRW's Flood Zone mapping

2.6 Surface water flood risk

The NRW Surface Water Flood Risk Map (Figure 2-6) shows that the site is largely free of surface water flood risk. What limited surface water flood risk that is predicted by NRW's national scale mapping originates from the canal and can be attributed to simplifications in the modelling of this feature.

The site is largely impermeable; thus, the proposed drainage strategy should be designed to reduce surface runoff from the site using a variety of sustainable drainage systems (SuDS).



3 Planning Policy and flood risk

3.1 Planning context

TAN-15 was introduced in 2004 by the Welsh Assembly Government. It is technical guidance related to development planning and flood risk using a sequential characterisation of risk based on the Welsh Government's Development and Flood Risk Advice Map (DAM). Its initial requirement is to identify the flood zones and vulnerability classification relevant to the proposed development, based on an assessment of current and future conditions.

TAN-15 assigns one of three flood risk vulnerability classifications to a development as shown in Table 3-1. The proposed development at Holly Street consists entirely of residential buildings. Consequently, the development is classified as highly vulnerable development as shown in Table 3-1.

Table 3-1 Development categories defined by TAN-15

Development category	Types
Emergency services	Hospitals, ambulance stations, fire stations, police stations, coastguard stations, command centres, emergency depots and buildings used to provide emergency shelter in time of flood.
Highly vulnerable development	All residential premises (including hotels and caravan parks), public buildings, (e.g. schools, libraries, leisure centres), especially vulnerable industrial development (e.g. power stations, chemical plants, incinerators), and waste disposal sites.
Less vulnerable development	General industrial, employment, commercial and retail development, transport and utilities infrastructure, car parks, mineral extraction sites and associated processing facilities, excluding waste disposal sites.

3.2 DAM zoning and vulnerability classification

Figure 3-1 shows that the proposed development site falls into Zone C1 of the DAM mapping. Zone C1 is described as areas of the floodplain which are developed and served by significant infrastructure, including flood defences. *Highly vulnerable development* within Zone C1 can take place subject to the application of justification test, including acceptability of consequences.

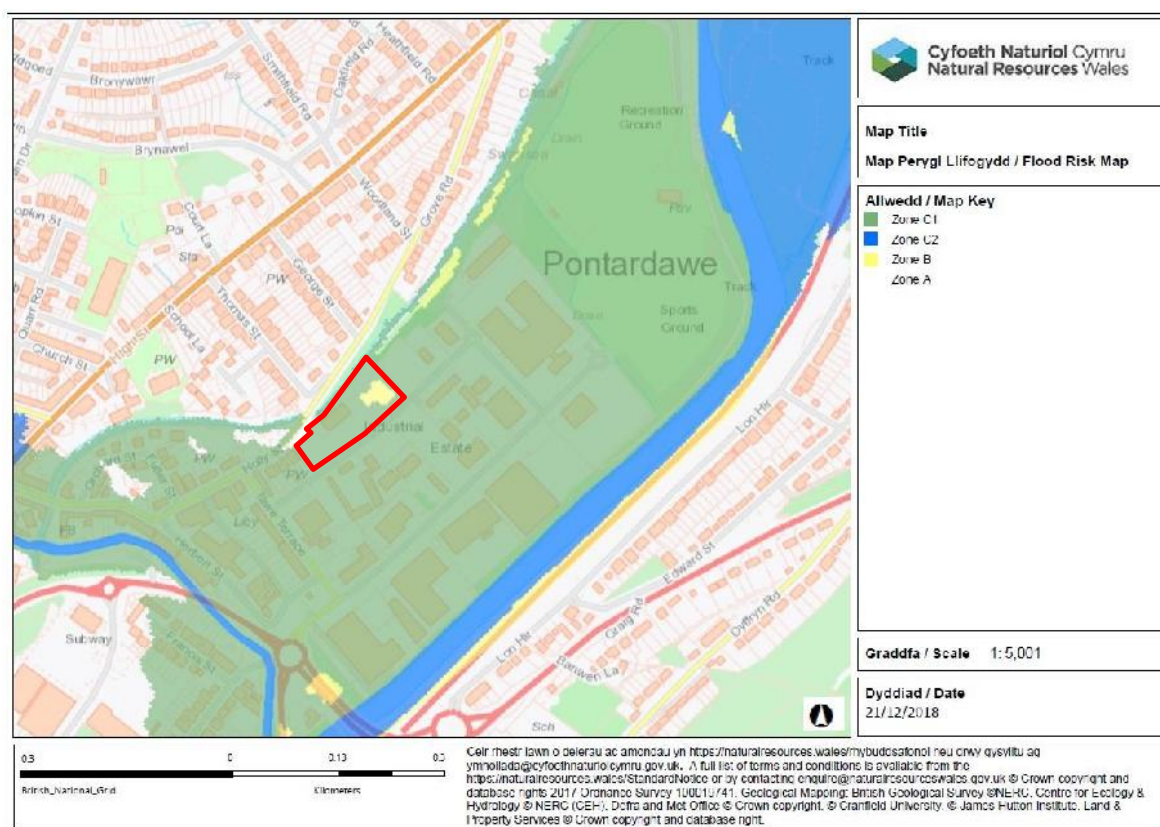


Figure 3-1: NRW's Development Advice Map

3.3 Neath Port Talbot County Borough Council's flood risk and development position

The Local Development Plan (LDP) is a land use document in which the County Borough sets out its land use development over a 15-year period. The current LDP, entitled 'Neath Port Talbot County Borough Council Local Development Plan (2011-2026)'² was adopted by Neath Port Talbot County Borough Council in January 2016.

Within the LDP, Pontardawe is identified as a key primary settlement and Strategic Growth Area, playing a critical role in the county. The Pontardawe area is identified to have the ability to accommodate, and has an evident demand for, an additional amount of new housing development. This growth in the Pontardawe area will help to support and enhance the town of Pontardawe, its retail and cultural amenities and will support and encourage economic development across the Swansea and Amman Valleys.

3.4 Justification test

TAN-15 states that development will be justified if it can be demonstrated that:

² 'Neath Port Talbot County Borough Council Local Development Plan (2011-2026)' https://www.npt.gov.uk/PDF/Ldp_written_statement_jan16.pdf Accessed: 20/09/2016

1. *Its location in zone C is necessary to assist, or be part of, a local authority regeneration initiative or a local authority strategy required to sustain an existing settlement;*

or

2. *Its location in zone C is necessary to contribute to key employment objectives supported by the local authority, and other key partners, to sustain an existing settlement or region;*

and

3. *It concurs with the aims of Planning Policy Wales and meets the definition of previously developed land;*

and,

4. *The potential consequences of a flooding event for the particular type of development have been considered, and found to be acceptable.*

The proposed development at Holly Street has been assessed against the requirements of the Justification Test with the results summarised in Table 3-2. All the criteria have been satisfied with regards to the proposed wellness development.

Table 3-2 Justification Test applied to the proposed development

TAN 15 Justification Criteria	Comments	Achieved
<i>Its location is necessary to assist a local authority regeneration initiative or strategy, or contribute to key employment objectives, necessary to sustain an existing settlement or region</i>	The Neath Port Talbot County Borough Council (NPTCBC) Local Development Plan (LDP) 2011 – 2026 was adopted in January 2016 and Pontardawe is identified as a key primary settlement and Strategic Growth Area. The impact of growth in Pontardawe will act as a catalyst to ensure the benefits of growth and regeneration are shared more widely throughout the valley communities.	✓
<i>The site meets the definition of previously developed land (i.e. it is not a Greenfield site) and concurs with the aims of Planning Policy Wales (i.e. the presumption in favour of sustainable development)</i>	This site is brownfield and was previously occupied by industrial buildings prior to being left dormant over 10 years ago.	✓
<i>A Flood Consequence Assessment has been produced to demonstrate that the potential consequences of a flood event up to the extreme flood event (1 in 1000 chance of occurring in any year) have been considered and meet the [Acceptability Criteria] ... in order to be considered acceptable</i>	The flood risk to the site has been explored in detail. The site layout has been strategically planned to ensure flood risk to the site's residents and users are managed together with the flood risk of neighbouring land. The flood risk assessment of the site is discussed in more detail in Sections 2 and 4.	✓

4 Flood risk assessment

4.1 Flood modelling

The current NRW Flood Map for the area is based on modelling undertaken by JBA on behalf of NRW in 2015. The model is a detailed 1D-2D ESTRY-TUFLOW model that is generally appropriate for detailed site assessment. This model has been licensed from NRW to inform this study.

Although the 2015 NRW model is relatively recent, it has been necessary to update the flood flow estimates to follow current Flood Estimation Handbook (FEH) methods and apply current Welsh Government climate change guidelines. The model has also been updated to run on the latest version of TUFLOW software (2018-03-AE). Appendix C contains the FEH calculation record for the updated hydrology and climate change has been applied as 30% for the 1% AEP flows in line with the latest Welsh Government guidance³.

The updated model hydrology is significantly reduced when compared to the previous model hydrology. This is because the NRW 2014 hydrology did not apply the distance factor to the QMED adjustment for the River Tawe estimation points, whereas this was applied for the current assessment. The FEH Statistical method was considered to be most appropriate for determining flow frequency at the flow estimation points. Although there are significant uncertainties associated with applying it to events beyond the 0.5% AEP event, due to the typically short length of river gauge records. To reduce these uncertainties, a hybrid approach has been taken to derive the 0.1% AEP event flow, as recommended in NRW's (2017) latest guidance on flood estimation. The 1% AEP event peak flows from the Statistical method have been adjusted using the ratio of the 0.1% and 1% AEP event flows from the ReFH2 model.

4.2 Pre-development fluvial flood risk

4.2.1 Pre-development (baseline) scenario

A pre-developed (baseline) model scenario was simulated for the 1% AEP plus climate change and the 0.1% AEP design events. The pre-development Holly Street scenario represents the current ground levels as taken from LiDAR.

4.2.2 Pre-developed results

The pre-development modelling results show that during the 1% AEP plus climate change event, flooding is mainly concentrated in the western half of the site and originates from overtopping of the canal. (**Figure 4-1**). Flood depths across the site are typically less than 100mm. Large scale maps of the model results are supplied in Appendix D.

³ CL-03-16 - Climate change allowances for Planning purposes. 2016.
<https://gov.wales/topics/planning/policy/policyclarificationletters/2016/cl-03-16-climate-change-allowances-for-planning-purposes/?lang=en>

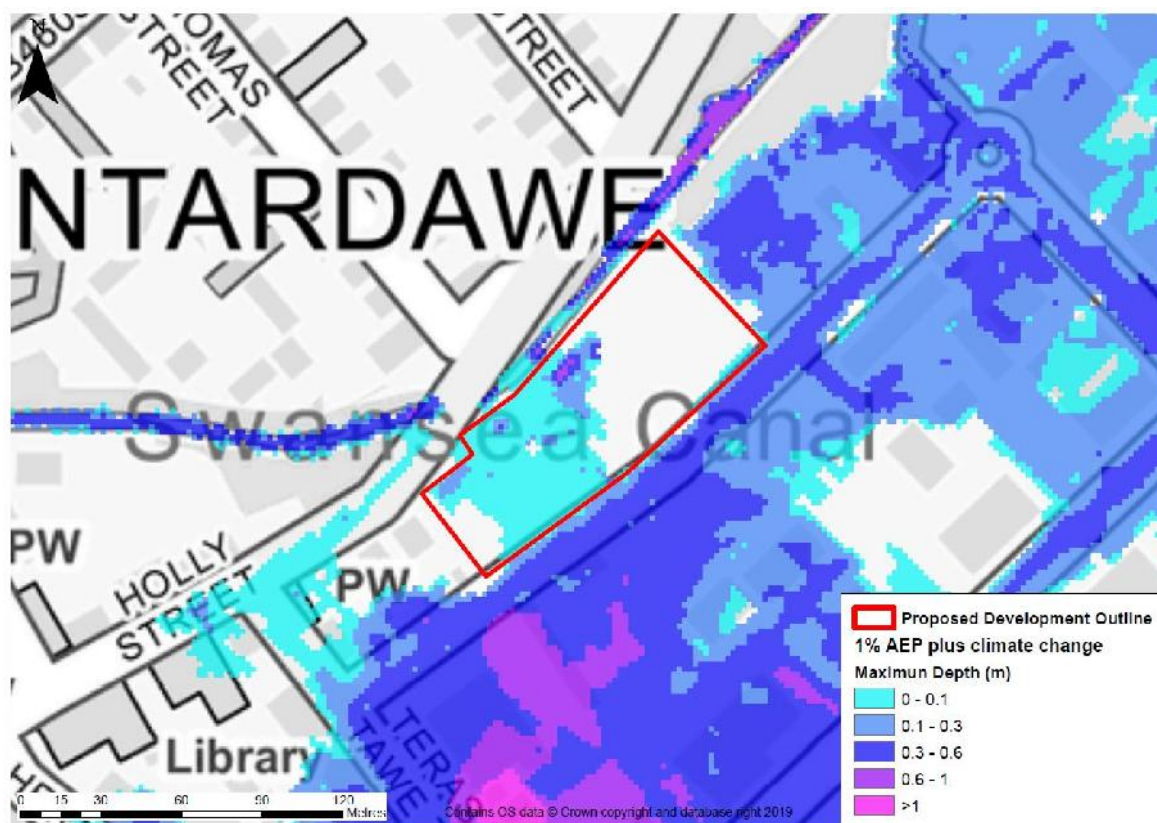


Figure 4-1 Pre-developed 1% AEP plus climate change maximum flood depths

The results for the 0.1% AEP pre-developed model simulation show that flooding occurs across the majority of the site as shown in Figure 4-2. Flooding in the south of the site reaches a maximum depth of 1.68m. Modelled flood depths are significantly lower towards the site's northern boundary where elevations are greater. The vast majority of the flood water originates from the River Tawe, where the flood defences have been overwhelmed. Some areas of shallow flooding originate from the canal.

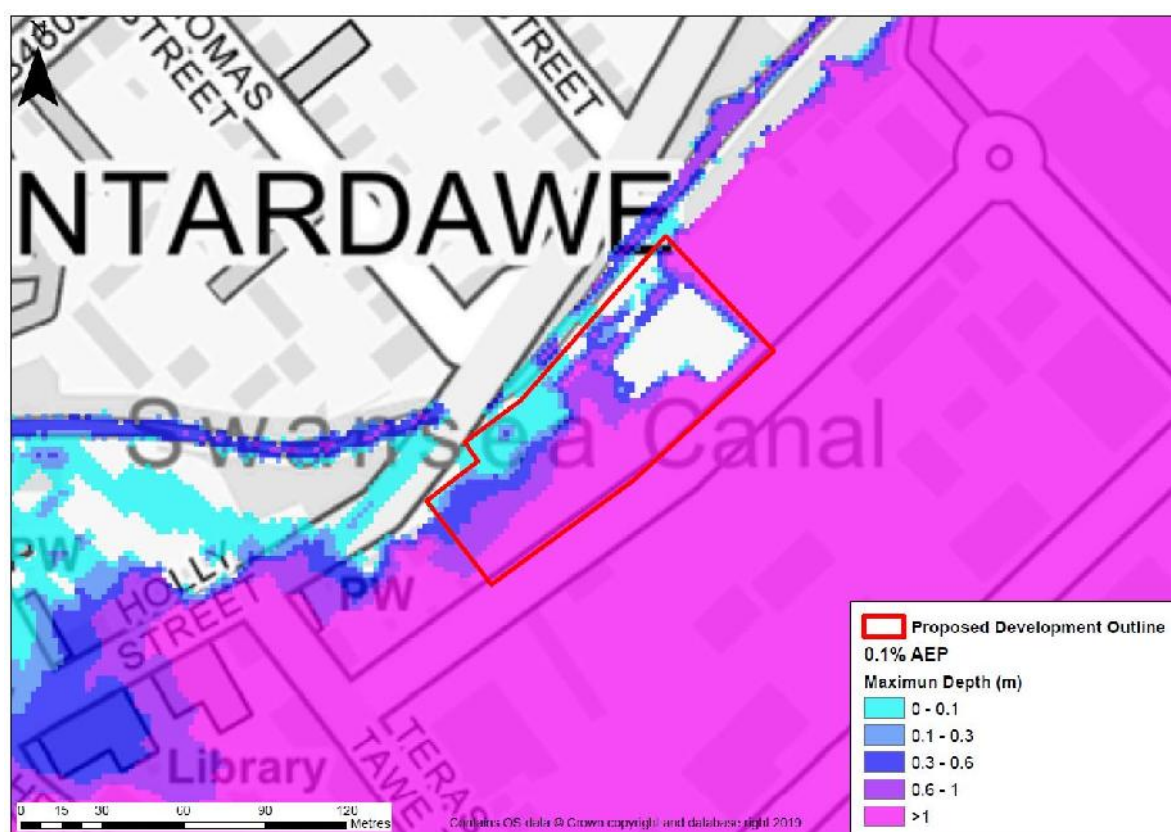


Figure 4-2 Post-developed 0.1% AEP maximum flood depths

4.3 Post-development fluvial flood risk

4.3.1 Post-development scenario

The post-development site layout has been carefully developed with a number of development constraints in mind, including flood risk.

TAN-15 states that highly vulnerable development should be demonstrated to be flood-free during the 1% AEP plus climate change event (TAN-15 Section A1.14) with flooding of less than 600mm during the 0.1% AEP event (TAN-15 Section A1.15).

By raising and levelling ground levels to remove the proposed development from the 1% AEP plus climate change flood extent, the proposed development has the potential to impact the maximum water levels of third parties by both displacing floodplain volume and affecting floodplain conveyance. Several proposed site elevations have been tested using the hydraulic model to minimise the impact on third-party flood risk.

Figure 4-3 shows the devised site layout and finished floor levels of the proposed development. The proposed levels include raising the tow path between the Swansea Canal and the site to 37m AOD (an increase of <500mm) to prevent canal overtopping affecting the site. The finished site level is to be raised to 32.9m AOD to the west raising slightly to 32.92m AOD to the east with the proposed buildings raised ~300mm above this level to 33.2m AOD. On this basis, the post -developed model scenario was simulated for the 1% AEP plus climate change and 0.1% AEP events.



Figure 4-3: Post-development site layout and levels

4.3.2 Post-development results

The maximum flood depths for a 1% AEP plus climate change event in the post-developed scenario are shown in Figure 4-4. The proposed ground raising successfully eliminates the risk of flooding on the site during this event. Access to the site from Holly Street remains operational and flood-free during this event.

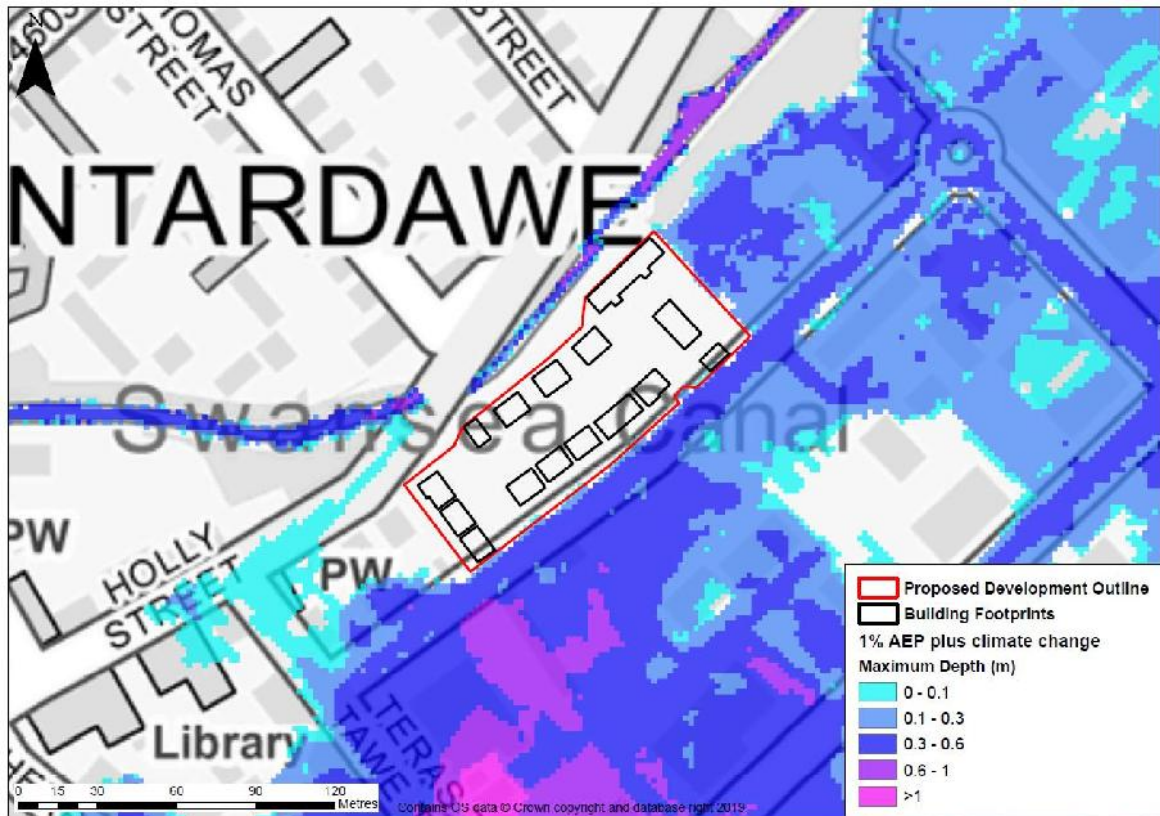


Figure 4-4 Post-developed 1% AEP plus climate change maximum flood depths

The maximum depths during the 0.1% AEP event for the post-developed scenario are shown in Figure 4-5. All flooding originates directly from the River Tawe, with no flooding from the canal overtopping.

TAN-15 states that depths of up to 600mm during the 0.1% AEP event are acceptable. The site-wide ground-raising proposed is such that depths reach a maximum of 600mm during this event. Maximum depths within the proposed properties are approximately 300mm less than this as a result of the raised finished floor levels.

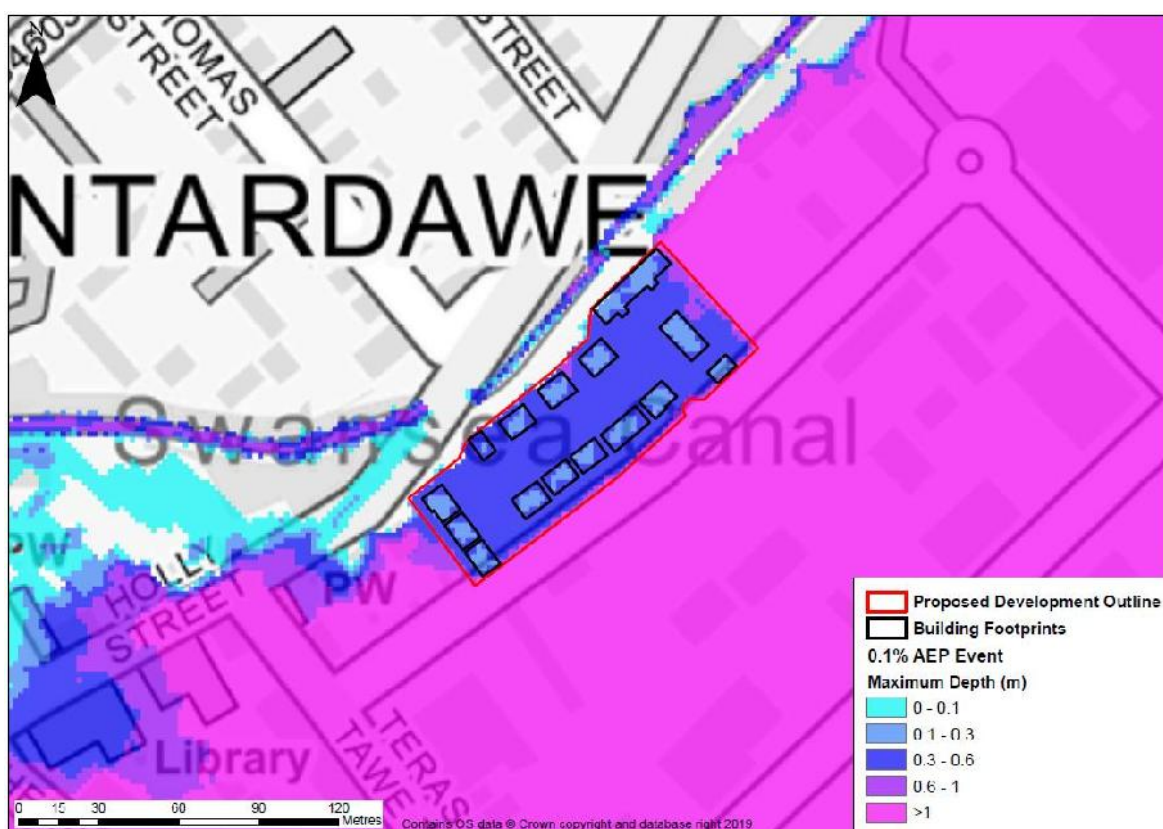


Figure 4-5 Post-developed 0.1% AEP maximum flood depths

4.3.3 Third party impacts

TAN-15 states that any proposed development should not adversely impact third party flood risk (Section 7.2). Further guidance on this aspect is provided in Appendix 1 of TAN-15 and NRW's 'Guidance Note: Modelling for Flood Consequence Assessments'⁴. A reportable increase in flood risk is assumed to be any increase over 5mm as modelled for the 1% AEP plus climate change and 0.1% AEP events. Whilst any development requiring changes in levels within a built-up area will in some way alter flood flows and levels, both positively and negatively, every effort has been made to minimise the effects in the design of the proposed development.

The maximum flood depths during the post-developed scenario were compared against the pre-developed results to understand any change in flood depths as a result of the development. Figure 4-6 shows that during the 1% AEP plus climate change event an increase in maximum water level is largely limited to within the Swansea Canal for a limited stretch. There is no change in the extent or frequency of flooding.

⁴ Guidance Note: Modelling for Flood Consequence Assessments, v4.0 July 2018. Natural Resources Wales. <https://cdn.naturalresources.wales/media/686496/gn-028-modeling-for-flood-consequence-assessments.pdf>

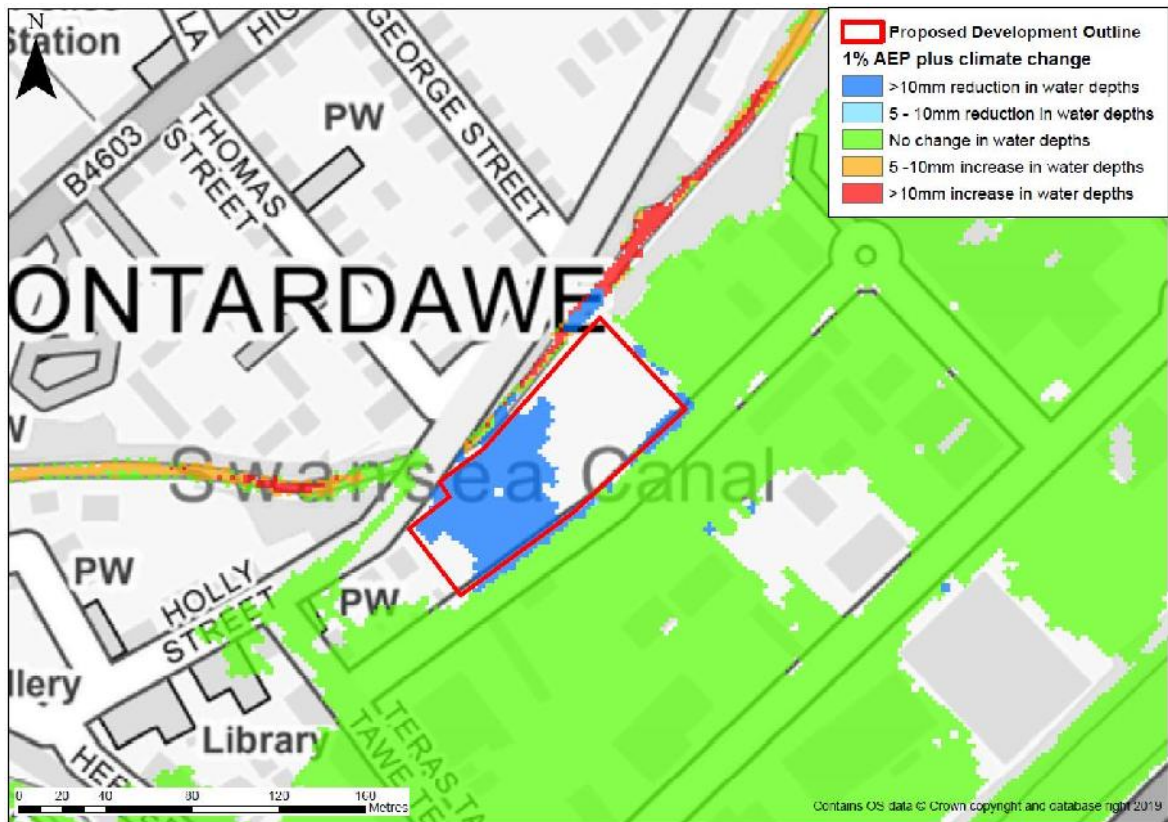


Figure 4-6 Pre-developed v post-developed 1% AEP plus climate change

Figure 4-7 shows the impacts of the proposed development on maximum depths during the 0.1% AEP event. The impacts during this extreme event are greater. The extent of the flood outline slightly increases in localised spots as shown in Figure 4-8. However, the area affected only experiences a maximum flood depth of 16mm when most flooded areas in Pontardawe are predicted to experience flood depths of >1m. Maximum flood depths to the east of the site on Old Foundry Road area increase by 7mm where depths already exceed 1m. The likelihood of a 0.1% AEP event is, by definition, extremely low and the changes in flood depths will have negligible effect on the overall flood risk in the area. Consequently, we conclude that there is no meaningful change in flood risk.

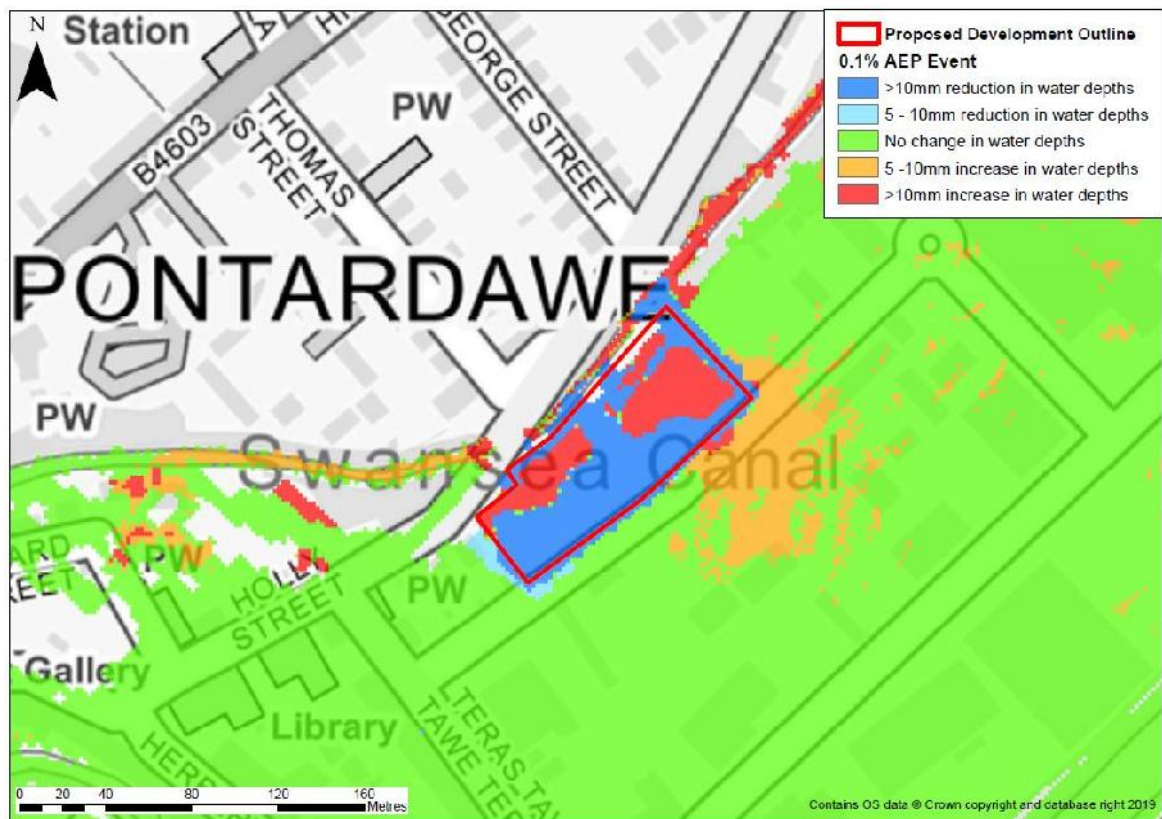


Figure 4-7 Pre-developed v post-developed 0.1% AEP

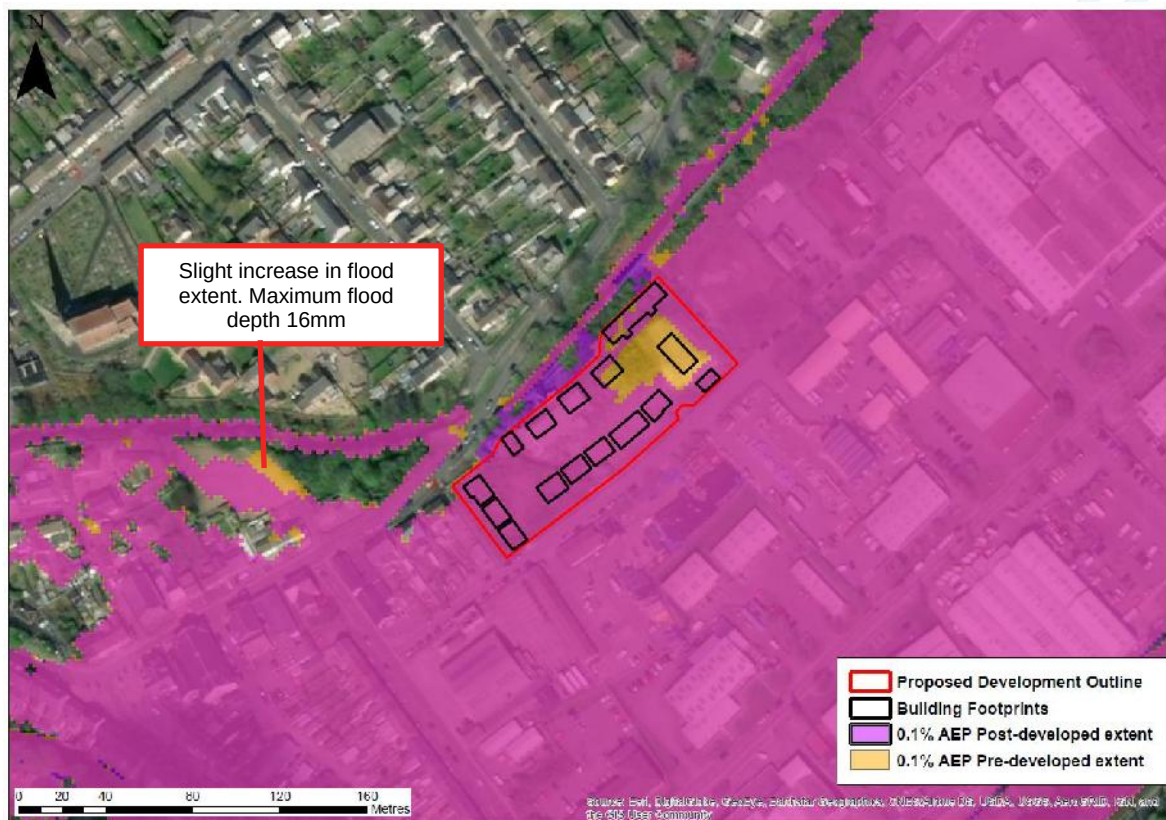


Figure 4-8 0.1% AEP pre-developed and post-developed flood extent

4.4 Canal breach assessment

Following discussions with Richard Dun at the Canal and Rivers Trust, a methodology to assess the flood risk in the event of a canal breach was agreed. The canal breach hydrograph shown in Table 4-1 was provided by the Canal and River Trust and JBA Consulting were asked to simulate this breach through the hydraulic modelling during a 'blue sky' event where the fluvial flows were at baseflow level. Three breach locations along the northern boundary of the site were analysed.

Table 4-1: Canal breach hydrograph provided by the Canal and River Trust

Time (hours)	Flow (cumecs)
0	0
0.4	3.6
0.9	1.8
2.3	0.9
3.8	0.45

Figure 4-9 to Figure 4-11 demonstrate the maximum depth as a result of the three modelled canal breaches. Maximum depths onsite are generally less than 200mm.

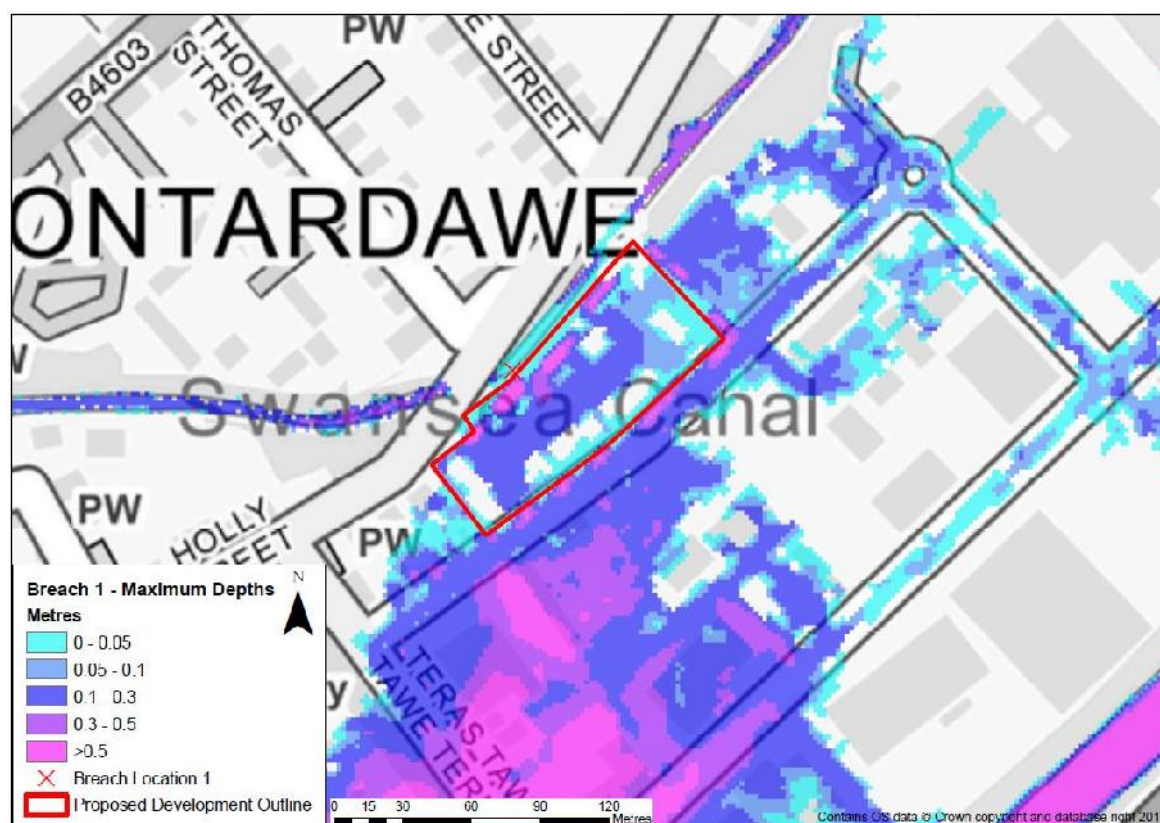


Figure 4-9: Breach 1: Maximum depth

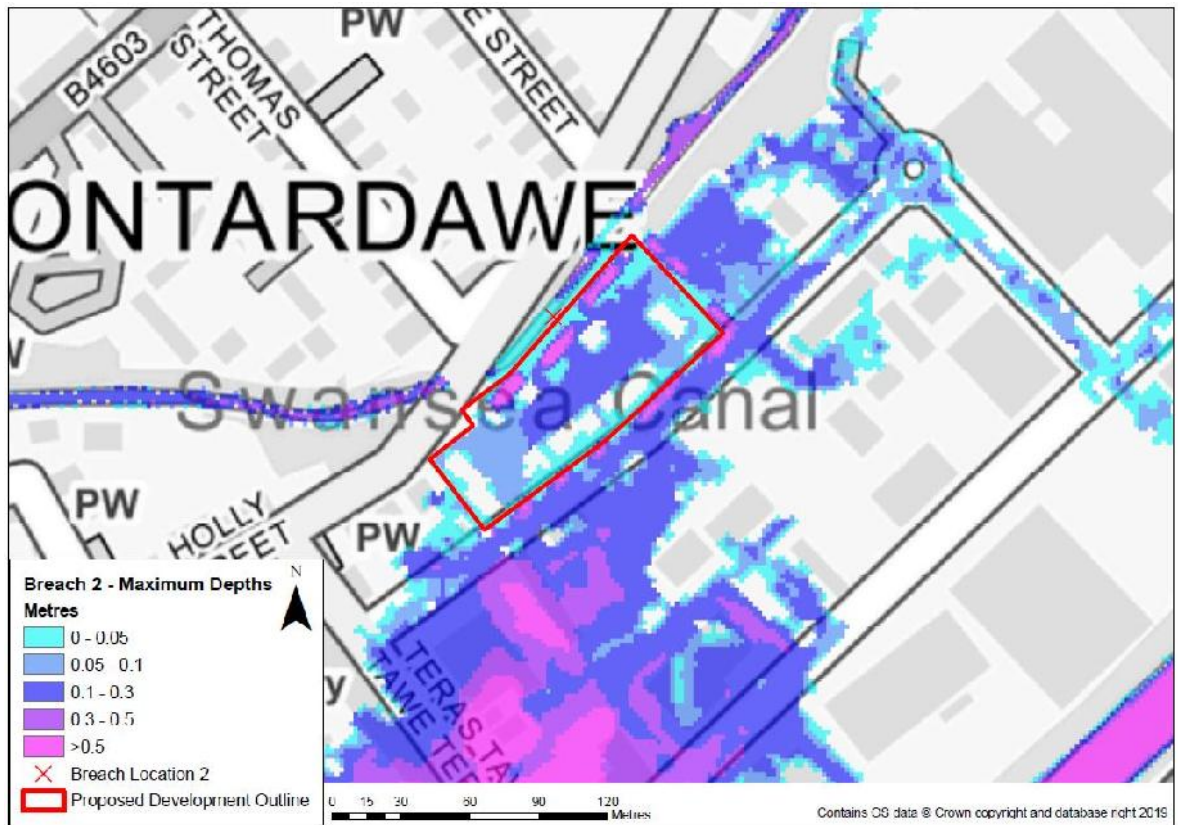


Figure 4-10: Breach 2: Maximum depth

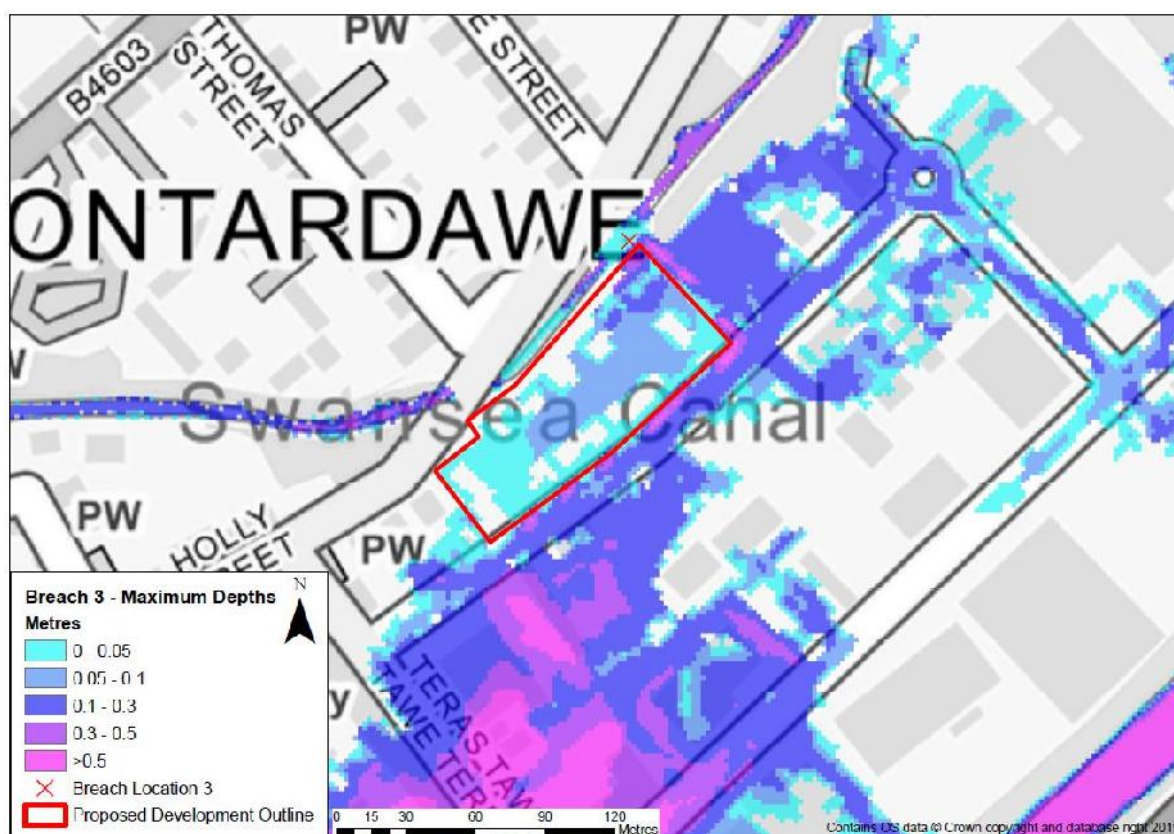


Figure 4-11: Breach 3: Maximum depth

The approximate maximum water level onsite during these events are 33.1m AOD. Figure 4-12 provides a mapped summary of maximum water levels for the breach scenario with the greatest depths. Based on this, it is recommended that plots 18-32 of the proposed development (those closest to the canal embankment) have a finished floor level of 33.4m AOD. The remaining plots can be at a level of 33.2m AOD as previously specified for the fluvial flood risk mitigation.

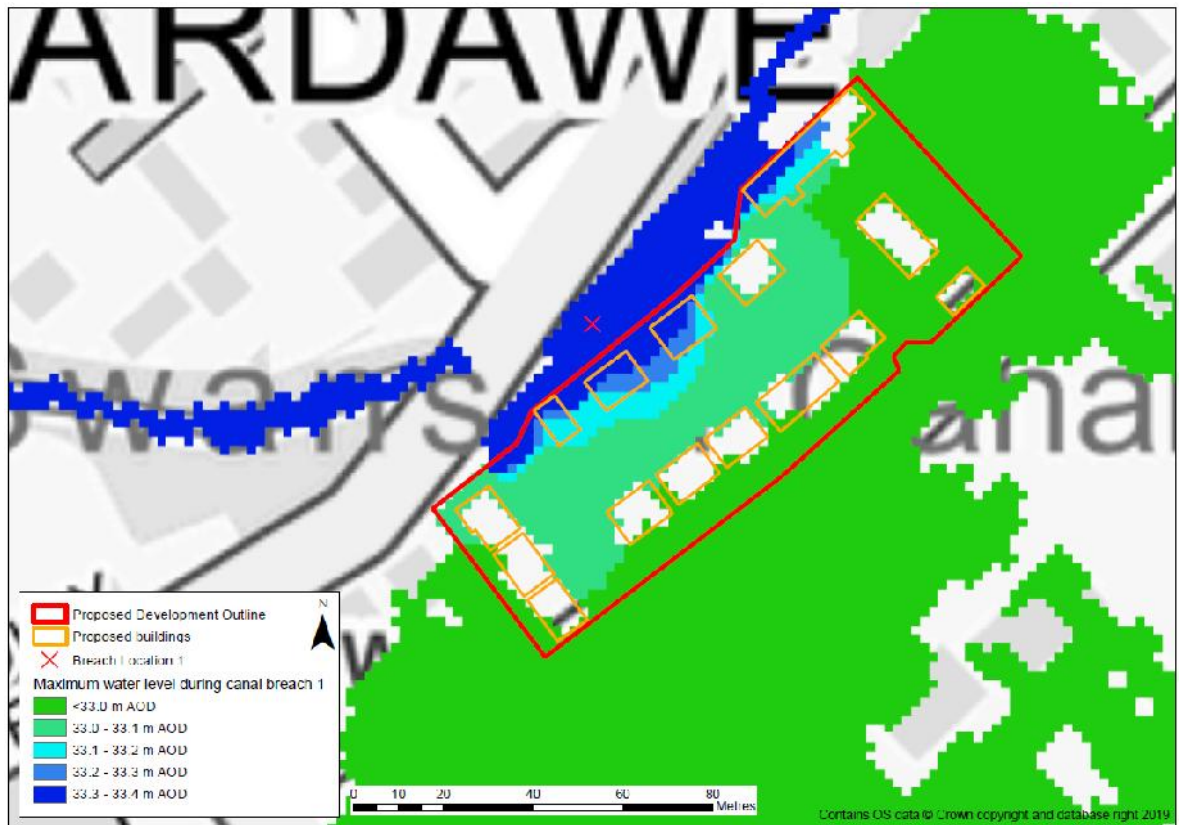


Figure 4-12: Breach 1: maximum water levels

5 Assessment of Acceptability Criteria

Section 3.4 describes the application of the Justification Test within TAN-15 and concludes that the proposed development meets the test's requirements. Table 5-1 assesses the proposed development against the acceptability requirements which forms the final element of the Justification Test.

Table 5-1 Acceptability Criteria assessment applied to the proposed development

TAN-15 Acceptability Criteria	Comments	Achievable?
<i>Developer is required to demonstrate that the site is designed to be flood free for the lifetime [Ref: TAN-15 A1.5] of development for a 1 in 100 (1%) chance (fluvial) flood event including an allowance for climate change in accordance with Tan-15 table A1.14.</i>	The proposed development is flood free during the fluvial 1% AEP plus climate change event.	✓
<i>In respect of the residual risk to the development it should be designed so that in an extreme (1 in 1000 chance) event there would be less than 600mm of water on access roads and within property, the velocity of any water flowing across the development would be less than 0.4m/seconds.</i>	Maximum depths on the site and access from Holly Street are less than 600mm during the 0.1% AEP event. Velocities across the majority of the site are less than 0.4m/s in the 0.1% AEP event including the access from Holly Street. The maximum velocity maps for the proposed scenario are included in Appendix D.	✓
<i>No flooding elsewhere</i>	The proposed development has been designed to minimise any adverse impacts on third-party flood risk as far as practical. Any development within a built-up area (e.g. garages, walls, fences, and extensions) and will in some way alter flood flows and levels. The proposed development has no adverse impacts on third-party depths during the 1% AEP plus climate change event and there are only localised impacts during the 0.1% AEP events where maximum depths already exceed 1m. There is a slight increase in flood extent during the 0.1% AEP event, however, the shallow depths (16mm) here are unlikely to enter property. The impact on actual flood risk is therefore considered to be negligible.	✓
<i>Flood defences must be shown by the developer to</i>	The existing flood defences protect the town to a 1% AEP standard and	N/A

TAN-15 Acceptability Criteria	Comments	Achievable?
<i>be structurally adequate particularly under extreme overtopping conditions (i.e. that flood with a 1 in 1000 chance of occurring in any given year).</i>	are maintained by NRW to be structurally adequate. The proposed development will not impact the formal flood defences	
<i>The developer must ensure that future occupiers of the development are aware of the flooding risks and consequences.</i>	The occupants and users should sign up to the NRW Flood warning service to provide warning in the event of an extreme flood event. A Flood Action Plan should be developed and adopted to ensure the correct action is taken in the event of a flood alert being issued.	✓
<i>Effective flood warnings are provided at the site.</i>	The site is covered by the Upper Tawe NRW Flood Alert Area and the River Tawe at Industrial Estate and Upper Clydach, Pontardawe NRW Flood Warning Area.	✓
<i>Escape/evacuation routes are shown by the developer to be operational under all conditions.</i>	The access routes along Holly Street to the north of the development remain operational during all conditions. A Flood Action plan should be developed and adopted to ensure appropriate action is taken in the event of a flood warning being issued.	✓
<i>The development is designed by the developer to allow the occupier of the facility for rapid movement of goods/possessions to areas away from flood waters.</i>	The proposed dwellings will be two storeys in design and are located on raised ground at a low risk from fluvial flooding. Appropriate actions in the event of a flood warning should be documented within an adopted Flood Action Plan.	✓
<i>Development is designed to minimise structural damage during a flooding event and is flood proofed to enable it to be returned to its prime use quickly in the aftermath of the flood.</i>	The proposed built development is not at risk of flooding during events more frequent than the 1% AEP plus climate change. Resilience methods could be using in the design of the homes, but the flood risk is such that internal flooding is highly unlikely.	✓

6 Mitigation measures

Based on detailed hydraulic modelling, the following measures are recommended to ensure that the proposed development is safe and acceptable in respect to flooding:

- 1 The ground levels within the proposed development should set to 32.9m AOD to the west raising slightly to 32.92m AOD to the east to ensure the site is flood free during the 1% AEP plus climate change event but that adverse third-party flood risk impacts are limited.
- 2 Proposed building finished floor levels should be raised 300mm above surrounding ground levels to discourage internal flooding. Plots 18-32 (those closest to the canal embankment) should have a finished floor level of 33.4m AOD. The remaining plots can be at a level of 33.2m AOD.
- 3 The canal tow path should be raised adjacent to the proposed development to prevent the site flooding via canal overtopping. The tow path should be raised by <500mm to 37m AOD for approximately 30m. If this is not possible a low boundary wall could be constructed to provide the same function.
- 4 The occupants and managers of the proposed site should sign up to the NRW Flood warning service to provide warning in the event of an extreme flood event.
- 5 A Flood Action Plan should be developed and adopted to ensure the correct action is taken in the event of a flood alert being issued.

7 Conclusions and recommendations

- JBA Consulting was commissioned by Bluefield Land Ltd. to produce a Flood Consequence Assessment (FCA) for a proposed residential development at a site off Holly Street in Pontardawe. This FCA follows Welsh Government guidance on development and flood risk as set out in the TAN-15.
- The 0.7ha site is brownfield in nature and has been left dormant after industrial operation at the site ceased over ten years ago. The previous buildings which were present have been demolished but the site remains largely impermeably surfaced.
- The site has elevations of 31.8m AOD to the south to 34m AOD to the north, with slightly higher elevations where previous buildings have been demolished. The Swansea Canal flows along the site's north-western boundary and the River Tawe is located approximately 240 metres south-east of the site's south-eastern boundary.
- The proposal is for ~36 residential units including houses and apartments. Emergency access via Holly Street is proposed.
- The site falls within Zone C1 of NRW's DAM. Zone C1 describes areas of the floodplain 'served by significant flood defence infrastructure'. The proposed development is residential in nature and is therefore classified as 'highly vulnerable development' as defined in TAN-15.
- TAN-15 states that highly vulnerable development, such as that proposed, is appropriate in Zone C1 subject to it satisfying the requirements of the Justification Test including the acceptability of consequences. The site is brownfield in nature, within the settlement boundary of Pontardawe- a key primary settlement and Strategic Growth Area according to the LDP- and will contribute to housing demand and regeneration within the town. Therefore, it is concluded that the site complies with the Justification Test criteria.
- The site is considered to be a no or low risk of flooding from tidal, reservoir, groundwater or surface water sources. However, the site is partially located within Flood Zone 2 and 3 of NRW's fluvial Flood Risk Mapping, which predicts the risk of flooding assuming the presence of no flood defences.
- NRW's 2015 ESTRY-TUFLOW 1D-2D model of the River Tawe through Pontardawe was updated to the latest version of TUFLOW and with updated with new hydrology. The updated hydrological estimation showed a decrease in flows compared to the previous hydrology calculated in 2014.
- The proposed site is protected by the River Tawe flood defences during the 1% AEP modelled event, also shallow flooding of the site is predicted from the Swansea Canal with the application of climate change. Consequently, the development (post-developed scenario) requires ground level changes to ensure that the site does not flood during the 1% AEP plus climate change event.
- The proposed levels include raising the canal tow path between the Swansea Canal and the site to 37.0m AOD to prevent canal overtopping affecting the site. The finished site level should be set to 32.9m AOD to the west raising slightly to 32.92m AOD to the east to ensure the site is flood free during the 1% AEP plus climate change event.
- The proposed buildings will be raised 300mm above the surrounding ground level to ~33.2m AOD. Plots 18-32 of the proposed development (those closest to the canal embankment) will have a finished floor level of 33.4m AOD to mitigate

against the canal breach risk. There are no adverse impacts to the flood risk of third-parties during the 1% AEP plus climate change event.

- Ground raising and levelling to 32.9-32.92m AOD is required to ensure maximum depths within the 0.1% AEP event are within the TAN-15 tolerances. Flood depths during the 0.1% AEP post-developed scenario do not exceed 600mm within the proposed development site. There is a localised increase in flood extent as a result of the proposed development, but the shallow depths produced are unlikely to result in internal flooding at third-party properties. There is also an increase in maximum depths to the east of the development site within the industrial estate. However, this increase is 7mm where maximum depths already exceed 1m, therefore, the impact is not considered to result in a meaningful increase in flood risk.
- A flood warning service is provided by NRW in the area. Access and egress to the site remains operational during all events. It is recommended that a Flood Action Plan be developed and adopted to ensure that correct action is taken in the event of a flood alert being issued.
- We conclude that on the grounds of flood risk, the Holly Street development proposal is compliant with Planning Policy Wales and the requirements set out in TAN-15.

Appendix A: Topographic survey

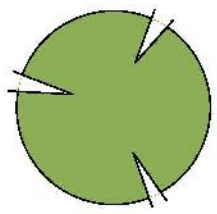
Appendix B: Proposed development layout



SITE KEY



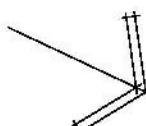
Site Boundary



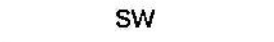
Indicates potential locations for mature tree planting



Indicates opportunities for soft landscaping



Dual aspect buildings



1.8m High brick screen wall with brick piers



1.8m High timber hit & miss fence



Trees to be removed



Root protection area

Accommodation Schedule

Ref	Description	sq/ft	No.
211	1 bedroom Apartment	548	6
321	2 bedroom Apartment	895	2
421	2 bedroom Semi/Link	895	15
531	3 bedroom Semi/Link	1011	11
532	3 bedroom detached	1011	2
Total			36

Status:PLANNING

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rev	date	description	by
A	11.06.19	Apartments amended	AH
B	24.06.19	Plots - 1 - 24 7 & 37 - 40 parking amended plots 2 & 17 substituted to 5.3.1 house types	CC
C	22.07.19	Trees constraints added to layout	CC

Drawn:	CC
Checked:	BJ
Date:	May 2019
Scale:	1:500 @ A1 & 1:1000 @ A3

Client:	Coastal Housing Group
Project:	Holly Street, Pontardawe
Title:	Site Layout
Ref:	2334 - 200

Rev: B



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Appendix C: Updated hydrology estimation- final numbers draft report

Flood estimation report: Bluefield Land - Holly Street, Pontardawe FCA

Introduction

This report template is based on a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the hydrological context, the method statement, the calculations and decisions made during flood estimation and the results.

Contents

1	Method statement	3
2	Locations where flood estimates required	10
3	Statistical method	12
4	Revitalised flood hydrograph 2 (ReFH2) method	17
5	Discussion and summary of results	19
6	Annex	25

Approval

	Name and qualifications	Date
Method statement prepared by:	Eleanor Maxfield BSc	21/12/2018
Method statement reviewed by:	Jenni Essex BSc MSc PhD CEnv MCIWEM C.WEM	06/12/2018
Calculations prepared by:	Eleanor Maxfield BSc	21/11/2018
Calculations reviewed by:	Jenni Essex BSc MSc PhD CEnv MCIWEM C.WEM	06/12/2018

Revision History

Revision reference	Date issued	Amendments	Issued to
V1.0	11/01/2019	-	Paul Markey
V2.0	02/12/2019	Text detailing discussion with NRW regarding donors; updates to tributary Statistical flows	Paul Markey

Abbreviations

AM.....	Annual Maximum
AEP	Annual Exceedance Probability
AREA	Catchment area (km ²)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE	Council for the Protection of Rural England
FARL.....	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FCA	Flood Consequence Assessment
FSR	Flood Studies Report
HOST.....	Hydrology of Soil Types
NRFA	National River Flow Archive
NRW	Natural Resources Wales
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH.....	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH.....	Windows Frequency Analysis Package – used for FEH statistical method

1 Method statement

1.1 Requirements for flood estimates

Overview	The purpose of the study is to review and update an existing 1D-2D hydraulic model of the River Tawe at Pontardawe, to support a Flood Consequence Assessment (FCA) for a development site at Holly Street in Pontardawe. The study requires a hydrological assessment of peak flows to update the existing (2014) model hydrology using the latest methods, software and data. The hydrological assessment will be undertaken in accordance with Natural Resources Wales (NRW) latest flood estimation technical guidance (GN008)¹. The model includes inflows representing the main River Tawe, and the tributary branches namely the Upper Clydach, Cwm Du and Cwm Sion. Four locations have been selected for flow estimation and are detailed in Section 2.1 Design peak flow estimates and hydrographs were derived for a range of annual exceedance probability (AEP) events in the 2014 hydrology assessment. For the current assessment, the following AEP flows have been generated: 50%, 20%, 10%, 5%, 1.33%, 1% and 0.1%. Only the 50%, 1% plus climate change and 0.1% AEP events are required for the modelling analysis and hydrographs have only been generated for these events. The effects of climate change will be accounted for using the latest guidance². An uplift of 30% will be made to the 1% AEP flow estimates, based on the location of the catchment within the wider West Wales River Basin District.
Project scope	The study is being undertaken for a small development application; the project scope reflects this purpose. There are 4 days available for the hydrological assessment, which constrains the complexity to a routine or moderate assessment.

¹ Natural Resources Wales (2017). Flood Estimation: Technical Guidance (GN008) version 1.0. Available at: <https://www.naturalresourceswales.gov.uk/media/684119/gn008-flood-estimation-technical-guidance.pdf>

² Welsh Government (2016) CL-03-16 Guidance for Flood Consequence Assessments – Climate Change Allowances. Available at: <https://gov.wales/docs/desh/publications/160831guidance-for-flood-consequence-assessments-climate-change-allowances-en.pdf>

1.2 The catchment

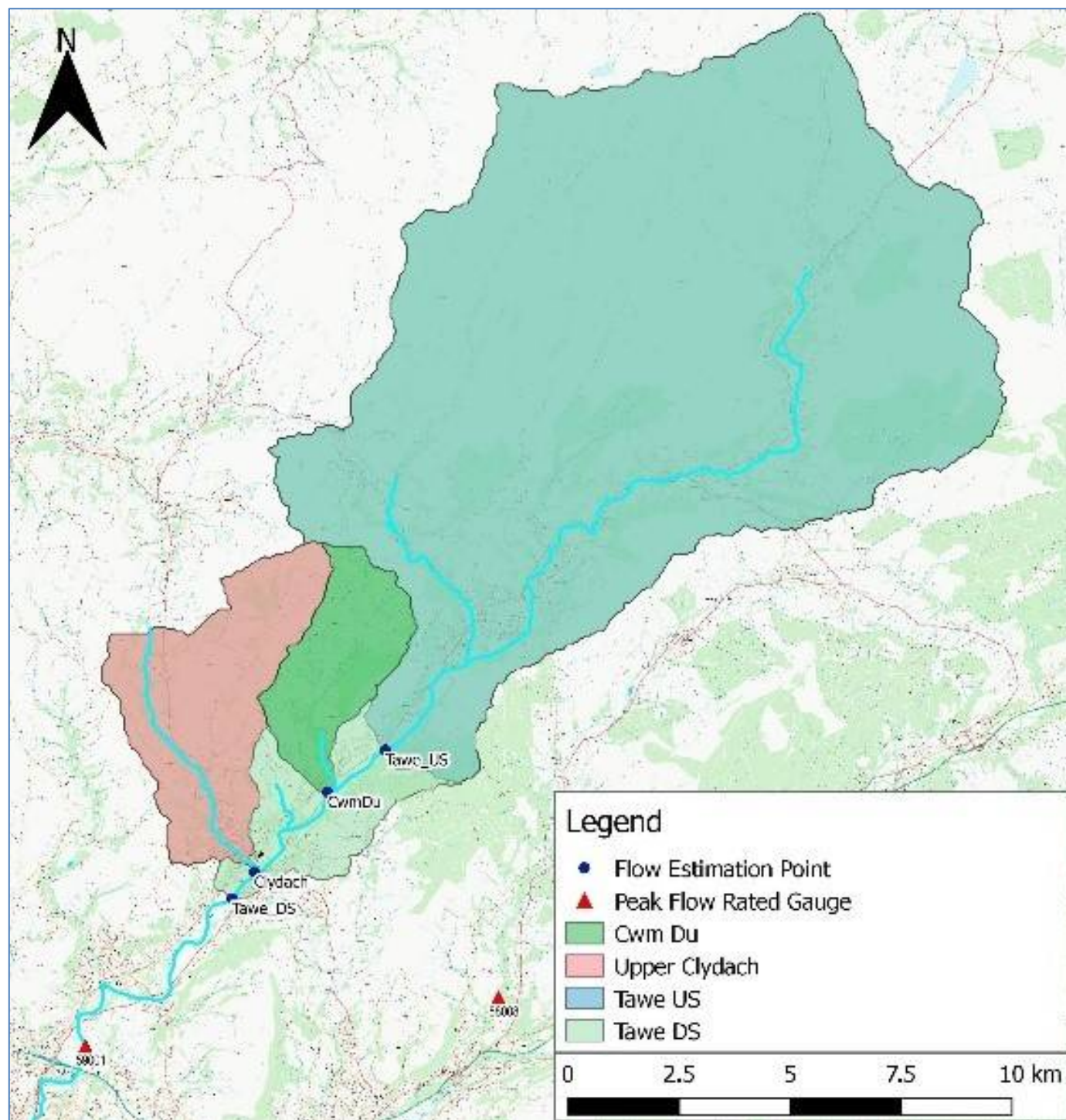


Figure 1-1 Catchment overview and flood estimation points

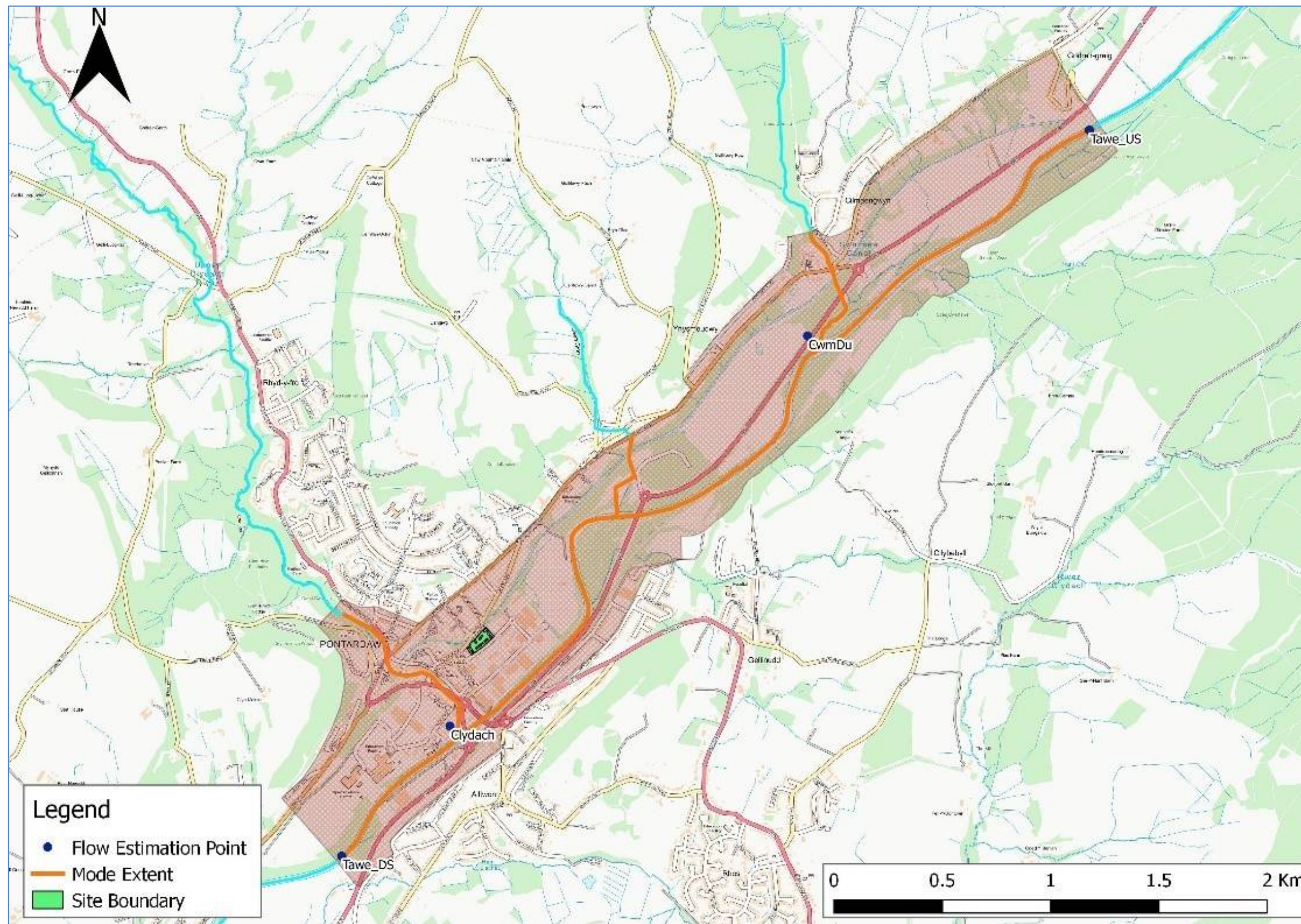


Figure 1-2 Model extent and site boundary

Description	The River Tawe catchment is approximately 189km² at the downstream extent of the model reach. The River Tawe rises in the mountains of Fforest Fawr in the west of the Brecon Beacons National Park. A third of the catchment lies within the Brecon Beacons National Park boundary. It flows in a south westerly direction through the Swansea Valley to Ystradgynlais and Pontardawe and onwards to Swansea where it discharges into Swansea Bay. Along the study reach, several tributary branches join the main River Tawe most notably (for the purpose of this study), from upstream to downstream: The Cwm Du, a right-bank tributary, which drains an area of approximately 10km² and joins the River Tawe upstream of the Holly Road development site. The Cwm Sion, a right-bank tributary, which drains an area of approximately 1.2km² and joins the River Tawe upstream of the development site. The Upper Clydach, a right-bank tributary, draining an area of approximately 19km² which enters the Tawe downstream of the development site, with its confluence in the settlement of Pontardawe. The disused Swansea Canal is located parallel to and above the right bank of the River Tawe. The canal extends from approximately 4km upstream of Pontardawe and terminates adjacent to the Upper Clydach. Catchment topography is steep with limited floodplain extent. A small tarn (Llyn y Fan Fawr) feeds the Nant y Llyn, a headwater tributary of the River Tawe; there are no other significant lakes or reservoirs within the catchment. The catchment is essentially rural and livestock farming is the predominant land use. There is substantial forestry and areas of upland heath. The main urban areas are Ystalyfera, Ystradgynlais and Pontardawe, with other smaller settlement areas such as Ynyswen further up the catchment. There is historic mining and quarrying within the catchment, with evidence of disused mines in the landscape. Underlying geology comprises sedimentary bedrock of mixed permeability. Impermeable strata are found in the catchment headwaters while mixed to moderate permeability bedrock is found in the mid and lower catchment, respectively³. Soils were assessed using the Soilsclapes website⁴. Slowly permeable, wet soils are typically found in upland areas and valley slopes with more freely draining soils found in the lower catchment and valley bottom. Isolated locations of restored soils mostly from quarry and opencast spoil are also predominantly located in the more upland locations. The catchment response to rainfall is likely to be rapid due to the steep topography and generally impermeable geology and soils. The more permeable soils located in the middle and lower catchment may act to provide a small amount of storage and hence moderate runoff in more frequent events. The tarn located in the headwaters is likely to have a minimal impact on runoff response due to its size and location (i.e. in the upper catchment). The historic mining and quarrying operations may have changed the natural runoff response in some areas of the uplands. It is difficult to determine or quantify the consequences of this, however the areas covered are relatively small compared to the overall catchment size.
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³ <https://nrfa.ceh.ac.uk/data/station/spatial/59001>

⁴ <http://www.landis.org.uk/soilsclapes/>

1.3 Source of flood peak data

Source	NRFA peak flows dataset, Version 7, released October 2018. This contains data up to water year 2016-17.
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1.4 Gauging stations (flow or level)

Water-course	Station name	Gauging authority number	NRFA number	Catchment area (km ²)	Type (rated / ultrasonic / level...)	Start of record and end if station closed
Tawe	Ynystanglws	059001	59001	227.7 km ²	Rated. Velocity Area. Pressure transducer with logger.	10/1956 - Present
Upper Clydach	Pontardawe	NRW 4119	-	18.8 km ²	Level gauge	26/04/2002 to present

1.5 Data available at each flow gauging station in Table 1.4

Station name	Start and end of NRFA flood peak record	Update for this study?	OK for QMED ?	OK for pooling ?	Data quality check needed ?	Other comments on station and flow data quality
Ynystanglws	10/1956 to present	N/A	Yes	Yes	No. NRFA gauge	Gravel bed provides unstable control. Pressure transducer installed in 2005 with logger attached. All but extreme floods contained since construction of floodbanks in 1959 and 1973, floodbanks raised in 1979. Gauged to within 21% of AMAX3. Suitable for Pooling from 1973.
Tabulate any updated or revised flood peak series in the Annex. Give link/reference to any further data quality checks carried out.					N/A	

1.6 Rating equations

Station name	Type of rating	Rating review needed?	Comments and link to any rating reviews
Ynystanglws	Empirical – velocity-area station	No	Rating review is not within scope of the study and the gauge is not within the model reach.

1.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Check flow gaugings	No	No	N/A	N/A
Historic flood data	Yes	No	Internet	An internet search and review of news articles suggests that Pontardawe has experienced flooding in recent years. Most of these references refer to local impacts from blockage of the Cwm Du, Cwm Sion and Clydach tributaries and were not located at the development site. No evidence was found of flooding from the River Tawe at Pontardawe. Evidence was found for flooding of Pontardawe as a result of the Swansea Canal breach on Friday 23rd October 1998⁵. This resulted from blockage of the Nant Cwm Sion grill inlet and instability of the culvert system under the canal causing significant flows to be passed directly into the canal. The Swansea Canal overtopping flooded a considerable part of the town including Lower Herbert Street, Tawe Terrace, parts of Ynysderw Road and Holly Street and the Alloy Industrial Estate were subject to water depths of up to 6 feet. There is no direct evidence available from this flood history search for flooding of the development site during this event. However, the development site is located off Holly Street adjacent to the Alloy Industrial Estate and therefore is likely to have experienced some flooding. Several remediation and flood prevention measures were carried out to the culvert and canal.
Flow or river level data for events	N/A	N/A	N/A	Flood event analysis is not within the scope of this study.
Rainfall data for events	N/A	N/A	N/A	
Potential evaporation data	N/A	N/A	N/A	

⁵ Exert of Swansea Canal Breach at Pontardawe on Friday 23rd October 1998: Summary Report British Waterways. Available at:

[https://www.npt.gov.uk/ldpexamination/AP10.3b%20Supporting%20Papers%20re%20British%20Waterways%20Report%20on%20Swansea%20Canal%20\(1999\).pdf](https://www.npt.gov.uk/ldpexamination/AP10.3b%20Supporting%20Papers%20re%20British%20Waterways%20Report%20on%20Swansea%20Canal%20(1999).pdf)

Results from previous studies	Yes	Yes	NRW/ JBA	Information is available for a previous Pontardawe modelling study undertaken by JBA on behalf of NRW ⁶ in 2014. In 2016, further modelling was carried out to support FCA's. Hydrology inflows were generated for the small tributary Cwm Sion as it was considered relevant to those sites, the other hydrology inflows were based on the 2014 NRW hydrology.
Other data or information	N/A	N/A	N/A	N/A

1.8 Hydrological understanding of catchment

Conceptual model	The main site of interest is the proposed development site located in the valley bottom and within the natural floodplain environment. Flooding is likely to result from peak flows and volumes exceeding channel capacity in the River Tawe and from peak flows in the Tawe coinciding with peak flows in tributary branches. Surface water may also contribute to flooding in the vicinity of the study site. However, surface water flooding is not within the scope of this hydrology assessment. The model includes fluvial sources of flooding only.
Any unusual catchment features to take into account?	There are no unusual features that would challenge the adequacy of standard FEH methodologies. However, there may be some interaction between the canal and the watercourses (particularly the upstream tributaries).

1.9 Initial choice of approach

Is FEH appropriate?	Yes.
Initial choice of method(s) and reasons How will hydrograph shapes be derived if needed? Will the catchment be split into sub-catchments? If so, how?	Both the FEH Statistical and ReFH2 methods are suitable for peak flow estimation. The study catchments are <1000km², not highly permeable or heavily urbanised. NRW requires the use of ReFH v2 with FEH13 rainfall statistics when applying a rainfall-runoff approach. The FEH Statistical and ReFH2 methods will both be applied, and the results compared. Hydrograph shapes will be derived using the ReFH2 model and scaled to the FEH Statistical method flows if this is the preferred approach for deriving the peak flows. Lateral inflow hydrographs, to be applied to the model downstream of point inflows, will be derived for the intervening catchment area using ReFH2. Modelled flows will be checked at the downstream lumped catchment flow estimation point (detailed in Section 2.1) to ensure that they approximate the preferred peak flow estimates. If necessary, the intervening area hydrographs will be adjusted following this check.
Software to be used	FEH Web Service/WINFAP v3 ⁷ / ReFH2.2

⁶ 2016s4324_Phase3_Summary_0.1

⁷ WINFAP-FEH v4 © Wallingford HydroSolutions Limited 2016.
2018s1312 - Hydrology Report_v2.0 (Dec 2019)

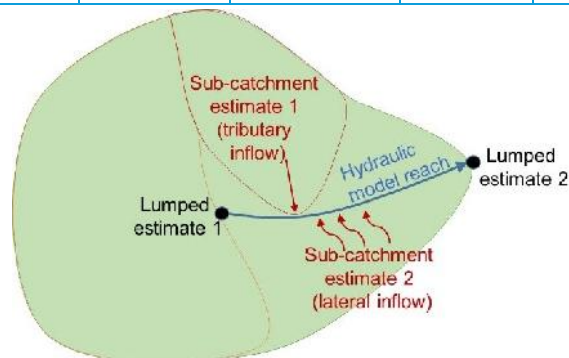
2 Locations where flood estimates required

2.1 Summary of subject sites

A flow estimation point has been generated for the upstream model extent, the two primary tributaries (Cwm Du and Upper Clydach) and the downstream extent of the model (as a check flow point). A separate flow estimation point has not been selected for the Cwm Sion tributary in this study; the catchment is small (1.4km²) and the Cwm Sion inflows are not considered a critical mechanism for flooding at the site. The Cwm Sion flows have therefore been included via the intervening area inflow to the model.

Site code	Type of estimate	Watercourse	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km ²)	Revised / calculated AREA if altered
Tawe_US	L	River Tawe	Upstream model extent	275300	206450	151	N/A
Tawe_DS	L	River Tawe	Downstream model extent	271850	203100	189	N/A
Tawe_DS_IA	S	River Tawe	Intervening area between Tawe_DS, Tawe_US, Cwm_Du and Upper_Clydach	N/A	N/A	N/A	9.4
Cwm_Du	S	Cwm Du	Tributary inflow, @ confluence with River Tawe	274000	205500	9.8	N/A
Upper_Clydach	S	Upper Clydach	Tributary inflow, @ confluence with River Tawe	272350	203700	18.8	N/A

Note: Lumped catchments (L) are complete catchments draining to points at which design flows are required. Sub-catchments (S) are catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system. There is no need to report any design flows for sub-catchments, as they are not relevant: the relevant result is the hydrograph that the sub-catchment is expected to contribute to a design flood event at a point further downstream in the river system. This will be recorded within the hydraulic model output files. However, catchment descriptors and ReFH model parameters should be recorded for sub-catchments so that the results can be reproduced. The schematic diagram illustrates the distinction between lumped and sub-catchment estimates.



2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 2000	FPEXT
Tawe_US	0.99	0.62	0.373	15.0	142	2024	0.018	0.042
Tawe_DS	1.00	0.62	0.389	17.5	144	1953	0.019	0.045
Tawe_DS_IA	N/A	0.62	0.519	3.43	149	1595	0.067	N/A
Cwm_Du	1.00	0.62	0.400	4.28	144	1713	0.004	0.038
Upper_Clydach	1.00	0.62	0.446	5.67	156	1690	0.017	0.023

Note: Red text indicates that values have been amended from the FEH values. URBEXT values have been updated to the current year (2018 at the time of the assessment).

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes	OS mapping and Lidar have been used to check the catchment boundaries. The FEH catchment boundary shapefile for each catchment has been overlain within a GIS application and the boundary checked against the surface water network as depicted on OS mapping. The FEH catchment boundary matched reasonably well to OS mapping and Lidar, with only a few minor errors noted which would make minimal / no difference to the results. Therefore, no adjustments to the catchment boundaries were undertaken.
Record how other catchment descriptors were checked and describe any changes.	SPRHOST and BFIHOST values were checked against the Cranfield University Soils map and found to be sensible for the soil types shown i.e. mixed and moderately permeable. URBEXT and FARL values have been checked against OS mapping and are found to be sensible. No adjustments were undertaken.
Source of URBEXT	URBEXT2000
Method for updating of URBEXT	CPRE formula from 2006 CEH report on URBEXT2000

3 Statistical method

3.1 Overview of estimation of QMED at each subject site

Site code	QMED (rural) from CDs (m ³ /s)	Final method	Data transfer					Urban adjust- ment factor UAF	Final estimate of QMED (m ³ /s)
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d _{ij} (km)	Modera- ted QMED adjust- ment factor, (A/B) ^a	If more than one donor			
						Weight	Weighted ave. adjustment		
Tawe_US	150	DT	59001	4.59	1.15	-	-	1.02	175
Tawe_DS	170	DT	59001	2.27	1.20	-	-	1.02	207
Cwm_Du	11.9	DT	59001	5.00	1.14	-	-	1.00	13.7
Upper_Clydach	17.9	DT	59001	7.68	1.13	-	-	1.02	20.5
Are the values of QMED spatially consistent?					Yes, QMED increases downstream.				
Method used for urban adjustment for subject and donor sites					WINFAP v4 ⁸				
Parameters used for WINFAP v4 urban adjustment if applicable									
Impervious fraction for built-up areas, IF			Percentage runoff for impervious surfaces, PR _{imp}		Method for calculating fractional urban cover, URBAN				
0.3			70%		From updated URBEXT2000				
Notes									
Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment); BCW – Catchment descriptors and bankfull channel width (add details); LF – Low flow statistics (add details).									
The QMED adjustment factor A/B for each donor site is given in Table 3.2. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is (A/B) ^a times the initial estimate from catchment descriptors.									
Important note on urban adjustment									
The method used to adjust QMED for urbanisation published in Kjeldsen (2010) ⁹ in which PRUAF is calculated from BFIHOST is not correctly applied in WINFAP-FEH v3.0.003. Significant differences occur only on urban catchments that are highly permeable.									

⁸ Wallingford HydroSolutions (2016). WINFAP 4 Urban adjustment procedures.

⁹ Kjeldsen, T. R. (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrol. Res. **41**. 391-405.

3.2 Search for donor sites for QMED

Gauged catchments were assessed to identify if any were suitable as donors for data transfer. Since research has shown that data transfer based on geographical distance performs better than one based solely on hydrological similarity¹⁰ the NRFA gauging stations (suitable for QMED) located geographically closest to the subject site have been explored as potential donors.

Two potential donor gauges were identified. 59001 Tawe at Ynystanglws presented the best donor for the River Tawe flows. The gauge is on the same river (approximately 6.5km downstream of Tawe_DS).

58008 Dulais at Cilfrew represented a good fit in terms of catchment similarity to the Upper_Clydach and the Cwm_Du.

Station Details:

59001 - Ynystanglws on the River Tawe. Refer to Section 1.5. The gauge covers a catchment size of 228km² on the same watercourse as the study site, the catchment centroid distance is 2.27km from the Tawe DS and 4.59km from the Tawe US. The station is gauged to within 21% of AMAX3, which is considered to represent a very good rating check. There are no data quality and reliability issues noted on the NRFA website. The catchment descriptors are similar to the Tawe flow estimation points catchment descriptors and the locations are very close. Consequently, the station is deemed an appropriate donor for the Tawe_US and Tawe_DS.

58008 - Cilfrew on the Dulais. Refer to Section 1.5. The gauge covers a catchment size of 43km² on a different watercourse from the study site, with a catchment centroid distance 9.1km from the Upper Clydach and 6.6km from the Cwm Du. The station is gauged to within 17% of QMED, which is considered to represent a good rating check. There are no data quality and reliability issues noted on the NRFA website. The catchment descriptors are similar to both the Clydach and Cwm Du due to the steep and relatively impermeable nature of the catchments. The location is close to both study catchments. Consequently, the station has been deemed reliable for use in this study.

NRW reviewed the hydrological assessment in September 2019. The review findings stated that the design peak flow estimates were not acceptable for use in the hydraulic model. The reason given for this was related to the choice of donors and the application of the donor adjustment. NRW stated the following:

- Ynystanglws and Teddy Bear Bridge gauges should both be used for the donor adjustment for the Tawe flow estimation points, with no application of the distance factor. The reasons given for this were:
 - The subject sites are located between the two gauges. The QMED factors at the gauge are similar, 1.34 and 1.25, respectively.
 - Use of the standard donor procedure, with the distance moderation applied, would result in a lower QMED factor between the stations than at either of the stations themselves. This is unrealistic and may result in a reduction in QMED downstream of the upstream gauging station.
- Review the QMED adjustment method for the tributaries and update the flows accordingly. The reasons given for this were:
 - Dulais at Cilfrew has been used as the donor but Ynystanglws is closer based on catchment centroids.
 - The moderated adjustment factor, using Cilfrew as a donor, is 1.07 but all gauges in the Tawe catchment and surrounding area have adjustment factors higher than this. This indicates that other locations in the Tawe catchment should also have adjustment factors in this range.

¹⁰ Kjeldsen, T.R., Jones, D.A. and Bayliss, A.C. (2008) Improving the FEH statistical procedures for flood frequency estimation. Science Report SC050050, Environment Agency
2018s1312 - Hydrology Report_v2.0 (Dec 2019)

After discussion with NRW the following was agreed:

- Tawe flow estimation points:
 - No change to the original JBA flows.
 - Although the adjustment factor used is lower than at the upstream and downstream gauges it follows the same trend, is of a similar magnitude, and is therefore not unreasonable.
 - QMED estimates at the subject sites are larger than at the upstream gauge and smaller than at the downstream gauge, hence there is spatial consistency in flows (they increase downstream).
- Tributary flow estimation points:
 - Use Ynystanglws as the sole donor.
 - Retain the distance moderation term as the gauge is not on the same watercourse as the tributaries.
 - The moderated adjustment factors, 1.13 at Upper_Clydach and 1.14 at Cwm_Du, are slightly less than the lowest value in the range of gauging station adjustment factors for the Tawe and surrounding area. This has been accepted by NRW.
 - The tributary QMED values and resultant peak flow estimates for other design events have been updated accordingly.

3.3 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing	Method (AM or POT)	Adjustment for climatic variation ?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)
59001	Located on same watercourse downstream of flow estimation points	AM	No	253	185	1.34

3.4 Derivation of pooling groups

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged?	Changes made to default pooling group, with reasons	Weighted average L-moments
Tawe_US	Tawe_US	No	Pooling group reviewed, and all stations retained. Pooling group was acceptably homogeneous.	L-CV 0.169 L-Skew 0.174

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged?	Changes made to default pooling group, with reasons	Weighted average L-moments
Tawe_DS	Tawe_DS	No	Pooling group reviewed. Removed: 73005 - Kent @ Sedgwick (duplicate watercourse) 72015 - Lune @ Lunes Bridge (duplicate watercourse) Added: 81003 - Luce @ Airyhemming (to increase years of data) 63001 - Ystwyth @ Pont Llolwyn (to increase years of data)	L-CV 0.161 L-Skew 0.169
Cwm_Du	Cwm_Du	No	Pooling group reviewed. Removed: 49005 - Bolingey Stream @ Bolingey Cocks Bridge (<8-years of data)	L-CV 0.193 L-Skew 0.21
Upper_Clydach	Upper_Clydach	No	Pooling group reviewed, and all stations retained. Pooling group was acceptably homogenous.	L-CV 0.202 L-Skew 0.186
Note: Pooling groups were derived using the procedures from Science Report SC050050 (2008). Final pooling groups are presented in the Annex (Section 6.1).				

3.5 Derivation of flood growth curves at subject sites

Site code	Method	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution	Growth factor for 100-year return period
Tawe_US	P	Tawe_US	Generalised Logistic (GL) – acceptable fit and recommended in the FEH for describing flood growth in the UK	Urban adjustment made using WINFAP 4	Location 1.0 Scale 0.167 Shape -0.177	2.18
Tawe_DS	P	Tawe_DS		Urban Adjustment Procedures	Location 1.0 Scale 0.159 Shape -0.172	2.11
Cwm_Du	P	Cwm_Du		No permeable adjustment required as most / all stations in the pooling groups have SPRHOST >20%	Location 1.0 Scale 0.191 Shape -0.211	2.48
Upper_Clydach	P	Upper_Clydach			Location 1.0 Scale 0.201 Shape -0.189	2.47

Site code	Method	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution	Growth factor for 100-year return period
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Notes

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.

Urban adjustments are all carried out using the method of Kjeldsen (2010).

Growth curves were derived using the procedures from Science Report SC050050 (2008).

3.6 Flood estimates from the statistical method

Site code	Flood peak (m ³ /s) for the following AEP (%) events						
	50	20	10	5	1.33	1	0.1
Tawe US	175	221	254	288	364	383	571
Cwm Du_ds	13.7	17.9	21.0	24.3	32.0	33.9	54.4
Upper Clydach_ds	20.5	27.0	31.7	36.6	47.7	50.5	78.9
Tawe DS	207	259	295	333	417	437	643

4 Revitalised flood hydrograph 2 (ReFH2) method

4.1 Catchment sub-divisions for ReFH2 model

Site code	Area (km ²)			
	Rural or un-developed	Paved	Only relevant if significant transfers of water via sewers crossing catchment boundaries...	
			Paved with sewers draining out of topographic catchment	Paved outside topographic catchment with sewers draining into catchment
Tawe_Us	147	4.32	N/A	N/A
Cwm_Du_DS	9.78	0.06		
Upper_Clydach_DS	18.31	0.51		
Tawe_DS	183	5.71		
Tawe_ds_IA	9.5	0.63		
Sources of information for creating sub-divisions	N/A		Sewer capacity (return period / rainfall intensity / flow rate) and source of information	N/A

4.2 Parameters for ReFH2 model

Site code	Method	Tp (hours)	C _{max} (mm)	PR _{imp} % runoff for impermeable surfaces	BL (hours)	BR
Tawe_us	CD	3.23	258.75	70	38.37	1.11
Cwm_Du_ds	CD	1.57	277.50	70	30.45	1.20
Upper_Clydach_ds	CD	1.80	312.78	70	34.58	1.36
Tawe_ds	CD	3.51	269.73	70	40.68	1.16
Tawe_ds_IA	CD	1.37	378.09	70	33.98	1.62
Brief description of any flood event analysis carried out (further details should be given in the annex)			N/A Source of design rainfall statistics = FEH13			
Methods: OPT: Optimisation, BR: Baseflow recession fitting, CD: Catchment descriptors, DT: Data transfer (give details)						

4.3 Design events for ReFH2 method: Lumped catchments

Site code	Season of design event (summer or winter)	Storm duration (hours)
Tawe_us	Winter	09:30:00
Cwm_Du_ds	Winter	04:15:00
Upper_Clydach_ds	Winter	04:45:00
Tawe_ds	Winter	10:30:00

Site code	Season of design event (summer or winter)	Storm duration (hours)
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?	Yes. The individual storm durations above have been used to generate peak flow estimates for comparison with the FEH Statistical method estimates. For application to the hydraulic model a uniform storm duration and areal reduction factor (ARF) will be used. This will be based on the Tawe_DS flow estimation point; a 10.5hr storm duration and ARF set to the value of Tawe_DS applied for all inflow hydrographs.	

4.4 Flood estimates from the ReFH2 method

Site code	Flood peak (m ³ /s) for the following AEP (%) events						
	50	20	10	5	1.33	1	0.1
Tawe_us	160	204	234	264	329	345	540
Cwm_Du_ds	10.3	13.5	15.7	17.9	22.6	23.8	39.6
Upper_Clydach_ds	15.5	20.0	23.2	26.4	33.2	35.0	58.7
Tawe_ds	176	222	253	286	354	371	585

5 Discussion and summary of results

5.1 Comparison of results from different methods

Site code	Ratio of peak flow to FEH Statistical peak					
	50% AEP			1% AEP		
	ReFH2	FEH DT	Ratio	ReFH2	FEH DT	Ratio
Tawe_us	160	175	0.91	345	383	0.90
Cwm_Du_ds	10.3	13.7	0.75	23.8	33.9	0.70
Upper_Clydach_ds	15.5	20.5	0.76	35.0	50.5	0.69
Tawe_ds	176	207	0.85	371	437	0.85

5.2 Final choice of method

Choice of method and reasons	The FEH Statistical method is considered to be most appropriate for determining flow frequency at the flow estimation points. Data transfer from donor stations has been used to improve the flow frequency estimates. Suitable donor gauges have been identified on the River Tawe, downstream of the study site and on the nearby River Dulais. The ReFH2 method flows presented here are based solely on catchment descriptors. For this reason, there is lower confidence in the flow estimates derived from the ReFH model. The ReFH2 flows are lower than those generated via the Statistical method. This is thought to be a result of data transfer increasing the QMED value derived from catchment descriptors for the Statistical method. The unadjusted catchment descriptor derived flows from the Statistical method are similar to those from ReFH2. The growth curves for the ReFH2 and the Statistical method are shown in Section 5.4, Figure 6.1 – 6.4 (along with the growth curve for flows from the 2014 NRW hydrology). The growth curves show a relatively consistent relationship between the ReFH2 and Statistical growth curves. Although the Statistical method is preferred here over the ReFH2 method, there are significant uncertainties associated with applying it to events beyond the 0.5% AEP event, due to the typically short length of river gauge records. To reduce these uncertainties, a hybrid approach has been taken to derive the 0.1% AEP event flow, as recommended in NRW's (2017) latest guidance on flood estimation. The 1% AEP event peak flows from the Statistical method have been adjusted using the ratio of the 0.1% and 1% AEP event flows from the ReFH2 model.
How will the flows be applied to a hydraulic model?	The ReFH2-generated hydrographs have been scaled to fit the peak flow estimates from the Statistical method. The Tawe_US hydrograph will be applied as a point inflow at the upstream extent of the hydraulic model and routed. Point inflows representing the tributary branches Upper_Clydach and Cwm_Du will also be applied. Lateral flows (i.e. the unaccounted flow between Tawe_US and Tawe_DS) will be distributed along the remaining model reach according to inflows as depicted on OS mapping. The modelled flows at Tawe_DS will be checked to ensure that they approximate the lumped estimates from the hydrological assessment. If necessary, the intervening area hydrographs will be scaled to better approximate the lumped estimate. Hydrographs have been derived for the 50%, 1% plus climate change and 0.1% AEP events using a 10.5hr storm duration.

5.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The main assumptions are: - The pooling groups used to define the growth curve for the FEH Statistical method are representative of the study catchments. This is likely to be the case for the River Tawe but may not be for the smaller tributaries as these catchments are not well represented in the dataset. - It is relevant to apply the distance factor when generating the donor adjustment factor for the River Tawe. The donor is on the same watercourse but several kilometres downstream, with reasonably large tributaries entering between the study site and the gauge. Therefore, the flow at the gauge may not be directly representative of flow at the study site. - The ReFH2 model provides a representative hydrograph shape. - The storm duration selected is representative of the critical conditions for the River Tawe, and the River Tawe is the main flood risk source for the proposed development site.
Discuss any particular limitations.	The main limitations are: - The FEH Statistical method has been applied beyond the AEP event range of the 1%, the reliability of estimates above is reduced above this AEP. - There are no flow records available for calibration and verification of the hydrological models.
Give what information you can on uncertainty in the results.	It is not possible to directly quantify the uncertainty for the ReFH2 method. There is no method provided in the FEH for estimating uncertainty for the common situation of an ungauged catchment, pooled growth curve and QMED estimated from a donor catchment. The uncertainty will depend on many factors, for example, how unusual the study catchment is relative to the pooling group and donor catchment, and the uncertainty in flow measurement at other gauges. A UK average measure of uncertainty is presented in a technical guidance report¹¹ generated by a R&D project into the FEH, local data and uncertainty (Environment Agency funded consortium of JBA, CEH and others). The report presents results for rural catchments ($URBEXT2000 < 0.03$) and moderately urbanised catchments ($0.03 \leq URBEXT2000 < 0.15$). The 95% confidence limits for a 1% AEP flood estimate for a rural catchment are: • Without donor adjustment of QMED: 0.45 – 2.23 times the best estimate • With donor adjustment of QMED (one donor): 0.47 – 2.12 times the best estimate
Comment on the suitability of the results for future studies.	The design peak flow estimates and hydrographs were derived for the purposes of this modelling study. If peak flow estimates and hydrographs are required for a different purpose it is recommended that, at a minimum, a review of the results is carried out.
Give any other comments on the study.	No further comments.

5.4 Checks

Are the results consistent, for example at	Yes. The design flow estimates at the Tawe_ds location are consistent with the flows at Tawe_us and the contributing flows from the Cwm_du_ds
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¹¹ Environment Agency. 2017. Using local data to reduce uncertainty in flood frequency estimation. 2018s1312 - Hydrology Report_v2.0 (Dec 2019)

confluences?	and Upper_Clydach_ds tributaries. Flows increase downstream within the study area.
What do the results imply regarding the return periods of floods during the period of record?	There is no flow gauge at the site of interest against which to compare the design flow estimates.
What is the range of 100-year growth factors? Is this realistic?	The range of growth factors for the FEH Statistical method 1% AEP event are 2.2 for the Tawe and 2.6 for the tributaries. The normal range of values is 2.1-4.0. The values for the Tawe are therefore at the lower end of the range. These values are realistic for a steep, wet catchment where flows are expected to be high for less frequent events (therefore constraining the flood growth curves). The tributary catchments are slightly more permeable than the wider Tawe catchment and therefore the slightly higher growth factor for these catchments is reasonable.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	The ratio of the ReFH2 0.1%/1% AEP event flows has been applied to the FEH 1% AEP event flows to produce the final 0.1% AEP event results. The ratio for the Tawe flow estimation points is about 1.6 and for the tributaries is about 1.7.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	The 2014 study design peak flow estimates generated by NRW have been compared to the flows generated for the current study. The 2014 flows were derived using the FEH Statistical method, using data transfer to adjust the QMED estimate. Detailed information has not been provided regarding the derivation of the flow estimates (e.g. the pooling group used). The location of the four flow nodes are the same as the current study and the same donor has been used for each inflow as per the current study. However, the NRW 2014 hydrology did not apply the distance factor to the QMED adjustment for the flow estimation points for the Ynystanglws donor gauge (Tawe nodes) or the Cilfrew donor gauge (tributaries). Consequently, the QMED values are higher for the NRW 2014 hydrology than for the current study. FEH guidance suggests the application of the distance factor unless there is a valid reason not to; no reasons could be identified as part of this study or within the information provided with the NRW 2014 flows. The gauge is not within the model reach, and there is no spatial inconsistency between QMED at the study estimation points and the gauge (i.e. QMED at the gauge, which is downstream of the study area, is higher than at the flow estimation points). It is anticipated that the flows generated by NRW may have been part of an assessment of the wider Tawe and that the distance factor was not applied to ensure spatial consistency in flows. However, this study is for a specific location and it is considered that the most appropriate approach for this location is applied here. Consequently, it was considered appropriate to continue to apply the distance factor in the present study. Figure 5-1 to Figure 5-4 shows the growth curves for each flow estimation point for the current study FEH Statistical and ReFH2 methods plotted against the NRW 2014 growth curves. Note: The tributary growth curves have not been updated for the FEH Statistical method following the amendments detailed in Section 3.2; the trend will be similar to that shown in the plots below. It can be seen that the NRW growth curve is steeper above the 1% AEP event than the current study curves. This is

likely to be due to the use of the ReFH1 0.1% / 1% AEP event ratio for the 2014 study compared to the ReFH2 ratio used in this study. The NRW growth curves for the tributaries are steeper from about the 10% AEP event. The same difference based on the ReFH1 and ReFH2 ratios will apply here. The differences for the 10% to 1% AEP events are likely to be differences in the pooling groups. Suitability for pooling may have been reclassified for some stations since the 2014 study and there is also additional data for the stations incorporated within the current study.

These factors (QMED and growth curves) result in lower flows for the current study than for the 2014 NRW hydrology study. The flows from the current study are preferred as they use the latest datasets and guidance.

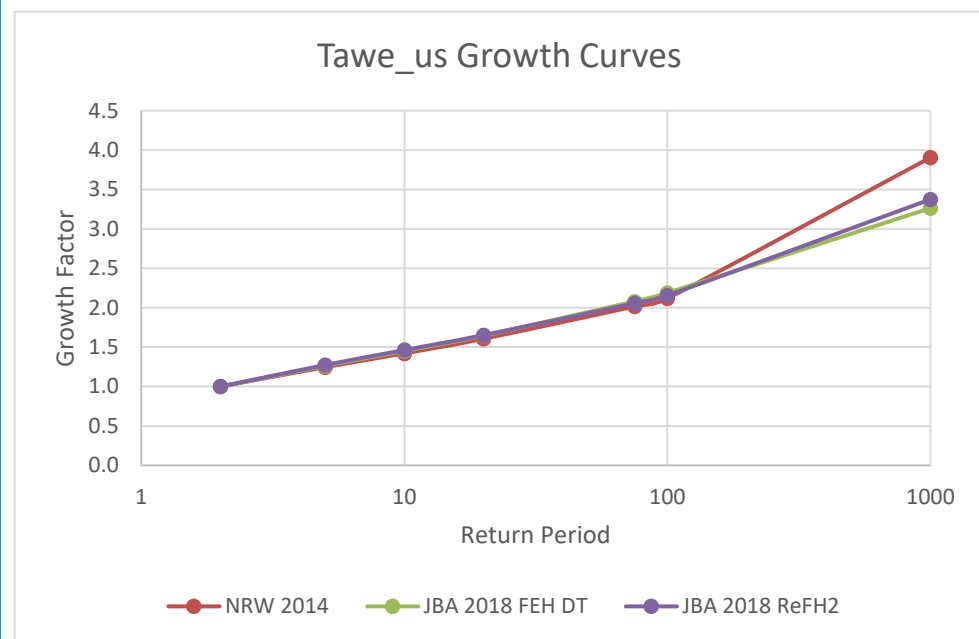


Figure 5-1 Growth curves Tawe upstream

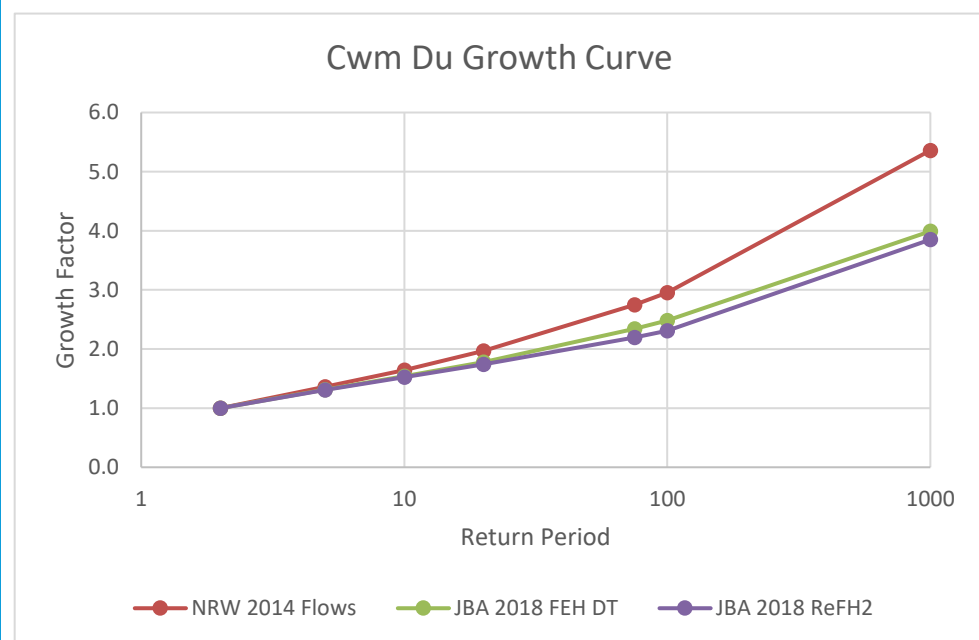


Figure 5-2 Growth curves Cwm Du downstream

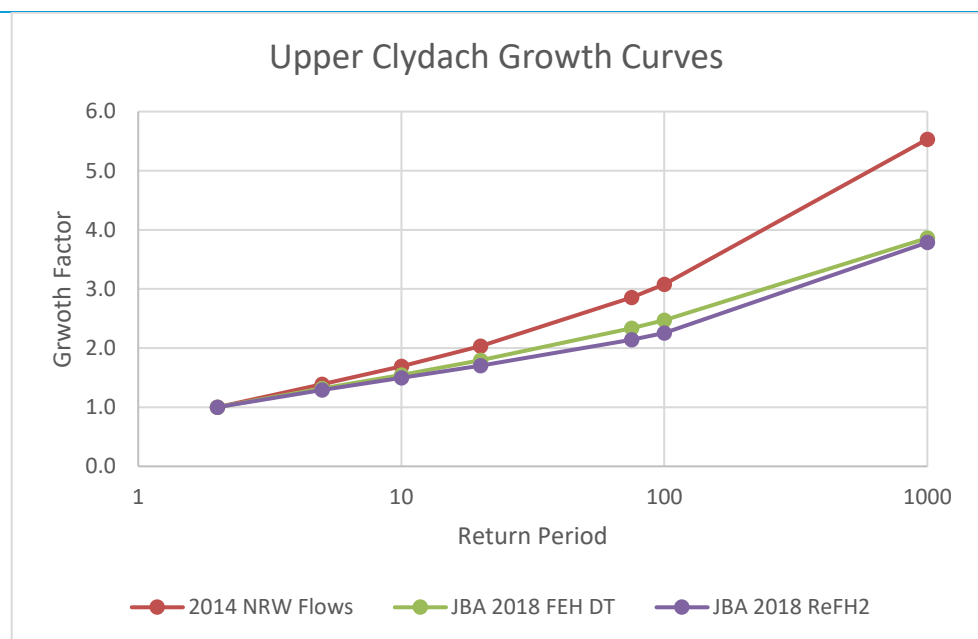


Figure 5-3 Growth Curves Upper Clydach downstream

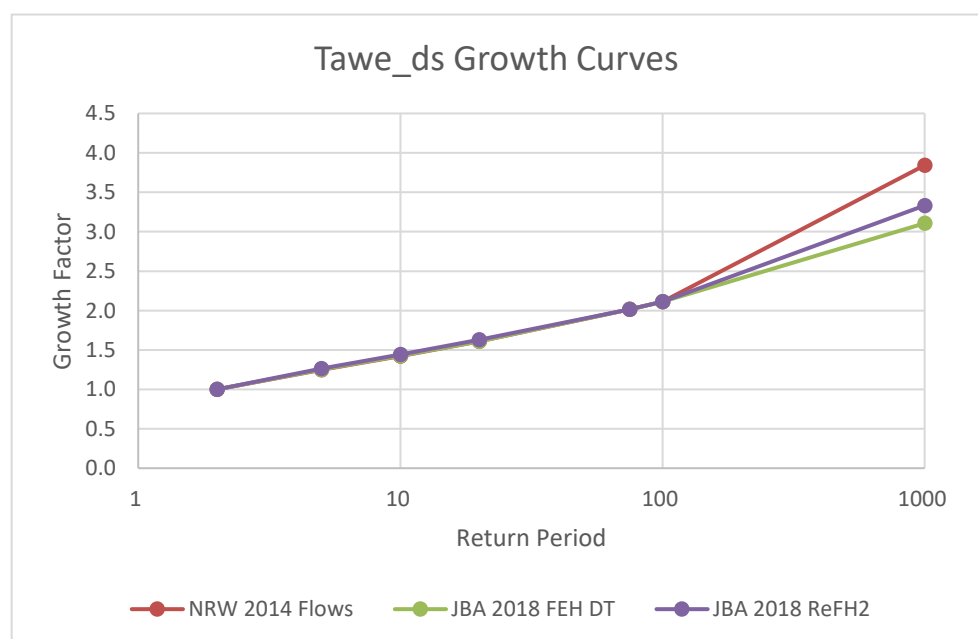


Figure 5-4 Growth curves Tawe downstream

Are the results compatible with the longer-term flood history?

There is no corresponding flow data from within the study area from which to compare flows. Moreover, the flood history that has been identified through this assessment is primarily related to tributary flows that have become blocked from debris or other confounding factors rather than high flow events affecting the study area.

Describe any other checks on the results

Modelled flood levels and extents will be sensibility-checked to ensure that flow inputs result in realistic outputs.

5.5 Final results

Site code	Flood peak (m ³ /s) for the following AEP (%) events			
	50	1	1+ CC	0.1
Tawe_u/s	175	383	498	599
Cwm Du_d/s	13.7	33.9	44.1	56.5
Upper Clydach_d/s	20.5	50.5	65.7	84.5
Tawe_d/s	207	437	579	702

If flood hydrographs are needed for the next stage of the study, where are they provided?	2018s1312 - Hydrographs_Stat peaks_10.5hr_v4 (Nov 2019).xlsx
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6 Annex

6.1 Pooling Group Composition

6.1.1 Tawe_us

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
58002 (Neath @ Resolven)	0.343	39	220	0.149	0.233	0.733
79004 (Scar Water @ Capenoch)	0.442	43	132.922	0.087	0.07	1.998
55026 (Wye @ Ddol Farm)	0.447	48	115.158	0.174	0.125	0.592
72015 (Lune @ Lunes Bridge)	0.447	38	202.095	0.145	0.15	0.519
73012 (Kent @ Victoria Bridge)	0.503	39	141.772	0.209	0.286	0.76
56006 (Usk @ Trallong)	0.505	44	163.605	0.193	0.148	1.204
60006 (Gwili @ Glangwili)	0.508	49	78.496	0.159	0.167	0.3
75009 (Greta @ Low Briery)	0.544	45	110.942	0.234	0.273	0.985
4005 (Meig @ Glenmeanie)	0.57	21	111.347	0.179	0.244	1.093
16003 (Ruchill Water @ Cultybraggan)	0.583	45	148.085	0.145	0.058	1.157
59001 (Tawe @ Ynystanglws)	0.595	43	253.057	0.123	0.248	1.554
81003 (Luce @ Airyhemming)	0.629	40	164.224	0.166	0.091	0.551
Total		549				
Weighted means				0.169	0.174	

6.1.2 Tawe_ds

Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
58002 (Neath @ Resolven)	0.082	39	220	0.149	0.233	0.784
59001 (Tawe @ Ynystanglws)	0.272	43	253.057	0.123	0.248	1.869
72005 (Lune @ Killington)	0.366	48	264.22	0.199	0.149	0.623
55026 (Wye @ Ddol Farm)	0.366	48	115.158	0.174	0.125	0.577
73012 (Kent @ Victoria Bridge)	0.369	39	141.772	0.209	0.286	1.555
56006 (Usk @ Trallong)	0.372	44	163.605	0.193	0.148	0.746
3002 (Carron @ Sgodachail)	0.393	43	177.884	0.151	0.154	0.082
46003 (Dart @ Austins Bridge)	0.445	59	234.379	0.165	0.105	1.162
27096 (Wharfe @ Netherside Hall)	0.456	14	202.182	0.122	0.094	1.805
79004 (Scar Water @ Capenoch)	0.547	43	132.922	0.087	0.07	1.607
81003 (Luce @ Airyhemming)	0.552	40	164.224	0.166	0.091	0.502
63001 (Ystwyth @ Pont Llolwyn)	0.582	56	93.934	0.186	0.231	0.688
Total		516				
Weighted means				0.161	0.169	

6.1.3 Upper Clydach

Final pooling group

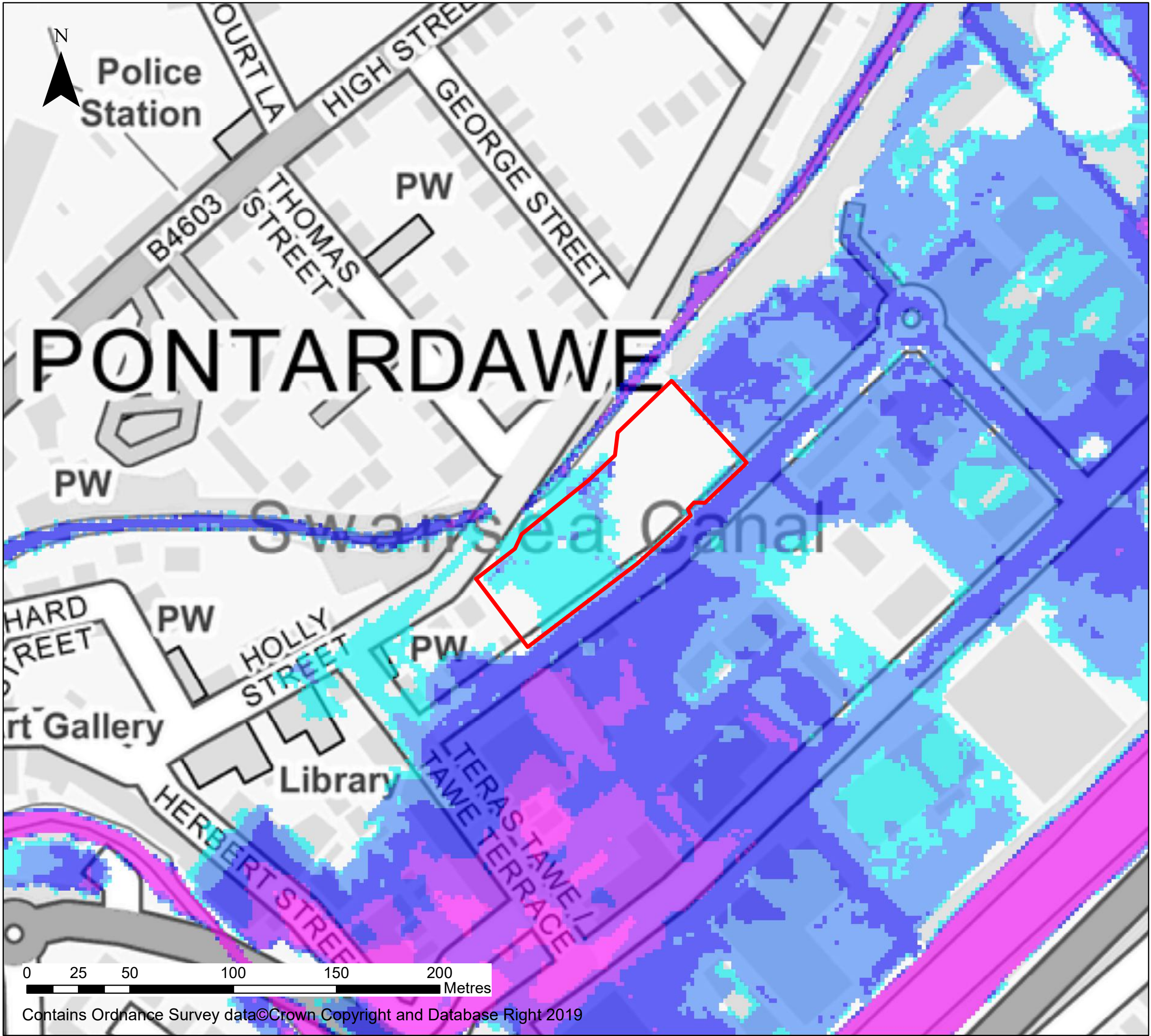
Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
48009 (st Neot @ Craigshill Wood)	0.364	12	8.469	0.245	0.373	0.556
206006 (Annalong @ Recorder)	0.384	48	15.33	0.189	0.052	1.83
27032 (Hebden Beck @ Hebden)	0.393	51	4.052	0.204	0.247	0.684
25012 (Harwood Beck @ Harwood)	0.397	48	32.945	0.191	0.234	0.697
49003 (de Lank @ de Lank)	0.503	51	14.324	0.225	0.206	0.165
46005 (East Dart @ Bellever)	0.521	53	39.242	0.157	0.057	0.434
48004 (Warleggan @ Trengoffe)	0.541	48	9.983	0.258	0.257	1.24
25011 (Langdon Beck @ Langdon)	0.617	28	15.878	0.238	0.318	0.781
49006 (Camel @ Camelford)	0.671	11	11.154	0.124	-0.185	1.91
47022 (Tory Brook @ Newnham Park)	0.686	24	6.651	0.265	0.138	2.201
57017 (Rhondda Fawr @ Tynewydd)	0.746	16	23.46	0.123	-0.076	1.141
25003 (Trout Beck @ Moor House)	0.765	44	15.142	0.168	0.294	1.387
71003 (Croasdale Beck @ Croasdale Flume)	0.818	37	10.9	0.212	0.323	0.566
72007 (Brock @ Upstream of a6)	0.897	39	28.011	0.202	0.214	0.409
Total		510				
Weighted means				0.202	0.186	

6.1.4 Cwm_du

Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
25003 (Trout Beck @ Moor House)	0.29	44	15.14	0.17	0.29	0.38
71003 (Croasdale Beck @ Croasdale Flume)	0.32	37	10.90	0.21	0.32	0.22
25011 (Langdon Beck @ Langdon)	0.55	28	15.88	0.24	0.32	1.14
49006 (Camel @ Camelford)	0.57	11	11.15	0.12	-0.19	1.91
206006 (Annalong @ Recorder)	0.57	48	15.33	0.19	0.05	2.08
28033 (Dove @ Hollinsclough)	0.65	38	4.23	0.23	0.41	0.57
47022 (Tory Brook @ Newnham Park)	0.70	24	6.65	0.27	0.14	1.27
54022 (Severn @ Plynlimon Flume)	0.79	38	14.99	0.16	0.17	0.82
92002 (Allt Coire Nan Con @ Polloch)	0.88	16	13.54	0.10	0.34	2.10
45816 (Haddeo @ Upton)	0.89	24	3.49	0.31	0.39	1.53
91802 (Allt Leachdach @ Intake)	1.03	34	6.35	0.15	0.26	0.83
57017 (Rhondda Fawr @ Tynewydd)	1.05	16	23.46	0.12	-0.08	0.97
49003 (de Lank @ de Lank)	1.14	51	14.32	0.23	0.21	0.23
46005 (East Dart @ Bellever)	1.21	53	39.24	0.16	0.06	0.53
27032 (Hebden Beck @ Hebden)	1.21	51	4.05	0.20	0.25	0.43
Total		513				
Weighted means				0.193	0.21	

Appendix D: Pre-developed model results



KEY

- Proposed Development Outline
- 1% AEP plus CC**
- Maximum Depth (m)**
- 0 - 0.1
 - 0.1 - 0.3
 - 0.3 - 0.6
 - 0.6 - 1
 - >1



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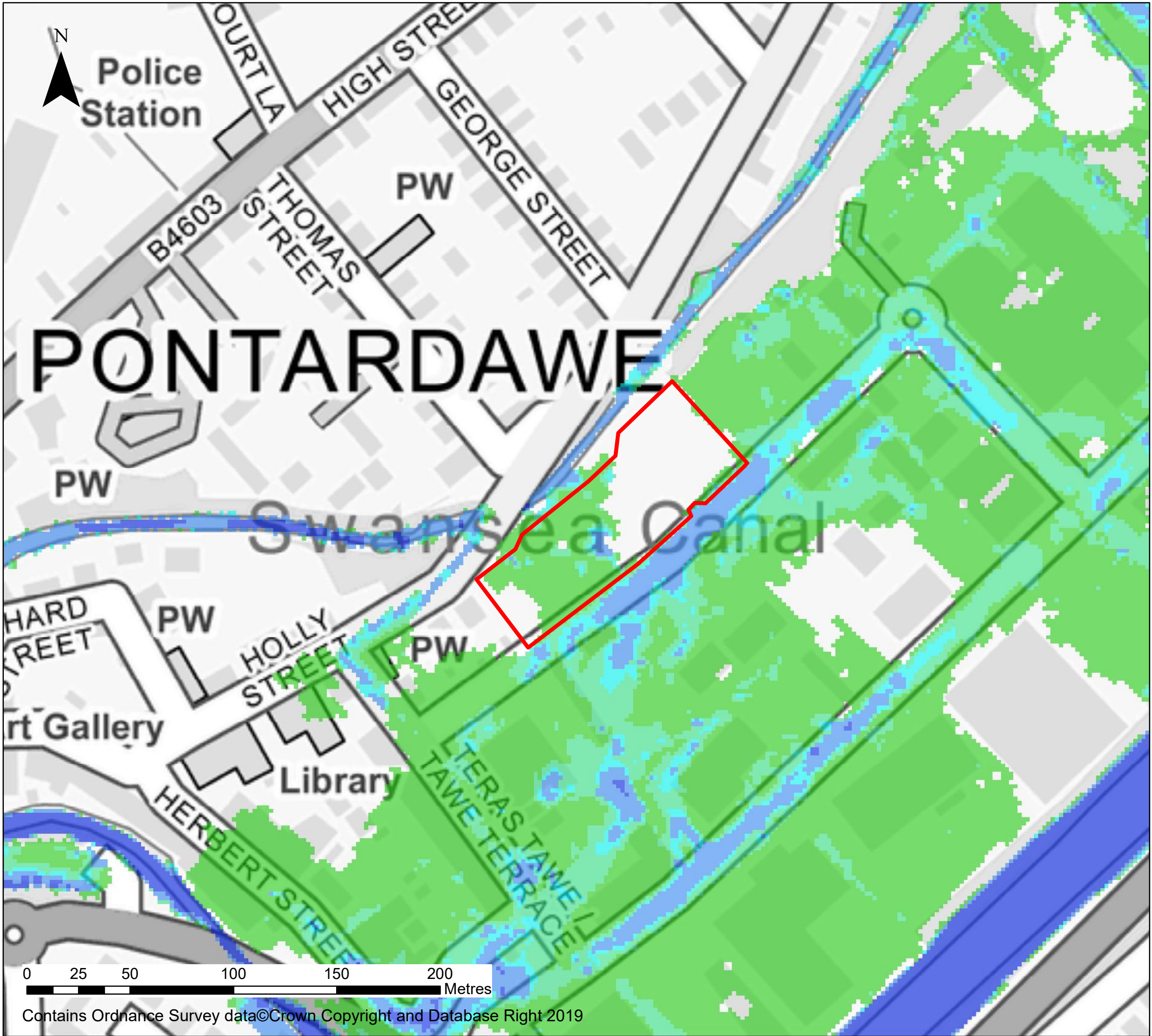
Pre-development

1% AEP plus climate change
- Depth

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Drawing Number: 2018s1312_001	Sheet No.: 1 of 1	Status:	Rev.: A
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KEY

- Proposed Development Outline
- 1% AEP plus CC**
- Velocity (m/s)**
- 0 - 0.15
- 0.15 - 0.3
- 0.3 - 0.4
- 0.4 - 1
- >1



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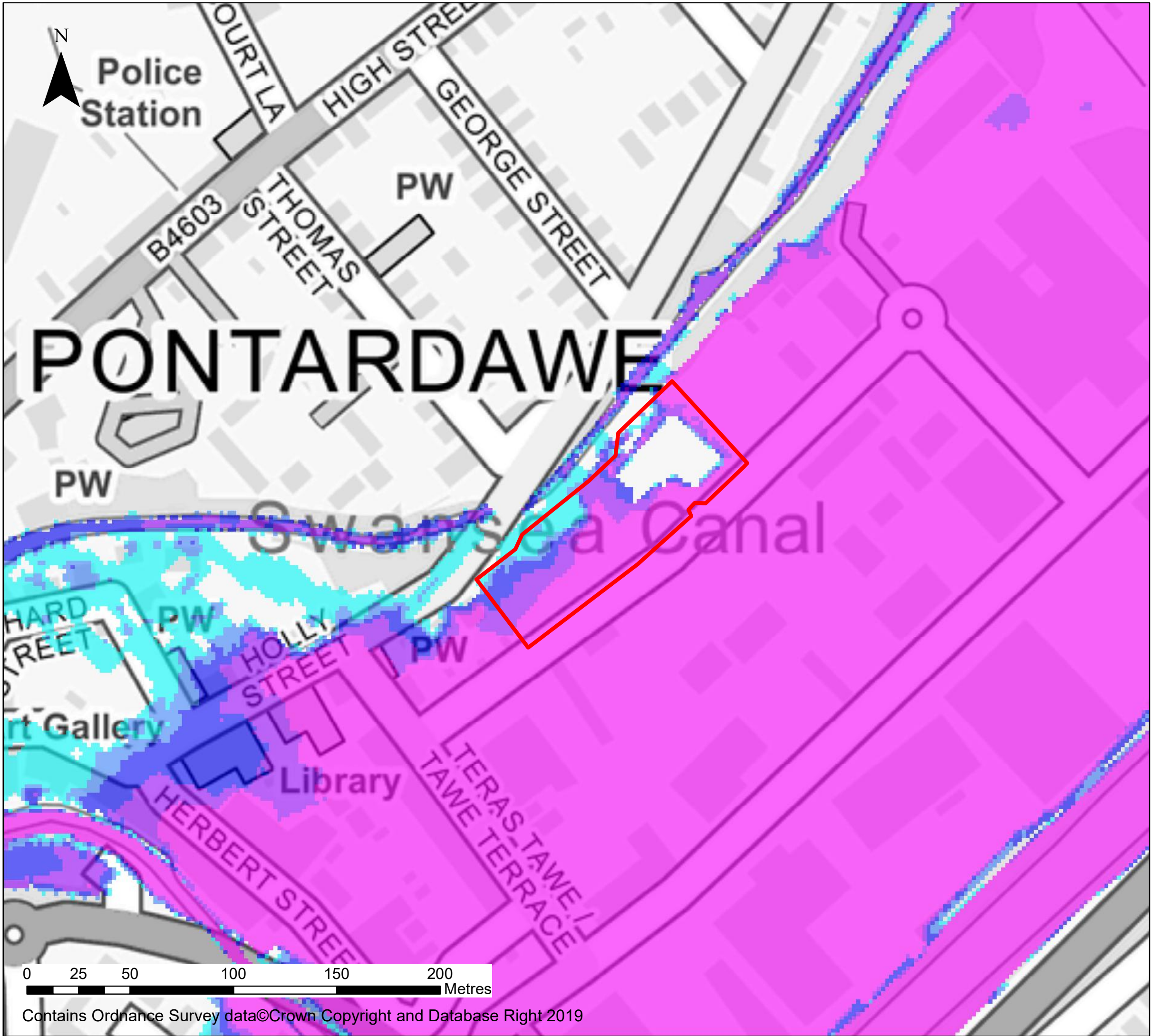
1% AEP plus climate change
- Velocity

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KEY

Proposed Development Outline

0.1% AEP

Maximum Depth (m)

- 0 - 0.1
- 0.1 - 0.3
- 0.3 - 0.6
- 0.6 - 1
- >1



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Pre-development

0.1% AEP - Depth

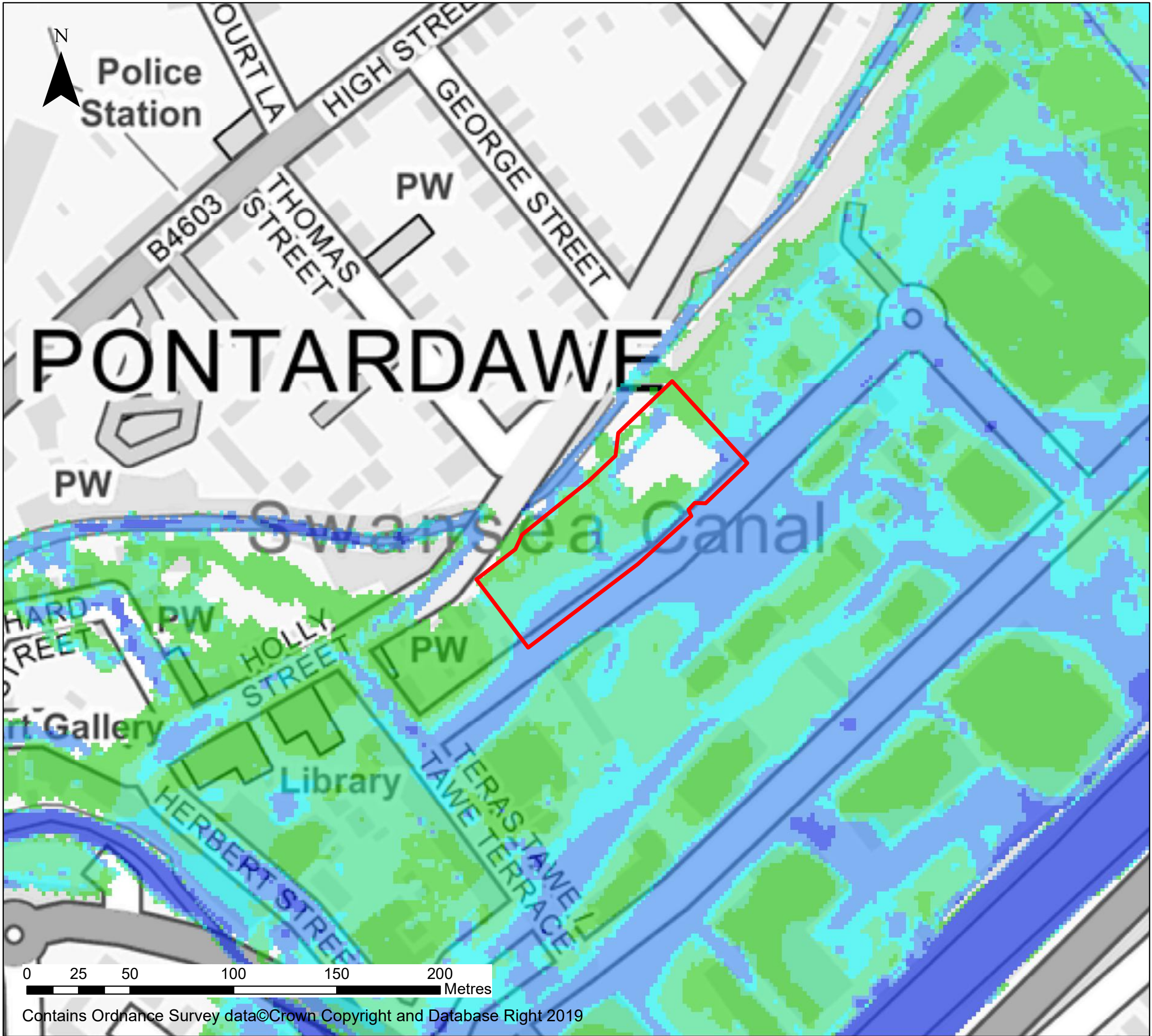
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0 25 50 100 150 200 Metres

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KEY

Proposed Development Outline

0.1% AEP

Velocity (m/s)

- 0 - 0.15
- 0.15 - 0.3
- 0.3 - 0.4
- 0.4 - 1
- >1



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Pre-development

0.1% AEP - Velocity

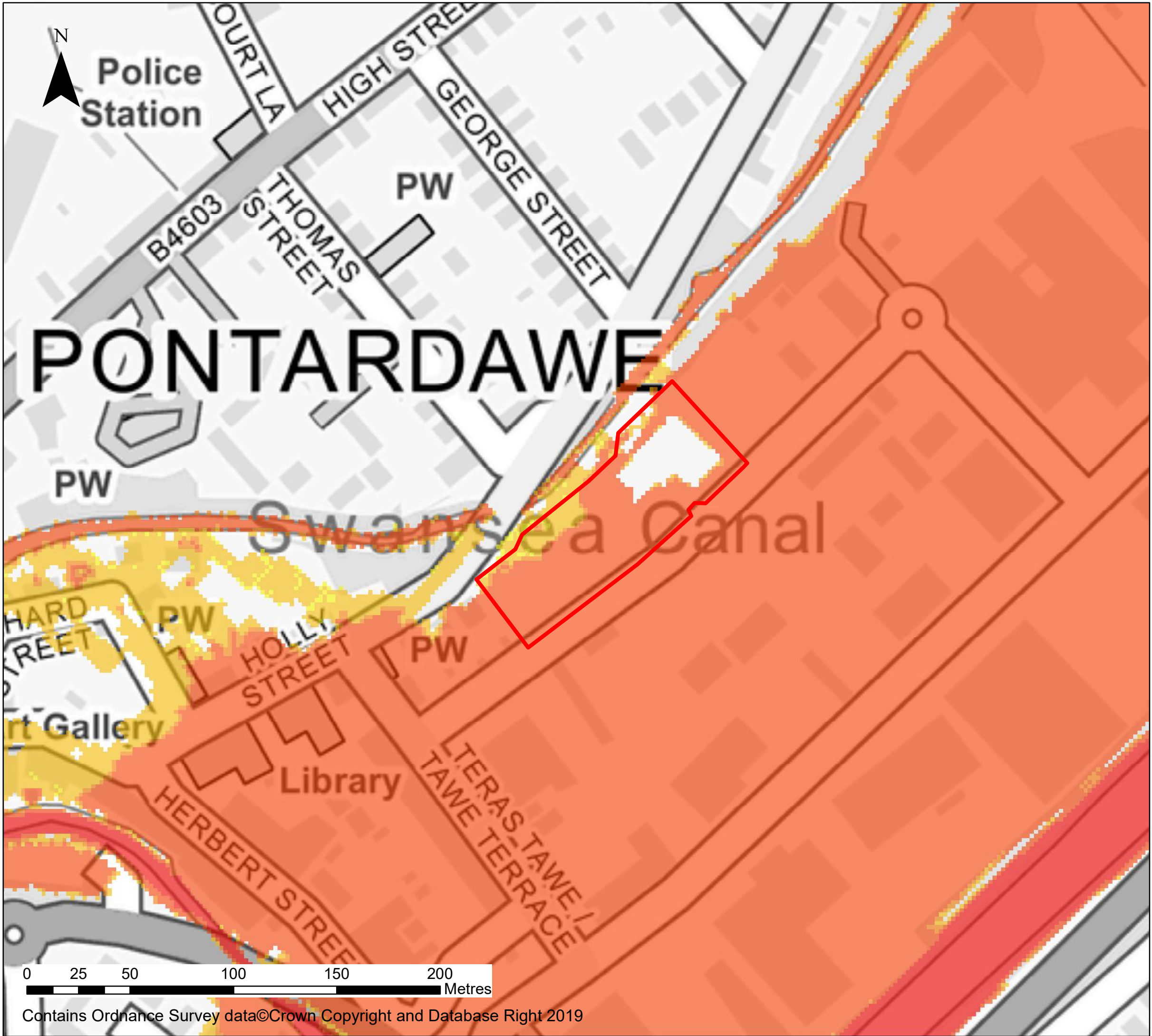
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0 25 50 100 150 200 Metres

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KEY

Proposed Development Outline

0.1% AEP

- 0.5
- 0.5 - 0.7
- 0.7 - 1
- 1 - 5
- >5



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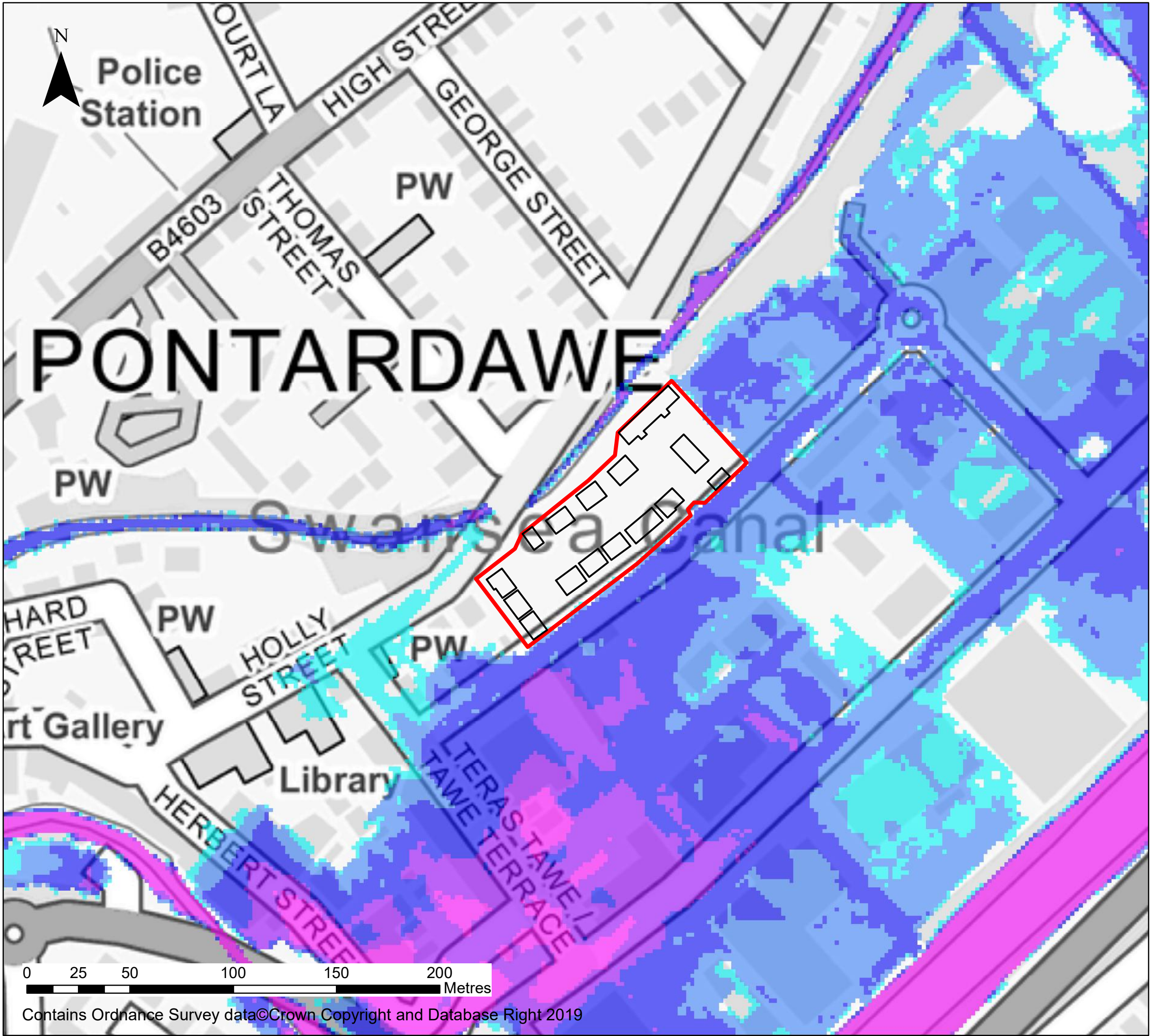
0.1% AEP - Hazard

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Appendix E: Post-developed model results

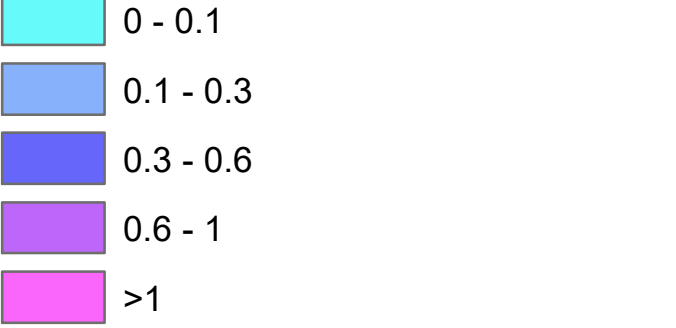


KEY
2d_zsh_HollySt_buildings_034_region

Proposed Development Outline

1% AEP plus CC

Maximum Depth (m)



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Post-development

1% AEP plus climate change
- Depth

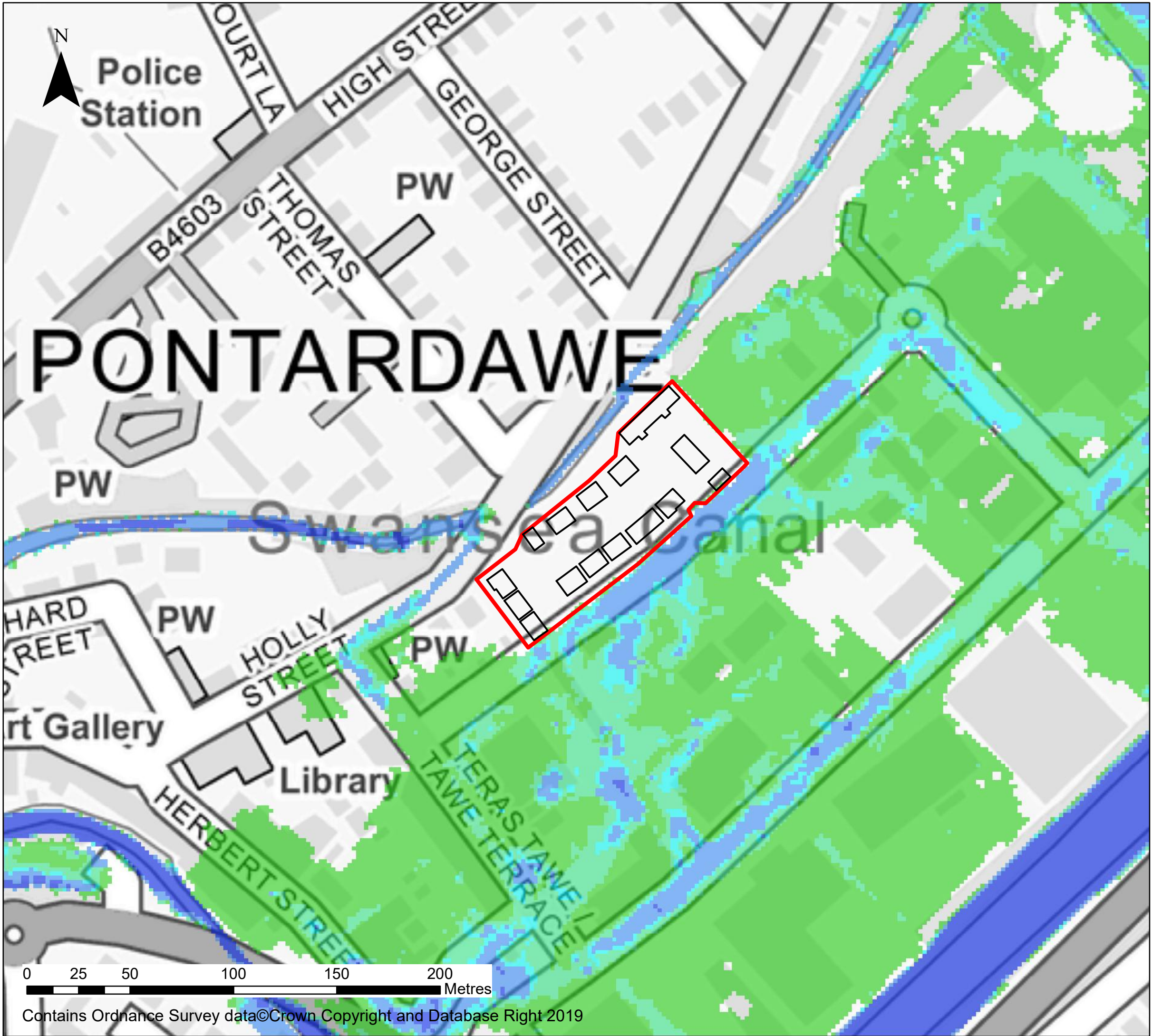
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0 25 50 100 150 200 Metres

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KEY
2d_zsh_HollySt_buildings_034_region

Proposed Development Outline

1% AEP plus CC

Velocity (m/s)

0 - 0.15

0.15 - 0.3

0.3 - 0.4

0.4 - 1

>1



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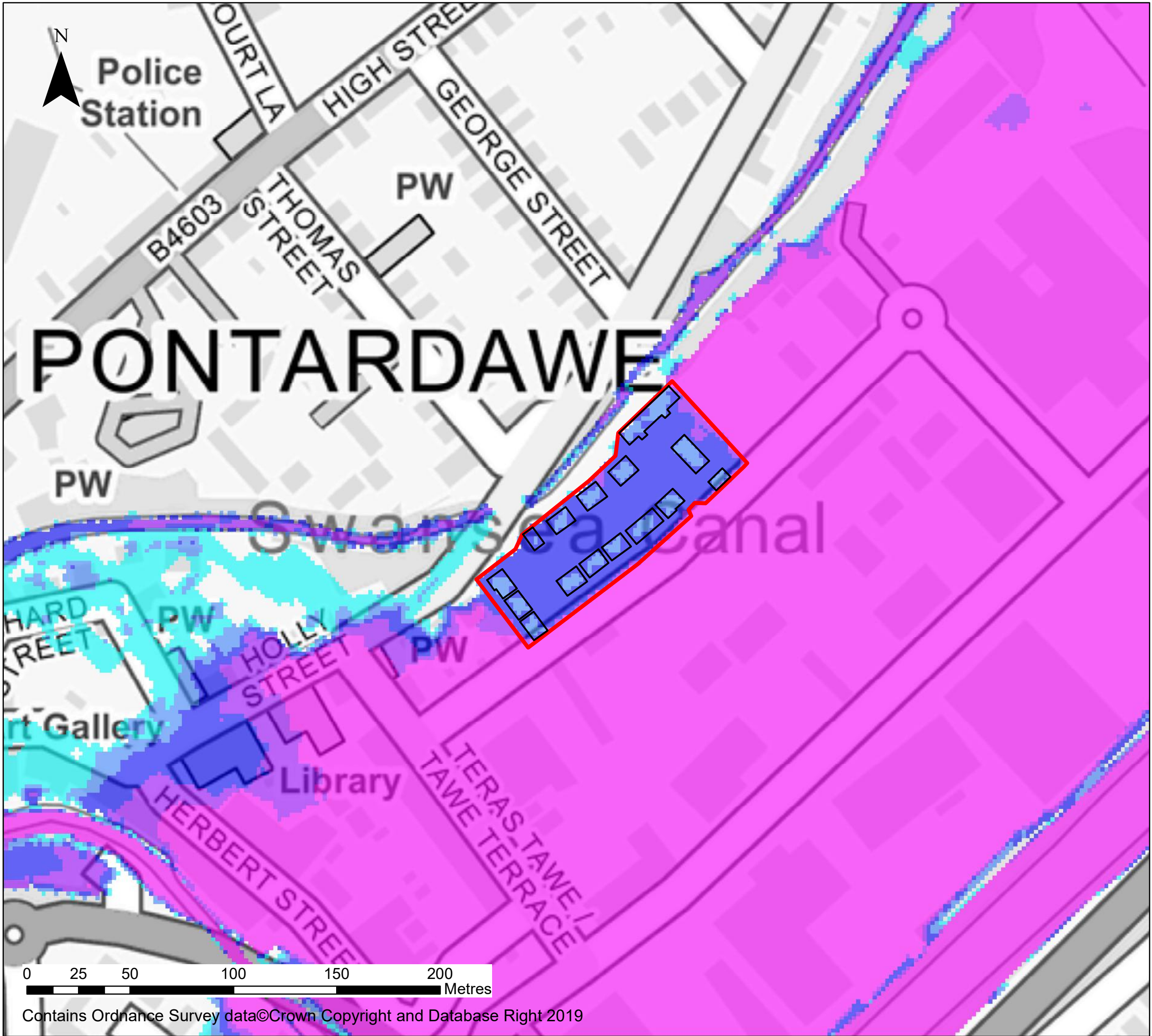
1% AEP plus climate change
- Velocity

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KEY
2d_zsh_HollySt_buildings_034_region

Proposed Development Outline

0.1% AEP

Maximum Depth (m)

- 0 - 0.1
- 0.1 - 0.3
- 0.3 - 0.6
- 0.6 - 1
- >1



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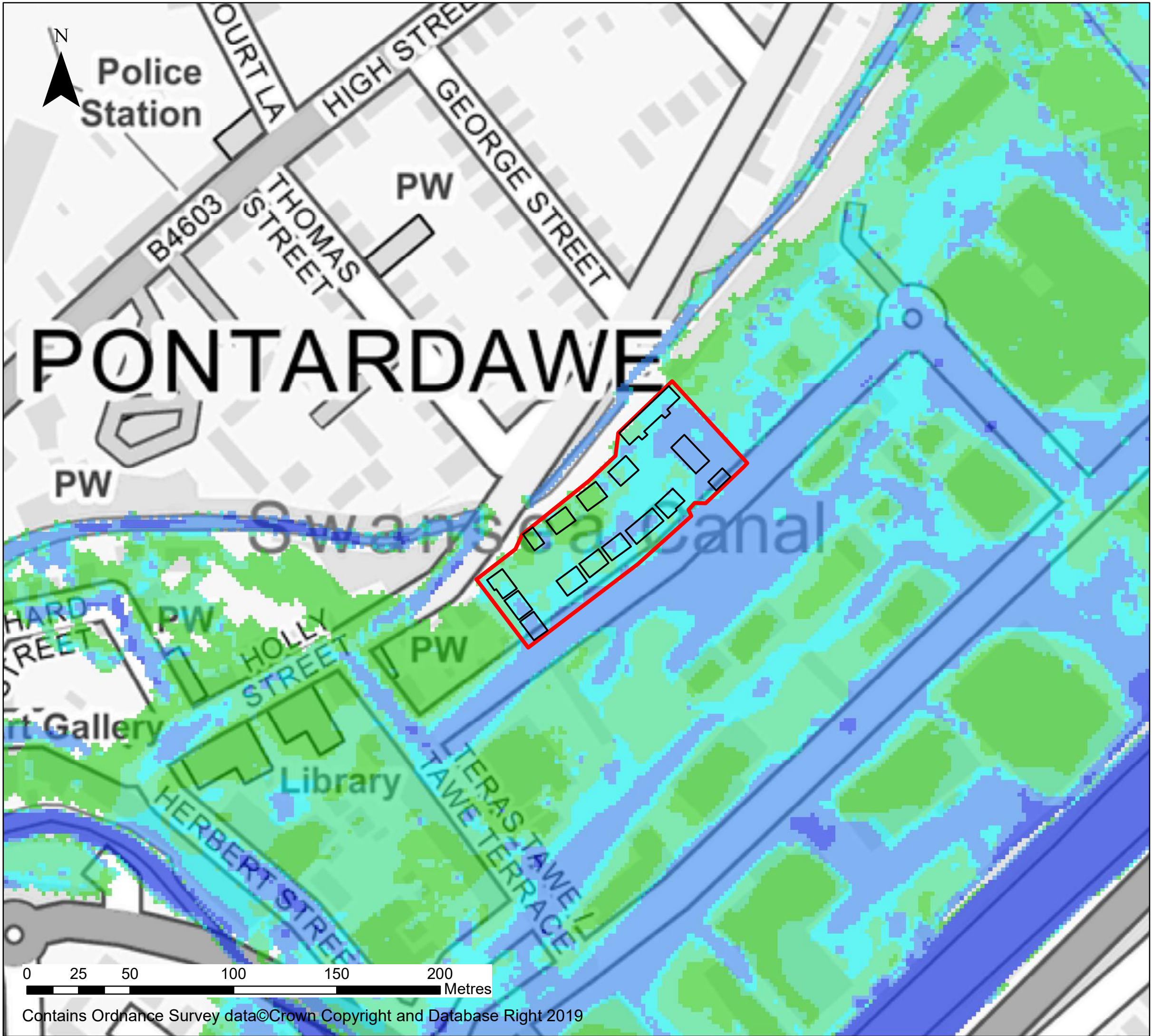
Post-development

0.1% AEP - Depth

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2d_zsh_HollySt_buildings_034_region

Proposed Development Outline

0.1% AEP

Velocity (m/s)

0 - 0.15

0.15 - 0.3

0.3 - 0.4

0.4 - 1

>1

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0.1% AEP - Velocity

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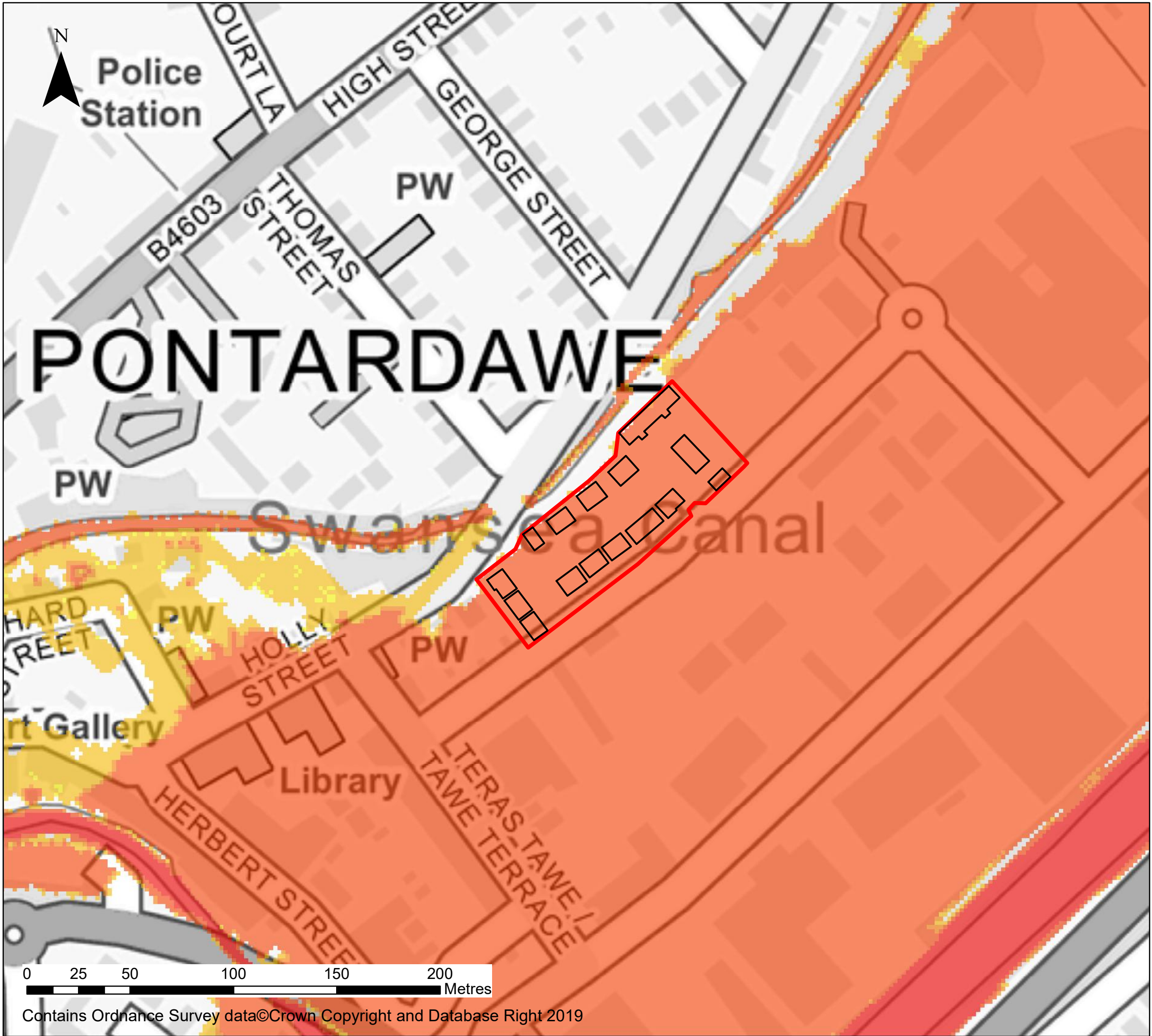
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KEY

2d_zsh_HollySt_buildings_034_region

Proposed Development Outline

0.1% AEP

0.5

0.5 - 0.7

0.7 - 1

1 - 5

>5

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0.1% AEP - Hazard

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