# WATERFORD NORTH QUAYS STRATEGIC FLOOD RISK ASSESSMENT

**DRAFT STRATEGIC FLOOD RISK ASSESSMENT | OCTOBER 2017**

**As part of the preparation of the Draft Planning Scheme for the Waterford North Quays Strategic Development Zone (S.I. No. 30 of 2016)**

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# Waterford North Quays

## Draft Strategic Flood Risk Assessment

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# 1. INTRODUCTION

This Flood Risk Assessment was prepared and informed by the Department of Environment, Housing and Local Government Guidelines for Planning Authorities (DEHLG & OPW, 2009) on 'The Planning System and Flood Risk Management' (and Technical Appendices) referred to hereafter as 'The Guidelines'. The Guidelines state that planning authorities are required to produce a flood risk assessment as an integral and leading element of a planning scheme. It sets out that development plan, local area plans and planning scheme as part of an SDZ designation must establish the fljood risk assessment as part of their strategic Environmental Assessment (SEA) requirements.

A Strategic Flood Risk Assessment (SFRA) is an area-wide assessment of the existing risks of flooding and the impact on those risks arising from proposed spatial planning decisions. A staged approach was adopted in the preparation of this flood risk assessment. Stage 1 identified that the area is at risk of flooding, and the principle sources of flooding identified are fluvial and tidal flooding. The Stage 2 Flood Risk Assessment confirmed the sources of flooding that affect the plan area. A Stage 3 Flood Risk Assessment was carried out to provide a quantitative appraisal of potential flood risk for the subject site.

The guidelines require the planning system at national, regional and local levels to:

(i) Avoid developments in areas at risk of flooding, particularly floodplains, unless there are proven wider sustainability grounds that justify appropriate development and where the flood risk can be reduced or managed to an acceptable level without increasing flood risk elsewhere.

(ii) Adopt a sequential approach to flood risk management when assessing the location for new development based on avoidance, reduction and mitigation of flood risk, and incorporate flood risk assessment into the process of making decisions on planning applications and planning appeals.

## 1.1 Strategic Development Zone, Waterford North Quays

The Government designated lands at the North Quays, Waterford City as a site for a Strategic Development Zone (SDZ) on 20th January 2016. Part IX of the Planning and Development Act 2000-2011 provides for the designation of a Strategic Development Zone (SDZ) to facilitate development which in the opinion of the Government is of economic or social importance to the State. Waterford City and County Council are specified as the Development Agency (S.I. No 30 of 2016) for the purpose of developing a planning scheme for the North Quays Strategic Development Zone.

The Government designation permits the establishment of an SDZ in accordance with the provisions of Part IX of the Planning and Development Act 2000 (as amended) for a mixed use development which may include commercial activities including, office, hotel, leisure and retail facilities, residential development and the provision of educational facilities, supporting transport infrastructure, emergency services and the provision of community facilities, including health and childcare services, as appropriate, as referred to in Part III of the First Schedule to the Act.

The SDZ has been designated taking into consideration existing planning policy to include:

- The National Spatial Strategy 2002-2020 which identifies Waterford as a Gateway;

- The South East 2010-2020 Regional Planning Guidelines which identify the North Quays as an area of key regional significance;
- The core strategy and objectives of the Waterford City Development Plan 2013-2019; and
- Wider Government policy to support balanced regional development.

Once a Planning Scheme comes into effect, any development within it will require planning permission from Waterford City and County Council. If development proposals are consistent with the Planning Scheme they will be granted permission. Proposals which are not consistent with the Planning Scheme will be refused permission. No party may appeal to An Bord Pleanála the decision of Waterford City and County Council on any application for permission in respect of a development within the area of a Planning Scheme.

## 1.2 Strategic Flood Risk Assessment and Strategic Environmental Assessment

The Planning System and Flood Risk Management Guidelines for Planning Authorities, (DEHLG & OPW, 2009) also sets out best-practice in terms of integrating the Strategic Flood Risk Assessment (SFRA) and Strategic Environmental Assessment (SEA).

In this regard, Section 3.10 of the Guidelines states that 'The SEA Process provides a good practice framework for scoping and considering a range of planning and environmental issues, including flooding in the plan making process' and that 'Flood risk assessments carried out in response to these Guidelines, should be integrated with the SEA process'.

The Guidelines further state that 'Where SEA and the environmental report is required, flood risk assessment should be undertaken as early as possible in the process so that the SEA is fully informed of the flood risks and impacts of the proposed zoning or development.

Accordingly, this SFRA for the Waterford North Quays SDZ has been prepared at the very outset of the plan-making process, as a working document to align with the initial scoping stage for the SEA. In this way, it is envisaged that the SFRA may be integrated into the parallel SEA Process.

## 1.3 Description of Study Area

The extents of the Waterford North Quays SDZ area are shown **Figure 1.1**. The North Quays are located on the North banks of the River Suir in Waterford City. The site was previously the city docks before these were relocated in the 1990's and the site has been relatively dormant since. The northern quays at present comprise an assembly of wharves consisting of disused open spaces and the Hennebique building on the site. The SDZ stretches from Rice Bridge 2km eastward to just before Abbey Church. It is bounded to the south by the River Suir and to the north by the Dock Road (R711) – a regional dual carriageway. The R711 connects Waterford City centre with the N29, located 4.7km to the northeast from the SDZ. The site is also traversed by the Rosslare to Waterford rail line in an east-west direction.

The North Quays SDZ character is influenced by its proximity to the River Suir. The River Suir rises in South Tipperary, flowing south east for 185km before discharging into the Atlantic Ocean at Waterford Harbour. The Suir Catchment is approximately

3,600km$^2$. Waterford City is on lower reaches of the Suir which exhibits a tidal influence at this point due to its proximity to the sea. The River Suir is normally referred to in the context of the "Three Sister" catchments (Barrow, Nore and Suir) which are contiguous and all three of which drain into Waterford Harbour.

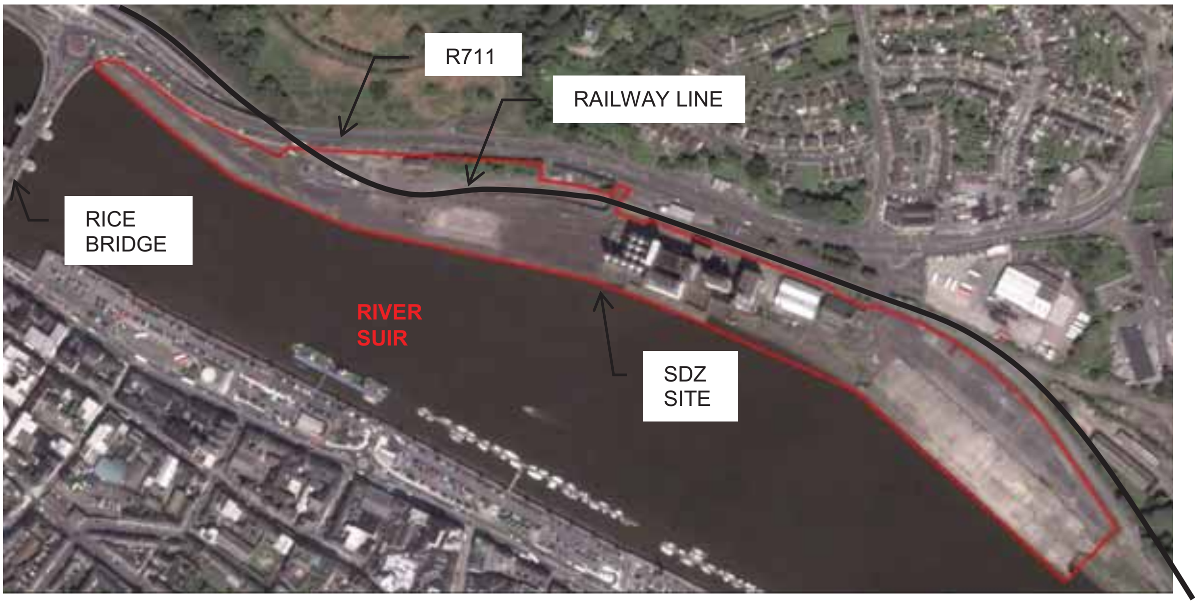



**Figure 1.1 North Quays SDZ Site (map underlay source: Google Maps)**

## 1.4 Waterford City Flood Alleviation Scheme

Waterford City has previously implemented a significant flood alleviation scheme. Historically Waterford City suffered recurring flooding with the River Suir and John's river experiencing out of bank events on multiple occasions in the latter half of the 20th Century. The flooding of the South Quays inundated the city's main thoroughfares and adjoining premises. The OPW and Waterford City Council commissioned consultants to undertake the Waterford City Flood Alleviation Scheme. The Scheme focused on containment of the watercourses within their channels. This was achieved through the construction of a series of flood defences in the form of reinforced concrete walls, glass walls, sheet piled walls, embankments, stormwater pumps, etc. The works were constructed in three separate civil works contracts and on completion is protecting the city from flooding from the rivers for events up to the 0.5% annual exceedance probability (1 in 200 years) in tidal areas and up to the 1% annual exceedance probability (1 in 100 years) in non tidal areas.

The flood defences are a maximum of 1.1 - 1.2m above ground levels to preserve river views. The design heights were increased from the modelled flood heights to accommodate the effects of climate change and uncertainty in flow estimation. A freeboard of 0.5m and 0.3m was implemented in tidal and non-tidal areas respectively. The design for Waterford South Quays flood defences features glass flood defences prominently. The implemented design height for the Waterford South Quays flood defence wall is 3.7mOD.

# 2. FLOOD RISK

## 2.1 Identification of Flood Risk

Flood risk is a combination of the likelihood of a flood event occurring and the potential consequences arising from that flood event and is then normally expressed in terms of the following relationship:

Flood risk = Likelihood of flooding x Consequences of flooding.

To fully assess flood risk an understanding of where the water comes from (i.e. the source), how and where it flows (i.e. the pathways) and the people and assets affected by it (i.e. the receptors) is required. Figure 2.1 below shows a source-pathway-receptor model reproduced from 'The Guidelines' (DEHLG-OPW, 2009).

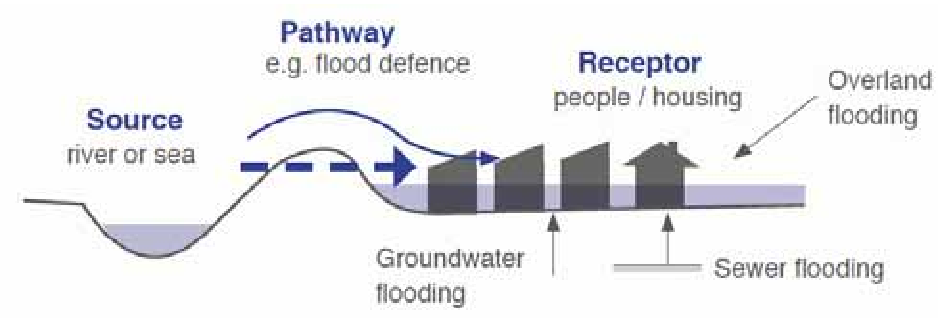



**Figure 2.1 Sources, Pathways and Receptors of Flooding**

The principal sources of flooding generally are rainfall or higher than normal sea levels. The principal pathways are rivers, drains, sewers, overland flow and river and coastal floodplains. The receptors can include people, their property and the environment. All three elements as well as the vulnerability and exposure of receptors must be examined to determine the potential consequences.

The Guidelines set out a staged approach to the assessment of flood risk with each stage carried out only as needed. The stages are listed below:

- *Stage I Flood Risk Identification* – to identify whether there may be any flooding or surface water management issues.
- *Stage II Initial Flood Risk Assessment* – to confirm sources of flooding that may affect an area or proposed development, to appraise the adequacy of existing information and to scope the extent of the risk of flooding which may involve preparing indicative flood zone maps.
- *Stage III Detailed Flood Risk Assessment* – to assess flood risk issues in sufficient detail and to provide a quantitative appraisal of potential flood risk to a proposed or existing development or land to be zoned, of its potential impact on flood risk elsewhere and of the effectiveness of any proposed mitigation measures.

## 2.2 Likelihood of Flooding

The Guidelines define the likelihood of flooding as the percentage probability of a flood of a given magnitude or severity occurring or being exceeded in any given year. It is generally expressed as a return period or annual exceedance probability (AEP). A 1% AEP flood indicates a flood event that will be equalled or exceeded on average once every hundred years and has a return period of 1 in 100 years. Annual Exceedance probability is the inverse of return period as shown Table 2.1 below.

**Table 2.1 Correlation Between Return Period and AEP**

| Return Period (years) | Annual Exceedance Probability (%) |
|---|---|
| 1 | 100 |
| 10 | 10 |
| 50 | 2 |
| 100 | 1 |
| 200 | 0.5 |
| 1000 | 0.1 |

## 2.3 Definition of Flood Zones

Flood zones are geographical areas within which the likelihood of flooding is in a particular range. These are split into three categories in The Guidelines:

**Flood Zone A**

Flood Zone A where the 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/tidal flooding);

**Flood Zone B**

Flood Zone B where the probability of flooding from rivers and the sea is moderate (between 0.1% or 1 in 1000 and 1% or 1 in 100 for river flooding and between 0.1% or 1 in 1000 or 0.5% or 1 in 200 for coastal/tidal flooding);

**Flood Zone C**

Flood Zone C where the probability of flooding from rivers and the sea is low (less than 0.1% or 1 in 1000 for both river and coastal/tidal flooding. Flood Zone C covers all plan areas which are not in zones A or B.

It is important to note that when determining flood zones the presence of flood protection structures should be ignored. This is because areas protected by flood defences still carry a residual risk from overtopping or breach of defences and the fact that there is no guarantee that the defences will be maintained in perpetuity.

## 2.4 Sequential Approach & Justification Test

The Guidelines outline the sequential approach that is to be applied to all levels of the planning process. This approach should also be used in the design and layout of a development and the broad philosophy is shown in Figure 2.2 below. In general, development in areas with a high risk of flooding should be avoided as per the sequential approach. However, this is not always possible as many town and city centres are within flood zones and are targeted for development.

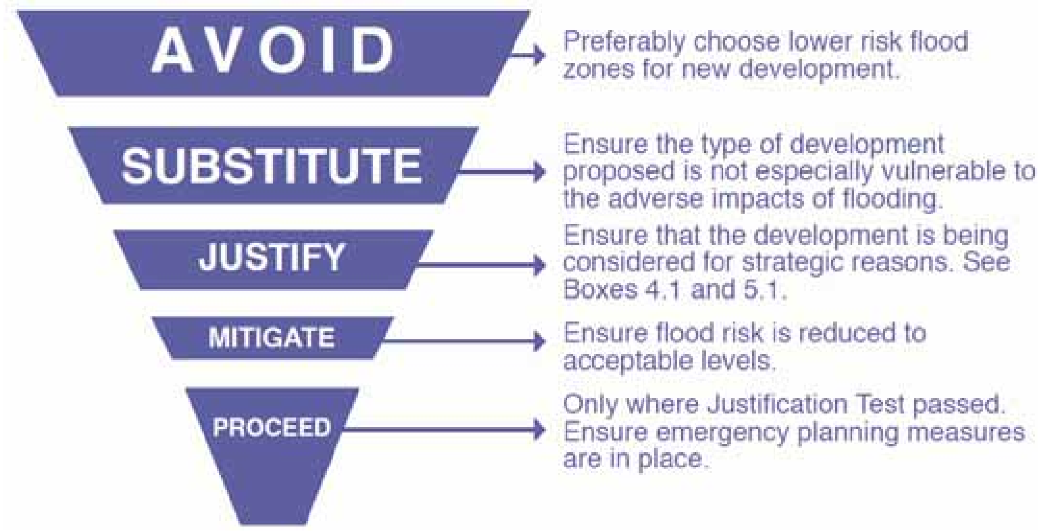



**Figure 2.2 Sequential Approach (Source: The Planning System and Flood Risk Management)**

The Justification Test has been designed to rigorously assess the appropriateness, or otherwise, of developments that are being considered in areas of moderate or high flood risk. The test comprises the following two processes.

- The first is the Plan-making Justification Test and is used at the plan preparation and adoption stage where it is intended to zone or otherwise designate land which is at moderate or high risk of flooding.
- The second is the Development Management Justification Test and is used at the planning application stage where it is intended to develop land at moderate or high risk of flooding for uses or development vulnerable to flooding that would generally be inappropriate for that land.

**Table 2.2 Matrix of Vulnerability Versus Flood Zone to Illustrate Appropriate Development that is Required to Meet the Justification Test (Source: The Planning System and Flood Risk Management)**

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

# 3. STAGE 1: FLOOD RISK IDENTIFICATION

## 3.1 General

This Stage 1 Flood Risk Identification includes a review of the existing information and the identification of any flooding or surface water management issues in the SDZ study area that may warrant further investigation.

## 3.2 Information Sources Consulted

The following information sources were consulted as part of the Stage 1 Flood Risk Identification:

**Table 3.1 Information Sources Consulted**

| Source | Data Gathered |
|---|---|
| OPW Preliminary Flood Risk Assessment (PFRA) maps | Fluvial, Pluvial, Coastal and Groundwater flooding examined; maps.opw.ie |
| Catchment Flood Risk Assessment and Management Study (CFRAM) | Waterford Fluvial & Tidal Flood Extent Mapping. OPW South-Eastern CFRAM Study |
| OPW National Flood Hazard Mapping | www.floodmaps.ie |
| Irish Coastal Protection Strategy Study | OPW Costal flood Maps |
| Geological Survey of Ireland (GSI) Maps | GSI Teagasc subsoils map consulted to identify if alluvial sediments are shown to be present at development site that may indicate the presence of a watercourse and floodplain. |
| Historical Maps | OSI 25” mapping assessed |
| News Reports | News reports published in newspapers or digital news websites. |

## 3.3 Primary Sources of Baseline Data

### (i) Preliminary Flood Risk Assessment

The PFRA is a national screening exercise, based on available and readily-derivable information, to identify areas where there may be a significant risk associated with flooding (referred to as Areas for Further Assessment, or AFA’s). As part of the PFRA study, maps of the country were produced showing the indicative fluvial, coastal, pluvial and groundwater flood extents.

The PFRA map at the SDZ location indicates that the site is located within fluvial 1%AEP with coastal flood 0.5%AEP extents. The PFRA mapping does not indicate any pluvial or groundwater flooding within or in the vicinity of the site.

The PFRA Maps for the area are reproduced in Appendix B.

### (ii) Catchment Flood Risk Assessment and Management Study

The Plan area is covered within the Waterford CFRAM study areas. The CFRAM programme led by the OPW, provides a detailed assessment of flooding in areas identified as AFA’s during the PFRA study. Catchment wide Flood Risk Management Plans were also developed as part of the programme.

The published Final CFRAM (02/08/2016) mapping indicates that the SDZ site has the potential to flood in 1% Fluvial AEP with 0.5% Tidal AEP flood events. The CFRAM mapping does not indicate any pluvial or groundwater flooding within or in the vicinity of the site.

The published CFRAM flood maps are reproduced in Appendix B.

**(iii) Irish Coastal Protection Strategy Study**

The Irish Coastal Protection Strategy Study (ICPSS) Phase 3, undertaken by the OPW, covers coastal flooding throughout Ireland. The aims of the ICPSS were to establish extreme coastal flood extents, produce coastal flood extent and flood depth maps and assess and quantify the hazard and potential risk associated with coastal erosion.

The ICPSS flood maps indicate that sections of the SDZ are within the 0.5% AEP coastal flood extent.

The published ICPSS flood maps are reproduced in Appendix B.

**(iv) OPW National Flood Hazard Mapping**

The OPW National Flood Hazard Mapping Web Site (www.floodmaps.ie) was examined to identify any recorded flood events within the vicinity of the SDZ site. Flood Events have been recorded on the south Quays however, no flood events are indicated on the northern quays.

The OPW Flood Hazard Mapping is reproduced in Appendix B.

**(v) Secondary Sources of Baseline data**

The following sources were also examined to identify areas that may be liable to flooding:

**Table 3.2 Secondary Sources of Baseline Data**

| Source | Data Gathered |
|---|---|
| **GSI Maps** | GSI Teagasc subsoils map shows the SDZ site is underlain by made ground. No evidence of Karst features have been identified within the vicinity of the site. Refer to Appendix B for GSI maps. |
| **Historical Maps** | No areas of the site have been identified as liable to flooding. Refer to Appendix B for Historical Maps. |
| **News Reports** | An article published on www.thejournal.ie on the 17th October 2012 entitled “Waterford train station is flooded… very flooded” describes how Waterford (Plunkett) train station which is in close proximity to Waterford North Quays SDZ was flooded following a period of heavy rain. Refer to Appendix B for News Reports. |

## 3.4 Conclusion of Stage 1 SFRA

In accordance with Stage 1 of the approach outlined in the Guidelines, the possible sources of flooding associated with this development have been identified. These are summarised in Table 3.3 (taken from Appendix A of the Guidelines).

**Table 3.3 Possible Sources of Flooding Associated with the SDZ Site**

| Source | Pathway | Receptor | Likelihood | Consequence | Risk |
|---|---|---|---|---|---|
| Tidal | Overland flow, out of bank | North Quays | High | High (large portion of site indicated to be affected) | High due to proximity to Tidal estuary and elevation of site |
| Fluvial | Overland flow, out of bank | North Quays | High | High (large portion of site indicated to be affected) | High due to proximity to watercourses and elevation of site |
| Surface Water | Overland flow | North Quays | Possible | Medium (no reported surface water flooding on site) | Low if appropriate drainage system is incorporated in development and maintained appropriately |
| Ground Water | Rising levels | North Quays | Low Possibility | High (due to tidal-groundwater interaction) | Low due to low permeability of soil cover |

The information provided in this section identifies that there is potentially elevated levels of Fluvial/tidal flood risk arising along the southern boundary of the SDZ; therefore, a Stage 2 SFRA is required to be undertaken.

# 4. STAGE 2 – INITIAL FLOOD RISK ASSESSMENT

## 4.1 General

A Stage 2 SFRA (initial flood risk assessment) was undertaken to:

- Confirm the sources of flooding that may affect the subject site;
- Appraise the adequacy of existing information as identified by the Stage 1 SFRA.

## 4.2 Sources of Flooding

**Flooding from Fluvial & Sea Level Rises / Coastal Flooding**

The proposed Waterford North Quays SDZ borders the River Suir for approximately 1km on its southern boundary. The section of the Suir is tidally dominated, as such; the most prevalent flood risk to the site is from extreme tidal inundation events or tidal events in combination with extreme fluvial events. Large portions of the site are indicated to be within flood zones A and B in the OPW South Eastern CFRAM Study, the OPW Preliminary flooding assessment and the Irish Coastal Protection Strategy study. The Waterford North Quays site is considered to require a stage 3 detailed flood risk assessment with respect to flooding derived from Fluvial and Tidal Flooding.

**Surface Water Flooding**

Surface water flooding occurs when the local drainage system cannot convey stormwater flows from extreme rainfall events. The rainwater does not drain away through the normal drainage pathways or infiltrate into the ground but instead ponds on or flows over the ground instead. Surface water flooding is unpredictable as it depends on a number of factors including ground levels, rainfall and the local drainage network. The drainage network for any development on the site will incorporate Sustainable Drainage Systems (SuDS) for the purpose for managing surface water in terms of both flow and quality. See section 7 for specific recommendations.

**Groundwater Flooding**

Ground water flooding is a result of upwelling in occurrences where the water table or confined aquifers rises above the ground surface. This tends to occur after long periods of sustained rainfall and/or very high tides. High volumes of rainfall and subsequent infiltration to ground will result in a rising of the water table. Groundwater flooding tends to occur in low-lying areas, where with additional groundwater flowing towards these areas, the water table can rise to the surface causing groundwater flooding. The sources consulted such as the CFRAM mapping and GSI records show no indication that the Waterford North Quays Site is subject to Groundwater derived flooding. The SDZ area is not considered to require a detailed flood risk assessment with respect to groundwater flooding.

**Pluvial Flood Risk**

Pluvial flooding results from heavy rainfall that exceeds ground infiltration capacity or more commonly in Ireland where the ground is already saturated from previous rainfall events. This causes ponding and flooding at localized depressions. Pluvial flooding is commonly a result of changes to the natural flow regime such as the implementation of hard surfacing and improper drainage design. The sources consulted such as the CFRAM mapping and PFRA mapping show no indication that the Waterford North Quays Site is subject to pluvial derived flooding. Pluvial flooding

will be considered in the design of drainage systems as part of planned developments. See section 7 for specific recommendations.

## 4.3 Conclusion of Stage 2 SFRA

The information provided in this section identifies that there is potentially elevated levels of coastal flood risk arising along the southern boundary of the SDZ; therefore, a Stage 3 SFRA is required.

# 5. STAGE 3 DETAILED FLOOD RISK ASSESSMENT

## 5.1 Stage 3 Summary

Stages 1 and 2 of the flood risk assessment of Waterford North Quays have indicated that the site is subject to flooding in medium and high probability exceedance events from fluvial and tidal sources. A one-dimensional (1D) model has been prepared to ascertain the effects of extreme tidal and combination tidal/fluvial events. A 1D model was utilised as it was determined that the Suir Estuary is dominated by tidal flows in the longitudinal flow direction.

The Model was developed with surveyed topographic and channel cross-sections, OPW Cross-sections and GSI / Marine Institute Infomar Sea bed survey of the Waterford Harbour Area, LiDAR data and a detailed hydrological assessment of the catchment (Appendix C). A medium range sea level rise scenario was adopted which is in keeping with the current OPW recommendations.

The findings from the hydraulic model (Appendix D) are that critical flooding and flood levels in the estuary and on the site are as a consequence of the tidal storm surge conditions. Fluvial flood flows at this location contribute very little to increasing the peak flood levels in the Suir. The minimum finished floor levels within the development lands should be set above 4.42mOD.

Although great care and modern widely-accepted methods have been used in the preparation and interpretation of the hydraulic model, there is inevitably a range of inherent uncertainties and assumptions made during the estimation of design flows and the construction of flood models. The inherent uncertainty necessitates a precautionary approach which has resulted in the inclusion of a freeboard of 0.5m as described below.

The following allowances are integrated into this minimum threshold:

- 200 year tide + 100 year fluvial Flood: 3.47mOD
- Freeboard: 0.5m (for uncertainty including local wave wake effects)
- Climate change: a 0.55m climate change allowance plus isostatic land tilt factor
- Minimum Finished Floor Level = 4.42mOD

Development of the site with relevant mitigation measures will greatly reduce flood risk from tidal inundation while having negligible impact on neighbouring developments upstream or downstream of the site. A scenario was modelled where the entire SDZ site flood volumes were assumed unavailable for flood conveyance and storage. Under this scenario the loss of 51,659$m^3$ of flood volume was seen to have a negligible effect in the context of the tidal extents of the Suir, Barrow, Nore and Waterford Harbour. No compensatory storage will be required. Recommendations determined from the SFRA are detailed in section 7.

# 6. JUSTIFICATION TEST FOR WATERFORD NORTH QUAYS

The flood risk assessment carried out for the purposes of the Planning Scheme for Waterford North Quays concluded that large sections of the site zoned for development are within lands at risk of flooding. In this context, the designation satisfies the Justification Test as outlined below:

## 6.1 The urban settlement is targeted for growth under the National Spatial Strategy, Regional Planning Guidelines, statutory plans, as defined above or under the planning guidelines or planning directives of the Planning and Development Act, 2000 (as amended).

The SDZ has been designated taking into consideration existing planning policy to include:

- The National Spatial Strategy 2002-2020 which identifies Waterford as a Gateway;
- The South East 2010-2020 Regional Planning Guidelines which identify the North Quays as an area of key regional significance; and
- The core strategy and objectives of the Waterford City Development Plan 2013-2019.

The National Spatial Strategy (NSS) identified Waterford City as an existing gateway. Gateways have a strategic location, and provide national scale social, economic infrastructure and support services. The NSS stipulates that existing gateways such as Waterford City must be supported and further development in gateways cities is to be encouraged. The NSS states that Waterford City, as the South-Eastern Gateway, should drive regional growth by providing a large and skilled population base, substantial capacity for additional residential and employment related functions and an improving transport network. The growth of Waterford City will be complemented by development in surrounding and adjacent towns; this provides a strong platform for balanced regional development.

The South-East Regional Authority adopted the Regional Planning Guidelines for the South-East Region 2010-2022 on 26th July 2010. The South East 2010-2020 Regional Planning Guidelines expand on the NSS identifying critical enabling priorities for Waterford City and the region. This includes the expansion of the commercial and civic centre of Waterford City through the redevelopment of the North Quays.

Waterford City Development Plan 2013-2019 supports the development of the North Quays SDZ which is zoned as part of a larger mixed use ‘opportunity site’. The opportunity site includes Plunkett Railway Station and lands to the North including Sion Hill House and the former Ard Rí hotel site. The Waterford North Quays - Urban Design Framework Plan prepared in 2008 set out a broad vision for this area comprising development concepts and urban design guidelines including infrastructure options to include a bridge crossing connecting the North Quays.

## 6.2 The zoning or designation of the lands for the particular use or development type is required to achieve the proper planning and sustainable development of the urban settlement and, in particular:

### I. To facilitate regeneration and/or expansion of the centre of the urban settlement.

The River Suir currently acts as the northern boundary to the Waterford City Urban core. The development of the North Quays SDZ will support an expansion of Waterford City northward. The SDZ area has the potential to become a major magnet for transport, employment, cultural and leisure uses of national importance. The site has been identified as an opportunity site in the Waterford City Development plan 2013-2019 (Policy POL 4.3.5) for which development is to be promoted. This is reflected in the SDZ planning scheme which provides the opportunity for a transformative development that can become a regeneration catalyst for the city and region.

### II. Comprise significant previously developed or under-utilised lands.

Yes, the North Quays comprise 8.23 hectares that has been effectively derelict since the relocation of Waterford Port to Bellview in the 1990s and as such comprises significant previously developed lands that are now under-utilised. Existing activity is now limited to occasional use as a dock for commercial and tourist ships. The subject site has no agricultural or amenity value. The site is easily accessible by road with the ability to incorporate rail access to the north and pedestrian access across the River Suir. The implementation of SDZ designation has been used on a number of sites nationally to effectively fast-track the development of lands with high economic and civic potential. Waterford North Quays has been identified at a regional and city level as an under-utilised site that is well suited for redevelopment.

### III. Is within or adjoining the core of an established or designated urban settlement?

Yes, Waterford North Quays comprises the land directly adjacent to the existing Waterford City centre. The distance between both quays is approximately 220 meters separated by the River Suir. The extent of the SDZ reflects a sequential approach to development and the need to ensure the effective consolidation of brown field sites and optimisation of public investment on infrastructure. This is reflected in the SDZ planning scheme which provides the opportunity for a renewal of the North Quays with proper expansion of the city core and the balanced future development of the city. The North Quays acts as a focus for this renewal.

The SDZ Planning Scheme includes proposals to further increase connectivity to the established city centre core to the south through the development of a sustainable transport bridge connecting the south to the SDZ across the River Suir. This supports recommendations of Waterford City Council's Planning Land Use and Transportation Study and the Waterford City Development Plan 2013-2019. The construction of such bridge will not only connect the SDZ site directly to the existing Waterford City urban core, but also greatly increase the connectivity between the city centre and the suburb of Ferrybank located further north of the SDZ site.

### IV. Will be essential in achieving compact and sustainable urban growth.

The development of Waterford North Quay SDZ site will facilitate compact and sustainable urban growth. The SDZ as outlined in the Waterford City

Development Plan 2013-2019 will be a mixed use development comprising both residential and commercial buildings. Other sites of this size are only available at the periphery of Waterford City, a considerable distance from the urban core. This is reflected in the SDZ planning scheme which provides the opportunity for the development of the North Quays to reinstate the primacy of the river by creating a compact city core centred on the River Suir.

**V. There are no sustainable alternative lands for the particular use or development type in areas of lower risk.**

The Waterford North Quays is the most appropriate site for the expansion of Waterford Citys urban core designated as such in the Waterford City Development Plan 2013-2019. The extent of the Waterford North Quays site reflects the need to ensure the effective consolidation of brownfield sites and optimisation of public investment on infrastructure. There are other “opportunity sites” on the south side of the Suir but these have an equal or greater percentage of their land area designated as flood zones A and B. The combination of large land availability, close proximity to the existing Waterford City urban core and the potential for providing for integrated transport infrastructure allows it to be both a self supporting vibrant destination by itself as well as a complimentative addition to the citys’ urban form.

## 6.3 SFRA must demonstrate that flood risk to the development can be adequately managed and the use or development of the lands will not cause unacceptable adverse impacts elsewhere.

Development on the site can be successfully managed through the increasing of floor levels above the modelled flood depths. The removal of the site as a tidal inundation area will have a negligible effect on the flood depths and will not have any perceivable effects on adjacent lands. Existing flood defence systems in Waterford city will require no alteration or improvement as a result of the development of Waterford North Quays. Refer to Appendix D for detailed modelling report.

## 6.4 Justification Test Conclusions

Waterford North Quays SDZ site has been determined to have satisfied all requirements of the justification test. Section 7 details the recommendations that are to be considered for any potential development on the SDZ site.

# 7. SFRA RECOMMENDATIONS

## 7.1 Site Specific Flood Risk Assessment

There will be a requirement for a site specific flood risk assessment for planning applications for the SDZ. These flood risk assessments shall consider the impact of the proposed development in accordance with the "The Planning System and Flood Risk Management" (DEHLG & OPW, 2009). No development shall be allowed that contradicts the recommendations of this SFRA or increases the flood risk to existing developments within the SDZ. As part of the applicants' site specific flood risk assessment a justification test will not be required as this has been done as part of the Waterford North Quays SFRA.

## 7.2 Minimum Floor Levels

The main approach to reduce flood risk at Waterford North Quays should involve raising the ground floor levels above modelled flood levels. The minimum finished floor level for all residential developments, commercial premises and entrances to underground spaces within the SDZ shall be above 4.42mOD, this includes an allowance for 0.5m sea level rise (mid range forecast for climate change as defined by the OPW) and a 0.5m freeboard accounting for uncertainty including local wave wake effects.

In limited circumstances where raising floor levels cannot be achieved, development will be restricted to "water-compatible developments" as described in the OPW's "The planning System and Flood Risk Management-Guidelines for Planning Authorities" (Table 7.1 lists potential water-compatible developments). If this is the case, then these would be required to be a flood-resistant construction using water-resistant materials. Basements shall be allowed to have a floor level below 4.42mOD but shall only be utilised for heavy goods vehicle (HGV) access/deliveries, vehicle parking and storage. Basement construction should provide impermeable solutions with possible pumping for seepage.

A sustainable transport bridge is proposed in the planning scheme connecting the Waterford North Quays SDZ to the south quays. The deck level at the northern abutment of any bridge connecting to the north quays shall be above 4.42mOD. A n application for consent shall be made under Section 50 of the Arterial Drainage Act, 1945 & EU (Assessment and Management of Flood Risks) Regulations SI 122 of 2010.

As part of the planning scheme it is proposed to move the Waterford (Plunkett) train station from its present isolated location west of Rice bridge into the North Quays. The relocated train station including the lobby, ticket hall and platforms may have a floor level below 4.42mOD under the condition that the train station is protected to 4.42mOD. Basement construction should provide impermeable solutions with possible pumping for seepage. All access points (which are considered prone to flooding) to the station shall be above 4.42mOD. Raising floor levels shall be the primary approach to reduce flood risk throughout the site. However the implementation of hard flood defences (walls, embankments etc.) should be used as a supplementary defence method where required and considered appropriate, to protect the railway line and train station.

**Table 7.1 OPW Defined Water-Compatible Developments**

| | Land uses and types of development which include |
|---|---|
| **Water-compatible developments** | Flood control infrastructure; |
| | Docks, marinas and wharves; |
| | Navigation facilities; |
| | Ship building, repairing and dismantling, dockside fish processing and refrigeration and compatible activities requiring a waterside location; |
| | Water-based recreation and tourism (excluding sleeping accommodation); |
| | Lifeguard and coastguard stations; |
| | Amenity open space, outdoor sports and recreation and essential facilities such as changing rooms; |
| | Essential ancillary sleeping or residential accommodation for staff required by uses in this category (subject to a specific warning and evacuation plan). |

## 7.3 Drainage

The Waterford North Quays site is categorised as Brownfield, (i.e. previously reclaimed and developed in the past). The site currently drains to the River Suir directly. The surface water drainage network draining land north of the site conveys water through the SDZ Site. All existing connections from north of the site will be maintained and continue to outfall directly to the Suir. No additional connections to the existing surface water drainage system shall be made.

New surface water drainage networks will be required as part of developments within designated SDZ. Sustainable Drainage Systems (SuDS) shall be implemented to treat surface water runoff prior to being discharged to the River Suir and manage surface water/pluvial flood risk within the SDZ. These networks should be designed in accordance with Ciria C753 'The SuDS Manual' and the Greater Dublin Strategic Drainage Strategy (GDSDS).

A SuDS Management Train is defined in Ciria 753 "The SuDS Manual" as "the sequence of drainage components that collect, convey, store and treat runoff as it drains through the site". A SuDS Management Train should be incorporated during the design stage whereby surface water should be managed locally in small sub-catchments rather than being conveyed to and managed in large systems further down the catchment. Use of a Management Train should for example, eliminate the requirement for conventional petrol interceptors.

The following SuDS components shall be considered as part of all proposed development within the SDZ:

- **Green roofs:** Green Roofs comprise a multi-layered system which covers the roof of a building with vegetation and landscaping over a drainage layer. They are designed to intercept and retain precipitation which reduces the volume and rate of surface water runoff. Green roofs can be used on a variety of roof types and sizes, although larger roof areas are typically more cost effective. They are particularly suited to flat / gently sloping roofs on commercial buildings, sports centres, schools, apartment blocks and other similar buildings.
- **Bioretention Areas / Modified Planters:** Bioretention areas are stormwater controls that collect and treat stormwater runoff. The runoff is treated using soils and vegetation in shallow landscaped basins to remove pollutants.

Treated runoff can then be conveyed further through the drainage network or allowed infiltrate into the subsoil or subgrade. Part of the runoff volume will be removed by evaporation and plant transpiration.

- **Rainwater harvesting:** Rainwater harvesting involves collection of rainwater from roofs and hard surfaces, similar in principle to Water Butts but generally on a much larger scale. Collected water is typically used for non-potable purposes such as irrigation, flushing toilets and washing machines. The size of the harvesting tank depends on catchment area, seasonal rainfall pattern, demand pattern and retention time. Stormwater attenuation can also be provided by additional storage capacity in the tank.
- **Permeable surfacing:** Permeable pavements provide a pavement suitable for pedestrian and/or vehicular traffic, while allowing rainwater infiltrate through the surface and into the underlying layers where it is subsequently infiltrates to the ground and/or is collected and conveyed to the drainage network. Permeable pavements are most suitable for areas with light traffic loads and volume. The pavement generally caters for rainwater which lands directly on its surface but in certain cases, can accept runoff from other impermeable areas.
- **Swales:** These are broad, shallow, vegetated drainage channels in which can be used to convey or store surface water. Swales are generally suited for small catchments with impermeable areas. They are generally good for removal of pollutants. Swales can be designed for infiltration to subsoil or detention and conveyance to another stage in the management train. Conveyance can be in the open channel or in a perforated pipe within a filter bed below the base of the channel.

## 7.4 Flood Resilient Design Implementation

In relation to basements and ground level access protection from pluvial flooding, the following Flood Resilience and Adaptation Measures are recommended:

- Doorway and access threshold levels are an important factor in determining the susceptibility of domestic and commercial properties to pluvial flooding. Doorway accesses to public and commercial premises are often at ground level to facilitate access. Shallow ramping up to property entrances may be sufficient to keep pluvial floodwater out of the building. For commercial premises where low floor level access is required and where ramping up to the floor level is impractical, demountable flood barriers shall be utilised.
- Particular care should be taken where there are street level accesses to below-ground infrastructure such as underground parking or the proposed relocated Waterford train station – in such circumstances, rapid inundation could pose a threat to life as well as potentially causing major disruption and damage. Access protection shall be implemented for all access ways into underground or below ground infrastructure. Shallow ramping should be considered to be the primary flood defence measure for pluvial flooding. Where this is not practical, demountable flood barriers shall be utilised.

# 8. CONCLUDING STATEMENT

This SFRA has considered the local hydrological conditions pertaining to Waterford North Quays SDZ and found that the site is subject to flooding for 1% and 0.1% AEP events. The proposed planning scheme satisfies the requirements of the Justification Test for development plans (as described in the OPW's "The Planning System and Flood Risk Management Guidelines for Planning Authorities") and is therefore deemed appropriate for the site. The findings of this SFRA indicate that flood risk to the site can be managed without increasing flood risk elsewhere. All planning applications for proposed development within the SDZ area should include a site-specific Flood Risk Assessment (FRA).

# APPENDIX A
*Glossary of terms*

RODROUGHAN & O'DONOVAN

Comhairle Cathrach
& Contae Phort Láirge
Waterford City
& County Council

# GLOSSARY OF TERMS

**Catchment:** The area that is drained by a river or artificial drainage system.

**Catchment Flood Risk Assessment and Management Studies (CFRAMS):** A catchment-based study involving an assessment of the risk of flooding in a catchment and the development of a strategy for managing that risk in order to reduce adverse effects on people, property and the environment. CFRAMS precede the preparation of Flood Risk Management Plans (see entry for FRMP).

**Climate change:** Long-term variations in global temperature and weather patterns, which occur both naturally and as a result of human activity, primarily through greenhouse gas emissions.

**Core of an urban settlement:** The core area of a city, town or village which acts as a centre for a broad range of employment, retail, community, residential and transport functions.

**Detailed flood risk assessment:** A methodology to assess flood risk issues in sufficient detail and to provide a quantitative appraisal of flood hazard and potential risk to an existing or proposed development, of its potential impact on flood elsewhere and of the effectiveness of any proposed measures.

**Estuarial (or tidal) flooding:** Flooding from an estuary, where water level may be influenced by both river flows and tidal conditions, with the latter usually being dominant.

**Flooding (or inundation):** Flooding is the overflowing of water onto land that is normally dry. It may be caused by overtopping or breach of banks or defences, inadequate or slow drainage of rainfall, underlying groundwater levels or blocked drains and sewers. It presents a risk only when people, human assets and ecosystems are present in the areas that flood.

**Flood Relief Schemes (FRS):** A scheme designed to reduce the risk of flooding at a specific location.

**Flood Defence:** A man-made structure (e.g. embankment, bund, sluice gate, reservoir or barrier) designed to prevent flooding of areas adjacent to the defence.

**Flood Risk Assessment (FRA):** FRA can be undertaken at any scale from the national down to the individual site and comprises 3 stages: Flood risk identification, initial flood risk assessment and detailed flood risk assessment.

**Flood Risk Identification:** A desk- based study to identify whether there may be any flooding or surface water management issues related to a plan area or proposed development site that may warrant further investigation.

**Flood Hazard:** The features of flooding which have harmful impacts on people, property or the environment (such as the depth of water, speed of flow, rate of onset, duration, water quality, etc.).

**Floodplain:** A flood plain is any low-lying area of land next to a river or stream, which is susceptible to partial or complete inundation by water during a flood event.

**Flood Risk:** An expression of the combination of the flood probability, or likelihood and the magnitude of the potential consequences of the flood event.

**Flood Storage:** The temporary storage of excess run-off, or river flow in ponds, basins, reservoirs or on the flood plain.

**Flood Zones:** A geographic area for which the probability of flooding from rivers, estuaries or the sea is within a particular range.

**Fluvial flooding:** Flooding from a river or other watercourse.

**Groundwater flooding:** Flooding caused by groundwater escaping from the ground when the water table rises to or above ground level.

**Initial flood risk assessment:** A qualitative or semi-quantitative study to confirm sources of flooding that may affect a plan area or proposed development site, to appraise the adequacy of existing information, to provide a qualitative appraisal of the risk of flooding to development, including the scope of possible mitigation measures, and the potential impact of development on flooding elsewhere, and to determine the need for further detailed assessment.

**Freeboard:** Factor of safety applied for water surfaces. Defines the distance between normal water level and the top of a structure, such as a dam, that impounds or restrains water.

**Justification Test:** An assessment of whether a development proposal within an area at risk of flooding meets specific criteria for proper planning and sustainable development and demonstrates that it will not be subject to unacceptable risk nor increase flood risk elsewhere. The justification test should be applied only where development is within flood risk areas that would be defined as inappropriate under the screening test of the sequential risk-based approach adopted by this guidance.

**Likelihood (probability) of flooding:** A general concept relating to the chance of an event occurring. Likelihood is generally expressed as a probability or a frequency of a flood of a given magnitude or severity occurring or being exceeded in any given year. It is based on the average frequency estimated, measured or extrapolated from records over a large number of years and is usually expressed as the chance of a particular flood level being exceeded in any one year. For example, a 1-in-100 or 1% flood is that which would, on average, be expected to occur once in 100 years, though it could happen at any time.

**Ordnance Datum (or OD) Malin:** is a vertical datum used by an ordnance survey as the basis for deriving altitudes on maps. A spot height may be expressed as AOD for “above ordnance datum”. Usually mean sea level (MSL) is used for the datum. In the Republic of Ireland, OD for the Ordnance Survey of Ireland is Malin Ordnance Datum: the MSL at Portmoor Pier, Malin Head, County Donegal, between 1960 and 1969. Prior to 1970, Poolbeg Ordnance Datum was used: the low water of spring tide at Poolbeg lighthouse, Dublin, on 8 April 1837. Poolbeg OD was about 2.7 metres lower than Malin OD.

**Management Train/Treatment Train:** the sequence of drainage components that collect, convey, store and treat runoff as it drains through the site.

**Mitigation:** The term is used to describe an action that helps to lessen the impacts of a process or development on the receiving environment. It is used most often in association with measures that would seek to reduce negative impacts of a process or development.

**Pathways:** These provide the connection between a particular source (e.g. high river or tide level) and the receptor that may be harmed (e.g. property). In flood risk management,

pathways are often ‘blocked’ by barriers, such as flood defence structures, or otherwise modified to reduce the incidence of flooding.

**Pluvial flooding:** Usually associated with convective summer thunderstorms or high intensity rainfall cells within longer duration events, pluvial flooding is a result of rainfall-generated overland flows which arise before run-off enters any watercourse or sewer. The intensity of rainfall can be such that the run-off totally overwhelms surface water and underground drainage systems.

**Regional Planning Guidelines (RPG):** These provide the regional context and priorities for applying national planning strategy to each NUTS III region and encourage greater co-ordination of planning policies at the city/county level. RPGs are an important part of the flood policy hierarchy as they can assist in co-ordinating flood risk management policies at the regional level.

**Resilience:** Sometimes known as “wet-proofing”, resilience relates to how a building is constructed in such a way that, although flood water may enter the building, its impact is minimised, structural integrity is maintained, and repair, drying and cleaning and subsequent reoccupation are facilitated.

**Receptors:** Things that may be harmed by flooding (e.g. people, houses, buildings or the environment).

**Residual risk:** The risk which remains after all risk avoidance, substitution and mitigation measures have been implemented, on the basis that such measures can only reduce risk, not eliminate it.

**Sequential Approach:** The sequential approach is a risk-based method to guide development away from areas that have been identified through a flood risk assessment as being at risk from flooding. Sequential approaches are already established and working effectively in the plan-making and development management processes.

**Sustainable Drainage System (SuDS):** Drainage systems that are considered to be environmentally beneficial, causing minimal or no long-term detrimental impact.

**Site-specific Flood Risk Assessment:** An examination of the risks from all sources of flooding of the risks to and potentially arising from development on a specific site, including an examination of the effectiveness and impacts of any control or mitigation measures to be incorporated in that development.

**Source:** Refers to a source of hazard (e.g. the sea, heavy rainfall).

**Strategic Flood Risk Assessment:** The assessment of flood risk on a wide geographical area against which to assess development proposed in an area (Region, County, Town).

**Vulnerability:** The resilience of a particular group of people or types of property or habitats, ecosystems or species to flood risk, and their ability to respond to a hazardous condition and the damage or degree of impact they are likely to suffer in the event of a flood. For example, elderly people may be more likely to suffer injury, and be less able to evacuate, in the event of a rapid flood than younger people.

***Source:*** *The definitions above are sourced from the DoEHLG Guidelines for Planning Authorities on ‘The Planning System and Flood Risk Management, 2009’ and Ciria 753 “the SuDS Manual”.*

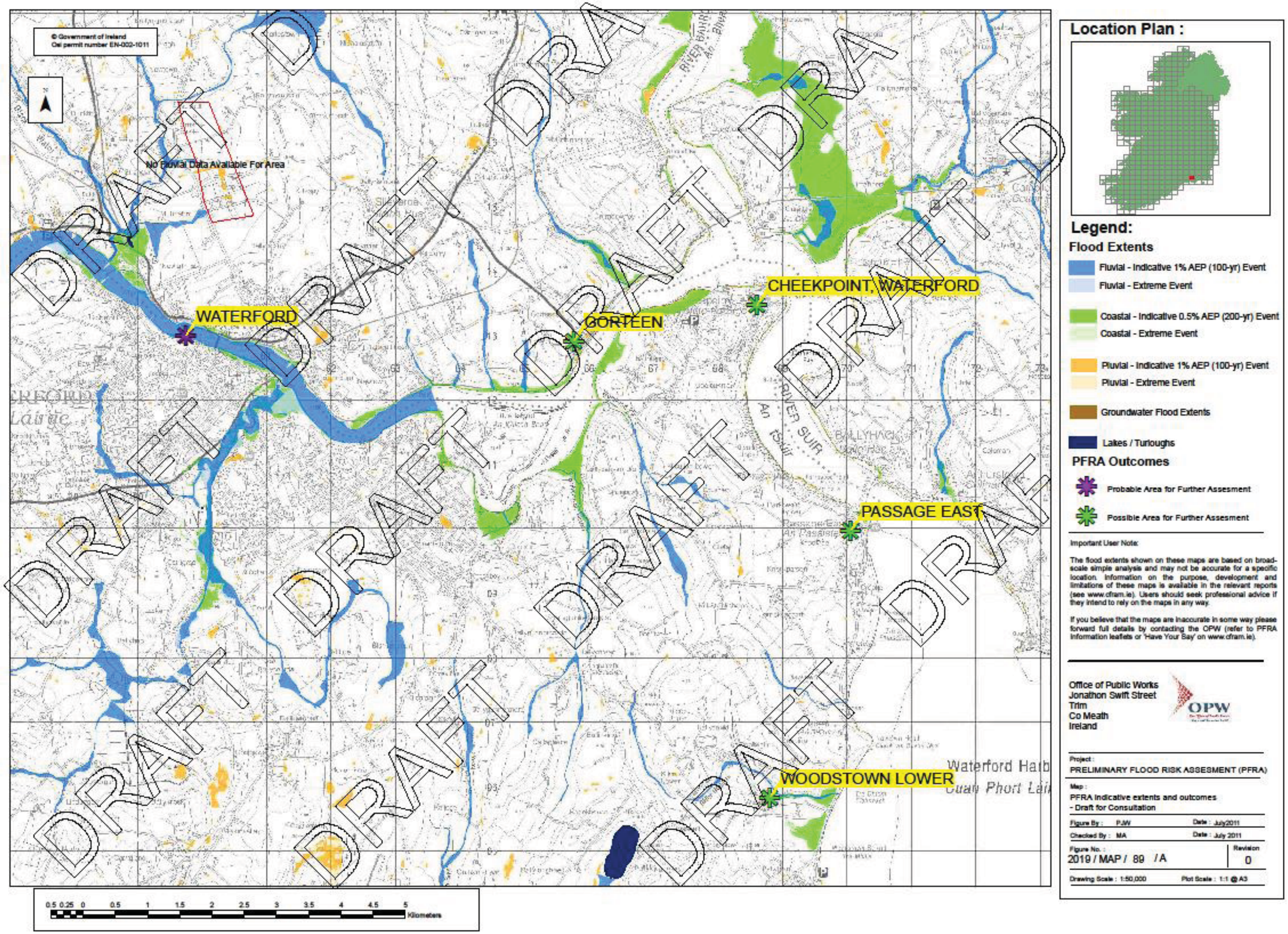
**APPENDIX B**

*Indicative flood sources*

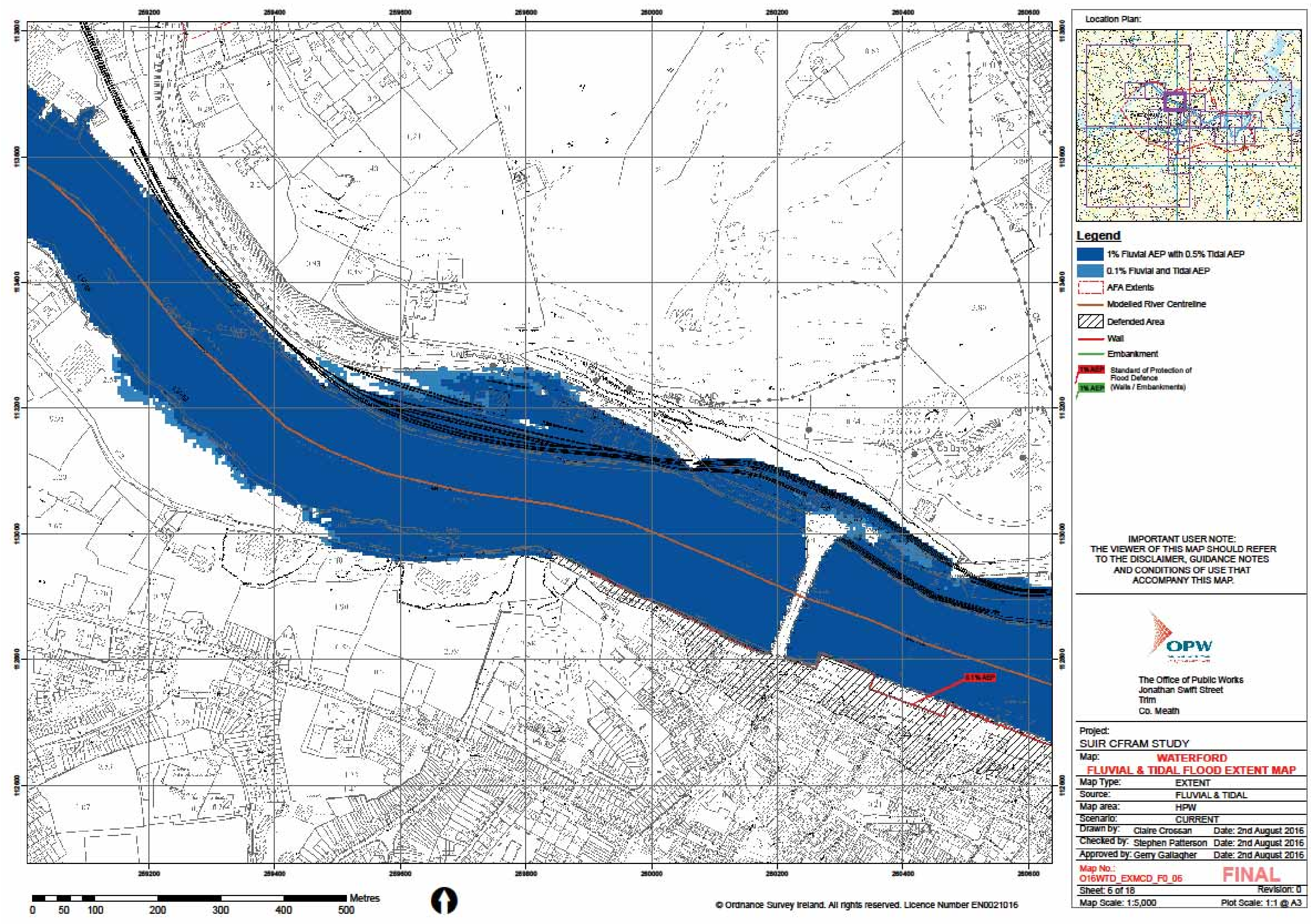
ROD ROUGHAN & O'DONOVAN

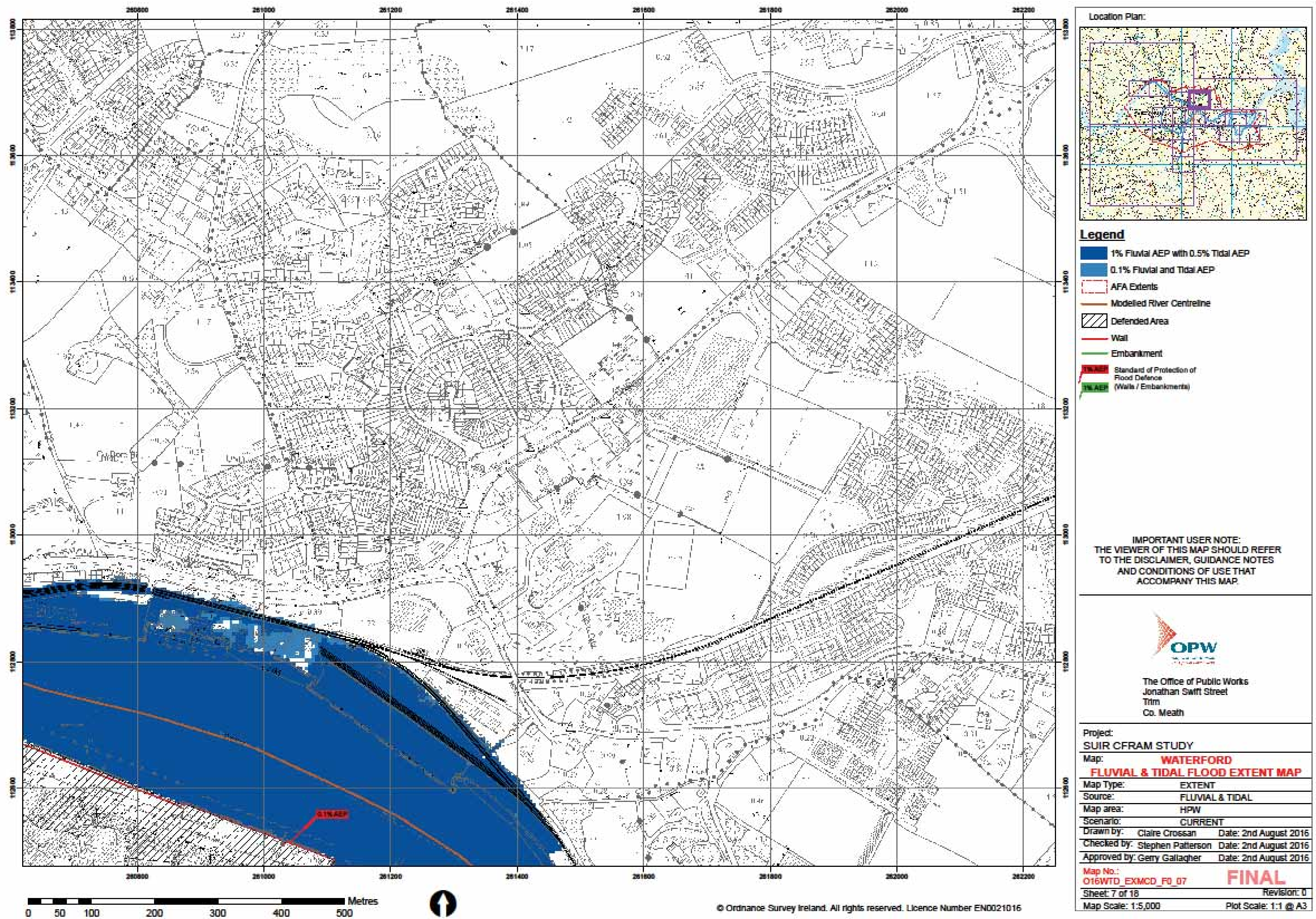
Comhairle Cathrach & Contae Phort Láirge
Waterford City & County Council

# Preliminary Flood Risk Assessment



# Catchment Flood Risk Assessment and Management Study

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261000
261200
261400
261600
261800
262000
262200
Metres
0
50
100
200
300
400
500
0.1% AEP
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Location Plan:
Legend
1% Fluvial AEP with 0.5% Tidal AEP
0.1% Fluvial and Tidal AEP
AFA Extents
Modelled River Centreline
Defended Area
Wall
Embankment
Standard of Protection of Flood Defence (Walls / Embankments)
1% AEP
IMPORTANT USER NOTE:
THE VIEWER OF THIS MAP SHOULD REFER
TO THE DISCLAIMER, GUIDANCE NOTES
AND CONDITIONS OF USE THAT
ACCOMPANY THIS MAP.
OPW
The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath
Project:
SUIR CFRAM STUDY
Map:
WATERFORD
FLUVIAL & TIDAL FLOOD EXTENT MAP
Map Type: EXTENT
Source: FLUVIAL & TIDAL
Map area: HPW
Scenario: CURRENT
Drawn by: Claire Crossan Date: 2nd August 2016
Checked by: Stephen Patterson Date: 2nd August 2016
Approved by: Gerry Gallagher Date: 2nd August 2016
Map No.:
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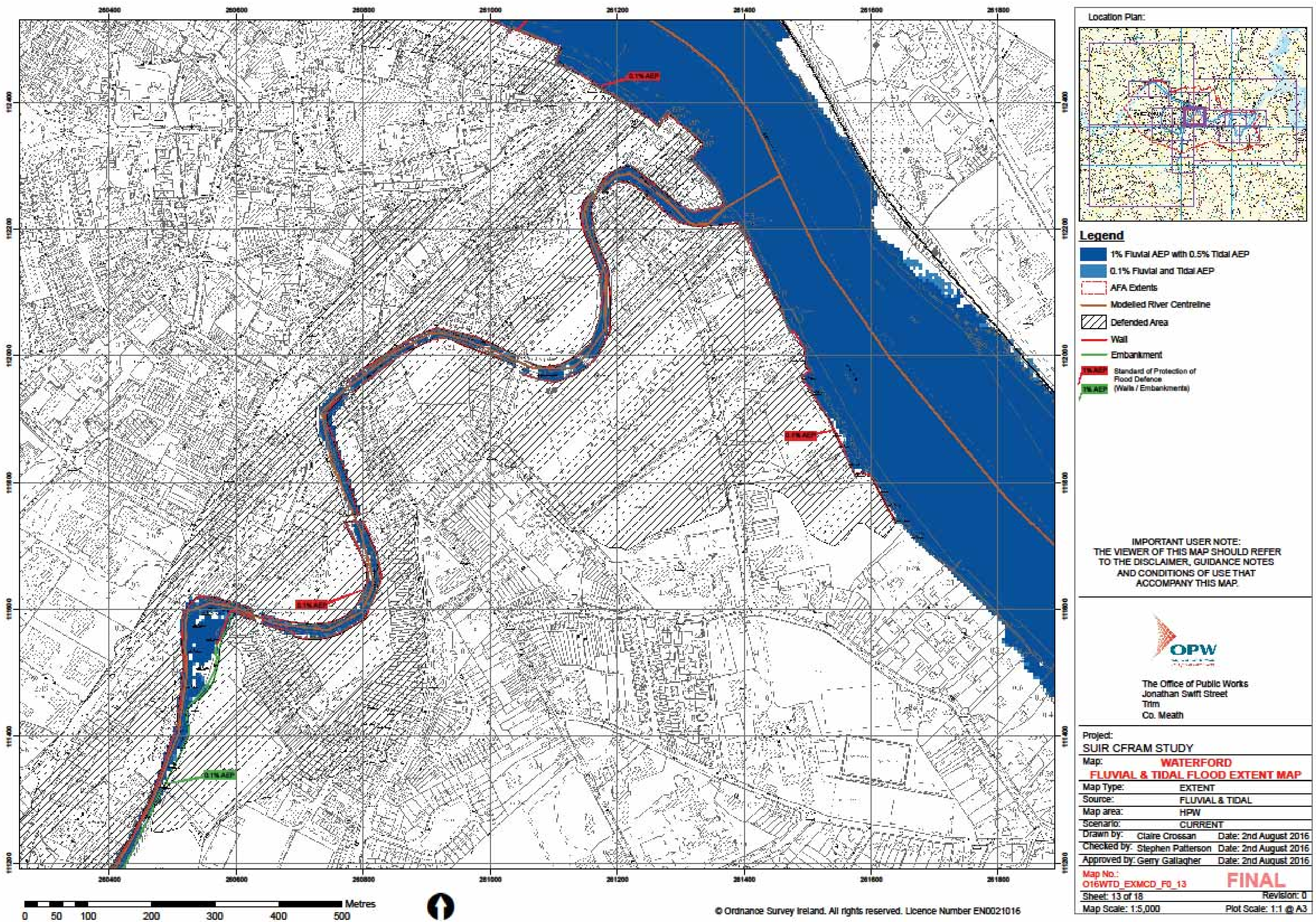
FINAL
Sheet: 7 of 18
Revision: 0
Map Scale: 1:5,000
Plot Scale: 1:1 @ A3


Location Plan:
Legend
1% Fluvial AEP with 0.5% Tidal AEP
0.1% Fluvial and Tidal AEP
AFA Extents
Modelled River Centreline
Defended Area
Wall
Embankment
Standard of Protection of Flood Defence (Walls / Embankments)
0.1% AEP
IMPORTANT USER NOTE:
THE VIEWER OF THIS MAP SHOULD REFER TO THE DISCLAIMER, GUIDANCE NOTES AND CONDITIONS OF USE THAT ACCOMPANY THIS MAP.
OPW
The Office of Public Works
Jonathan Swift Street
Trim
Co. Meath
Project: SUIR CFRAM STUDY
Map: WATERFORD FLUVIAL & TIDAL FLOOD EXTENT MAP
Map Type: EXTENT
Source: FLUVIAL & TIDAL
Map area: HPW
Scenario: CURRENT
Drawn by: Claire Crossan Date: 2nd August 2016
Checked by: Stephen Patterson Date: 2nd August 2016
Approved by: Gerry Gallagher Date: 2nd August 2016
Map No.: O16WTD_EXMCD_F0_13
FINAL
Sheet: 13 of 18
Revision: 0
Map Scale: 1:5,000
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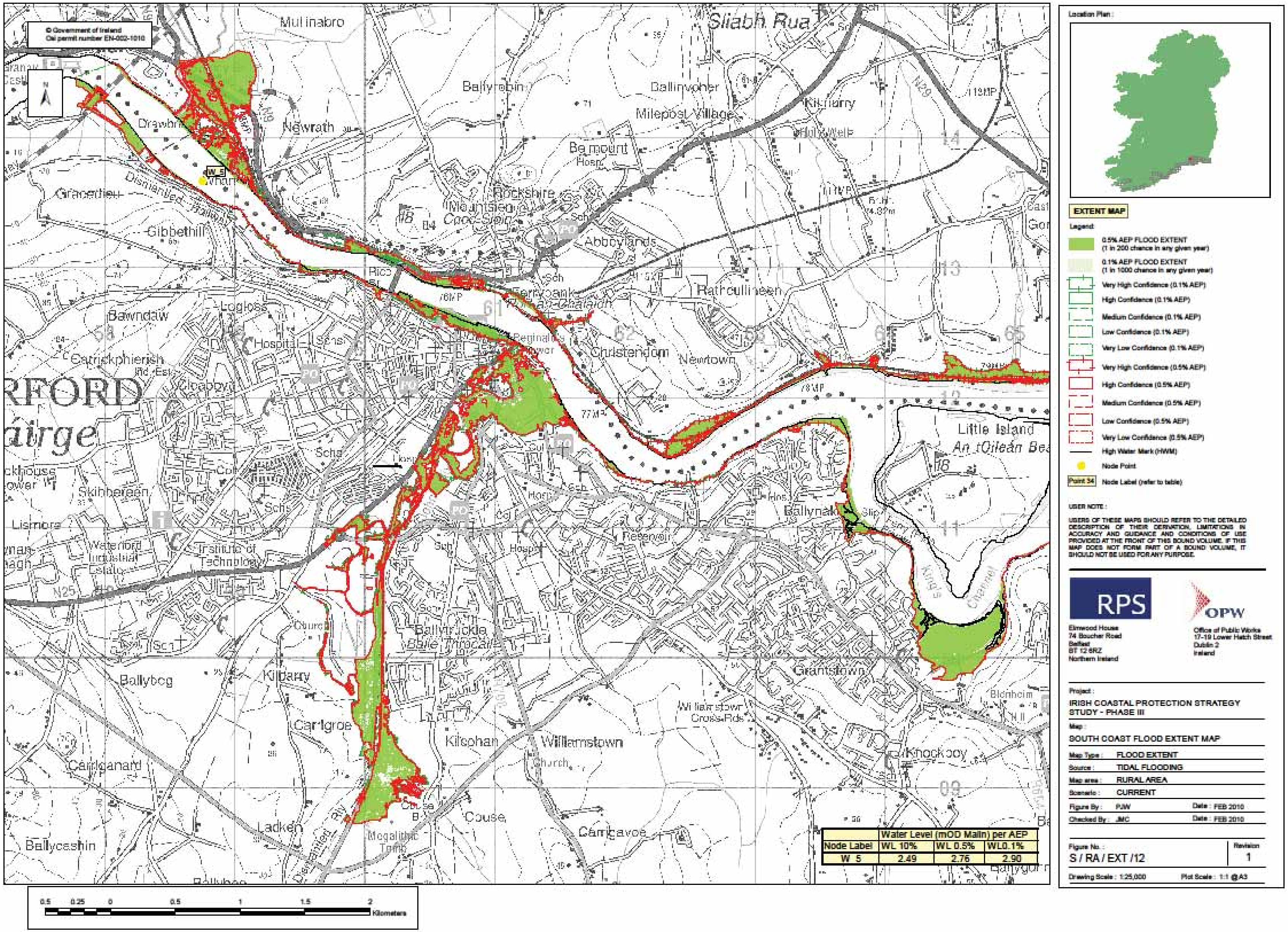
# Irish Coastal Protection Strategy Study



# OPW Flood Hazard Mapping

**OPW** *National Flood Hazard Mapping*

### *Summary Local Area Report*

This Flood Report summarises all flood events within 2.5 kilometres of the map centre.

**The map centre is in:**

**County:**

**NGR:** S 608 128

This Flood Report has been downloaded from the Web site www.floodmaps.ie. The users should take account of the restrictions and limitations relating to the content and use of this Web site that are explained in the Disclaimer box when entering the site. It is a condition of use of the Web site that you accept the User Declaration and the Disclaimer.

**Map Scale** 1:12,969

**Map Legend**

- Flood Points
- Multiple / Recurring Flood Points
- Areas Flooded
- Hydrometric Stations
- Rivers
- Lakes
- River Catchment Areas
- Land Commission *
- Drainage Districts *
- Benefiting Lands *

* Important: These maps do not indicate flood hazard or flood extent. Thier purpose and scope is explained in the Glossary.

## 13 Results

1. Scotch Quay Newtown Park Road Oct 2004 — Start Date: 27/Oct/2004
County:Waterford — Flood Quality Code:1
Additional Information: Reports (5) More Mapped Information

2. Suir Waterford City Quay Oct 2004 — Start Date: 27/Oct/2004
County:Waterford — Flood Quality Code:1
Additional Information: Reports (5) More Mapped Information

3. St John's River Tramore Road Oct 2004 — Start Date: 27/Oct/2004
County:Waterford — Flood Quality Code:1
Additional Information: Reports (5) More Mapped Information

4. St John's River Poleberry Oct 2004 — Start Date: 27/Oct/2004
County:Waterford — Flood Quality Code:1
Additional Information: Reports (5) More Mapped Information

5. St John's River Waterside Oct 2004 — Start Date: 27/Oct/2004
County:Waterford — Flood Quality Code:1

Report Produced: 01-Mar-2017 15:08

Additional Information: Reports (5) More Mapped Information

6. St. Johns River Tramore Road Waterford Recurring — Start Date:
County:Waterford — Flood Quality Code:2
Additional Information: Photos (7) Reports (6) Videos (1) Press Archive (4) More Mapped Information

7. Kingsmeadow Roundabout Waterford Oct 2004 — Start Date: 27/Oct/2004
County:Waterford — Flood Quality Code:1
Additional Information: Reports (5) More Mapped Information

8. Suir Scotch Quay William St area Feb 1994 — Start Date: 28/Feb/1994
County:Waterford — Flood Quality Code:2
Additional Information: Photos (6) Press Archive (2) More Mapped Information

9. Suir Waterford City Quay Feb 1994 — Start Date: 28/Feb/1994
County:Waterford — Flood Quality Code:2
Additional Information: Photos (5) More Mapped Information

10. Scotch Quay Area Waterford Recurring — Start Date:
County:Waterford — Flood Quality Code:2
Additional Information: Photos (7) Reports (4) More Mapped Information

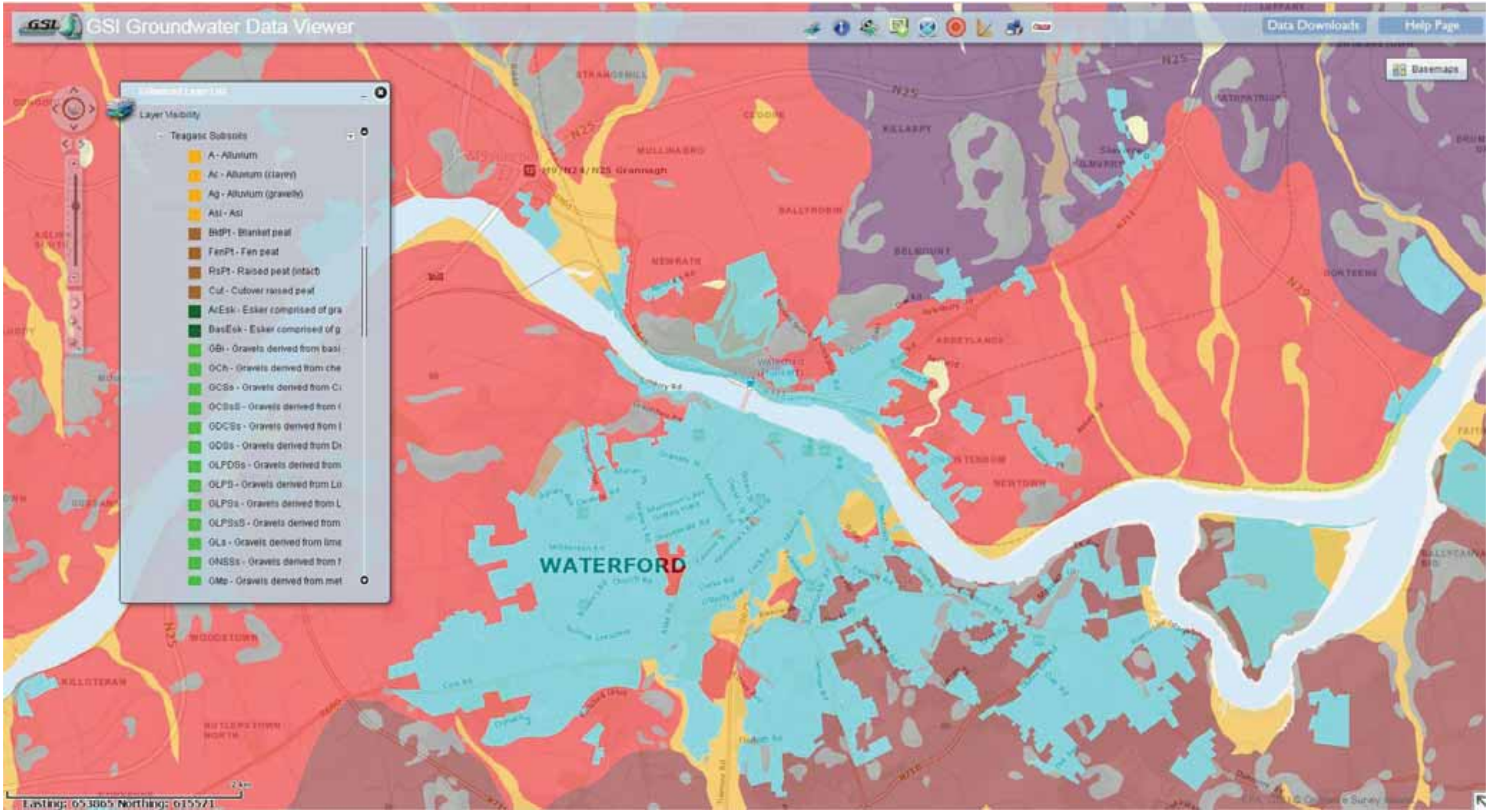
11. Suir Waterford City Quay recurring — Start Date:
County:Waterford — Flood Quality Code:2
Additional Information: Photos (7) Reports (5) Press Archive (73) More Mapped Information

12. Suir Newtown Road/Park Road recurring — Start Date:
County:Waterford — Flood Quality Code:3
Additional Information: Photos (1) Reports (3) Press Archive (5) More Mapped Information

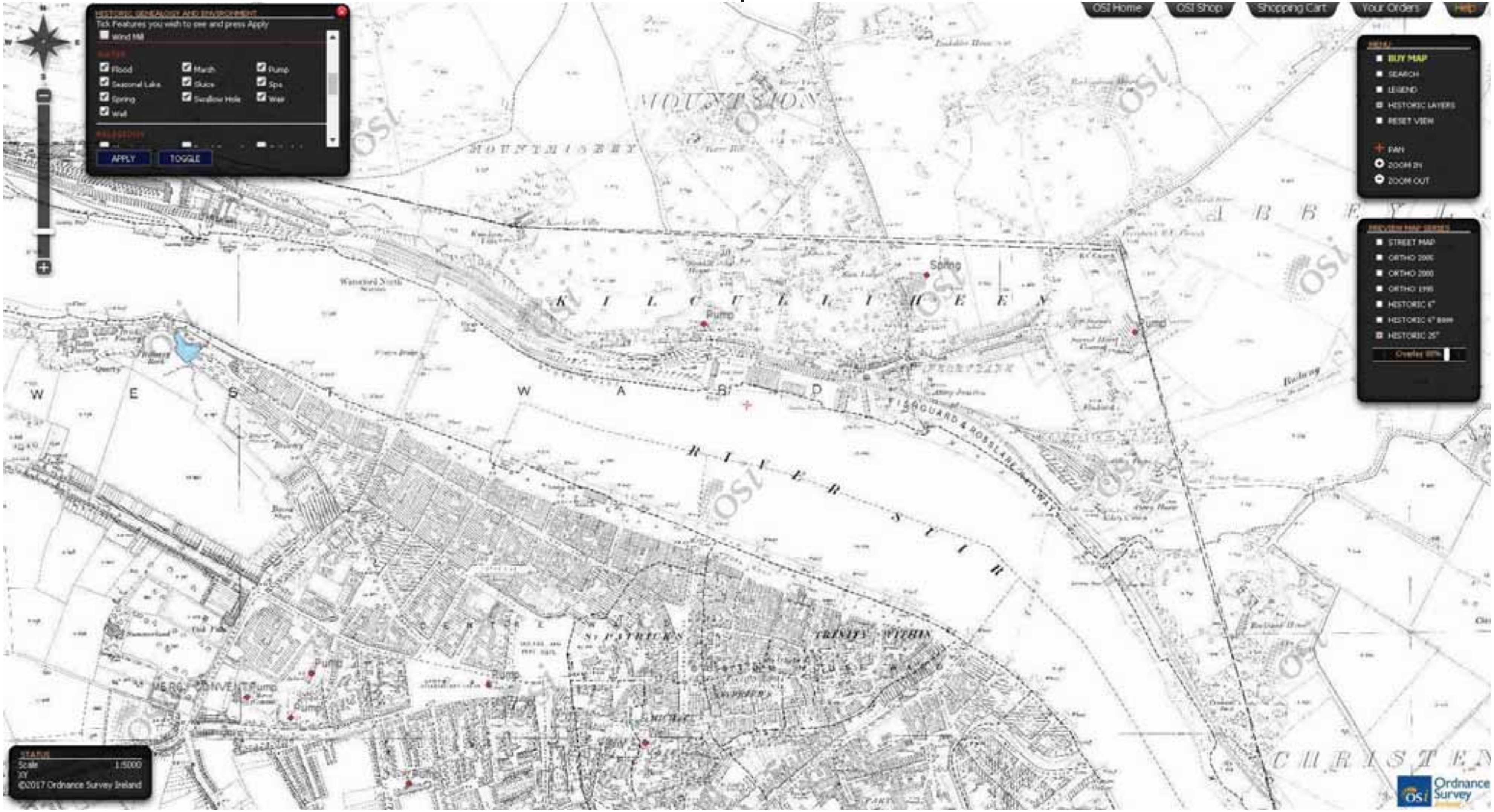
13. Poleberry Bath St Waterford Recurring — Start Date:
County:Waterford — Flood Quality Code:3
Additional Information: Photos (1) Reports (5) More Mapped Information

Report Produced: 01-Mar-2017 15:08

## Geological Survey of Ireland: Teagasc Subsoil Mapping



# Historical Maps: 6" Cassini



## News Reports



thejournal.ie

# Waterford train station is flooded… very flooded

Last night's heavy rain led to this happening to the station.

BY AOIFE BARRY | WEDNESDAY 17 OCT 2012, 10:32 AM | HTTP://JRNL.IE/638505

**LAST NIGHT'S HEAVY rain led to flooding around parts of Ireland – and Waterford train station got hit particularly badly.**

**This image, which was tweeted by Irish Rail, shows the full extent of the flooding caused by the downpour.**

**Bus transfers are in place from Waterford to Kilkenny while Irish Rail works to get the station back up and running.**

**Read: Heavy overnight rain leads to flooding, delays>**





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**Aoife Barry** | **@sweetoblivion26** | **aoife@thejournal.ie**

**APPENDIX C**

*Hydrology report*

RODROUGHAN & O'DONOVAN

Comhairle Cathrach
& Contae Phort Láirge
Waterford City
& County Council

# Hydrology Report

## 1 River Flow Estimation

The relevant rivers requiring flow estimation for the predictive flood modelling of the Waterford Strategic Development Zone are the mainline rivers of the Suir, Nore and Barrow. All of which enter and contribute to flows in Waterford Harbour tidal waters.

All three rivers have a reasonable spatial spread of reliable hydrometric Gauges, located both mainline and on the larger tributaries. This provides the necessary flow data to generate a reliable pooling group of gauged hydrometric stations for return period estimation and also provides a choice of gauged donor sites to improve the reliability of the annual maxima flood flow estimate and also the flow duration curve for these rivers.

The 50-percentile river flow (i.e. flows that are exceeded on average 50% of the time in an average year) is estimated from gauged stations to be approximately 14l/s per km$^2$ for the River Suir, 11.5l/s per km$^2$ for the River Nore and 10.2l/s per km$^2$ for the River Barrow. The total Catchment Area of the River Suir to Carrick-on-Suir is 2728km$^2$, to Waterford City it is 3,460km$^2$ (Rice Bridge) and to Cheekpoint in Waterford Harbour (confluence with the Barrow it is 3501km$^2$). The total catchment area of the River Barrow to St. Mullins is 2,813km$^2$ and 2,945km$^2$ to Cheekpoint at the Suir confluence. The total catchment area of the River Nore to Inistioge Village is 2,446km$^2$ and 2,508km$^2$ to its confluence with the River Barrow. The estuarine reaches of these rivers extend to 1km upstream of Carrick-on-Suir on Suir, 0.5km upstream of Inistioge on the Nore and 1.5km upstream of St. Mullins and 4km south of Graignamanagh on the Barrow.

**Table 1 50-percentile flow estimates for the Suir, Nore and Barrow**

| River | Catchment Area (km$^2$) | 50-percentile River Flow (cumec) |
|---|---|---|
| Suir | 3460 | 48.6 |
| Nore | 2812 | 32.4 |
| Barrow | 2945 | 30.2 |

## 2 Return Period Flood Flow Estimation

### *2.1 Index Flood Estimate (Qmed) using Flood Studies Update (FSU) Estimation Method*

The recent FSU method determines as an Index Flood the median flood magnitude from catchment descriptors for the subject site and provides the option of adjusting the ungauged estimate using a suitable donor (gauged) site, referred to as a pivotal site. The flood growth curve for this method is derived from a pooling group of the most hydrologically similar gauged sites from the FSU dataset (which has 215 gauged stations and 6725 station years available for Ireland (represents an average of 31years of Annual maxima per station)) with the number of stations selected in order of similarity so that it produces 5T station years (where T is the return period, e.g. 500 station years of Annual maxima required/recommended for estimating the 100year growth factor). There are insufficient station years to estimate the 1000year flood event based on this rule and growth curve derived from the 500 stations years is used. The degree of certainty associated with the 1000year estimates is poor, whereas the 100year estimate is much more robust and reliable.

The estimated statistical standard factorial error for this FSU method is 1.38. Therefore the 66.7-percent confidence interval for Qmed estimate is contained between 0.725 and 1.38 times the Qmed magnitude. At 95-percentile certainty the Qmed quantile lies between 0.525and 1.904 times Qmed (which is almost a factor of 2).

The FSU method used to determine the index flood (Qmed) is based on physical catchment descriptors accessed via a GIS system on the FSU Web Portal Site and provides an option to use a gauged site as a donor / pivotal site to adjust the Qmed estimate.

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

The urban Adjustment to the rural Qmed is defined as follows:

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

$$Qmed\ (urban) = Qmed\ (rural) \times UAF$$

Adjusted QMED estimate using Donor/Analogue Catchment

$$Qmed^s = Qmed^d \left( \frac{Qmed^s(model\ rural\ )}{Qmed^d(model\ rural\ )} \right)$$

**Table 2 FSU Catchment Descriptors**

| Catchment Descriptor |
|---|
| AREA Catchment area (km2) |
| BFISOIL Baseflow Soil index factor (runoff coefficient) |
| SAAR - mean annual rainfall in mm |
| FARL - Flood attenuation factor |
| DRAIND Drainage Channel length m per km2 |
| S1085 main stream Slope |
| ARTDRAIN2 Arterial Drainage factor |
| URBEXT Urban area ratio |

The key estimation points for the hydraulic mode are the upstream boundary nodes on the Suir, Nore and Barrow and at the Confluences of the Nore and Barrow and the Suir and Barrow and the Suir upstream of the SDZ Site at Waterford City.

The key gauged pivotal / donor sites for the Flow Estimation using the FSU method are presented below in Table 3.

**Table 3 Flood Estimation Pivotal Sites for adjustment of FSU Qmed estimates**

| Pivotal Site | Catchment | Catchment Area ($km^2$) | Qmed gauged (cumec) | Qmed PCDs (cumec) | Adjustment Factor |
|---|---|---|---|---|---|
| Clonmel (16011) | Suir | 2144 | 245.3 | 231.4 | 1.060 |
| Brownsbarn (15006) | Nore | 2418 | 303.6 | 206.8 | 1.468 |
| Graiguenamanagh (14029) | Barrow | 2778 | 183.8 | 167.4 | 1.098 |

The pooling group for the Flood Growth curve on the Suir, Nore and Barrow are presented below in Tables 4, 6 and 8 respectively.

## 2.2 Flood Growth curve from Pooling Group for Return Period Estimates

**Table 4 River Suir Pooling Group (approx. 500 Station Years)**

| Station | Similarity Euclidean DIST(ij) | # years | Cumulative station-years |
|---|---|---|---|
| 16011 | 0.34 | 51 | 51 |
| 16009 | 0.451 | 52 | 103 |
| 18002 | 0.504 | 49 | 152 |
| 26007 | 0.732 | 53 | 205 |
| 16008 | 0.83 | 51 | 256 |
| 15006 | 0.924 | 47 | 303 |
| 26005 | 0.957 | 51 | 354 |
| 25017 | 0.966 | 34 | 388 |
| 15002 | 0.984 | 48 | 436 |
| 12001 | 1.008 | 49 | 485 |
| 30012 | 1.039 | 9 | 494 |

**Table 5 River Suir Growth Curve Flood and estimate peak Flood flows for Estimation Points at Carrick-on-Suir and Waterford**

| Return Period | Growth Factor | Carrick-on-Suir Area $2728km^2$ | Waterford Area $3460km^2$ |
|---|---|---|---|
| **t=2** | 1 | 307.7 | 384.5 |
| **t=5** | 1.21 | 372.6 | 465.7 |
| **t=10** | 1.35 | 415.6 | 519.4 |
| **t=20** | 1.48 | 456.8 | 570.9 |
| **t=50** | 1.66 | 510.2 | 637.6 |
| **t=100** | 1.79 | 550.2 | 687.6 |
| **t=200** | 1.92 | 590.0 | 737.4 |
| **t=1000** | 2.22 | 682.3 | 852.8 |

**Table 6 River Nore Pooling Group (approx. 500 Station Years)**

| Station | Similarity Euclidean DIST(ij) | # years | Cumulative station-years |
|---|---|---|---|
| 15006 | 0.031 | 47 | 47 |
| 15002 | 0.316 | 48 | 95 |
| 7012 | 0.474 | 19 | 114 |
| 14029 | 0.594 | 47 | 161 |
| 14034 | 0.597 | 17 | 178 |
| 14019 | 0.597 | 52 | 230 |
| 14018 | 0.605 | 51 | 281 |
| 15012 | 0.782 | 16 | 297 |
| 7009 | 0.801 | 29 | 326 |
| 25006 | 0.802 | 52 | 378 |
| 7041 | 0.805 | 7 | 385 |

| Station | Similarity Euclidean DIST(ij) | # years | Cumulative station-years |
|---|---|---|---|
| 16008 | 0.818 | 51 | 436 |
| 26007 | 0.836 | 53 | 489 |

**Table 7 River Nore Growth Curve Flood and Peak Flood Flow Estimates for Estimation Points at Inistioge and at the Barrow Confluence**

| Return Period | Growth Factor | Inistioge Area 2446$km^2$ | Barrow confluence Area 2508$km^2$ |
|---|---|---|---|
| t=2 | 1 | 308.9 | 311.4 |
| t=5 | 1.23 | 380.0 | 383.0 |
| t=10 | 1.39 | 429.4 | 432.8 |
| t=20 | 1.53 | 472.7 | 476.4 |
| t=50 | 1.72 | 531.4 | 535.6 |
| t=100 | 1.87 | 577.7 | 582.3 |
| t=200 | 2.01 | 620.9 | 625.9 |
| t=1000 | 2.34 | 722.9 | 728.7 |

**Table 8 River Barrow Pooling Group (approx. 500 Station Years)**

| Station | Similarity Euclidean DIST(ij) | # years | Cumulative station-years |
|---|---|---|---|
| 14029 | 0.05 | 47 | 47 |
| 7012 | 0.132 | 19 | 66 |
| 14018 | 0.211 | 51 | 117 |
| 14034 | 0.349 | 17 | 134 |
| 7009 | 0.472 | 29 | 163 |
| 7041 | 0.503 | 7 | 170 |
| 15006 | 0.535 | 47 | 217 |
| 14019 | 0.574 | 52 | 269 |
| 7005 | 0.646 | 29 | 298 |
| 15002 | 0.716 | 48 | 346 |
| 25006 | 0.799 | 52 | 398 |
| 25011 | 0.936 | 51 | 449 |
| 15012 | 0.977 | 16 | 465 |
| 36019 | 1.012 | 47 | 512 |

**Table 9 River Barrow Growth Curve Flood and Peak Flood Flow Estimates for Estimation Points at St. Mullin's and additional catchment area to the Suir Confluence (Cheekpoint) excluding the Nore catchment.**

| Return Period | Growth Factor | St. Mullins Area 2812km$^2$ | Suir confluence Area 2945km$^2$ |
|---|---|---|---|
| t=2 | 1 | 191.2 | 199.6 |
| t=5 | 1.25 | 238.9 | 249.5 |
| t=10 | 1.42 | 271.4 | 283.5 |
| t=20 | 1.58 | 302.0 | 315.4 |
| t=50 | 1.79 | 342.2 | 357.3 |
| t=100 | 1.94 | 370.8 | 387.3 |
| t=200 | 2.1 | 401.4 | 419.2 |
| t=1000 | 2.45 | 468.3 | 489.1 |

## 3 Hydrograph generation

The return period design hydrographs for the Suir, Nore and Barrow model inflows are estimated using the new FSU hydrograph methodology which uses a statistical approacgh to hydrograph generation as opposed to a physical deterministic unit hydrographs. This statistical approach involves determining the median widths of observed hydrographs for selected reliable gauging stations (79 A1 gauging Stations). The hydrograph shape is described by the following three parameters namely:

- Shape parameter of a Gamma hydrograph - n
- Translation / location parameter of a Gamma hydrograph - Tr
- Recession parameter of an exponential recession - C

For a range of pre-selected flood events the parameters n, Tr and C were calculated using hydrograph width analysis for the 79 selected A1 gauging Stations. A regression analysis on these stations was carried out to relate the three hydrograph shape parameters to physical catchment descriptors as follows:

$$n = 3.86\ BFI^{-0.96}\ FARL^{2.98}$$
$$T_r = 54.98\ BFI^{1.32}\ (1+ALLUV)^{-13.08}\ (1+ARTDRAIN)^{-3.70} S_{1085}^{-0.20}$$
$$C = 310.75\ BFI^{3.44}\ FARL^{-4.88}$$

This method does not include baseflow which must be included after the hydrograph has been synthesised used the FSSR No 16 relationship:

$$Baseflow = (33(CWI\text{-}125) + 3*SAAR + 5.5)*10^{-5}$$

A catchment wetness index of 120mm was used and SAAR is mean annual rainfall depth in mm., BFI is baseflow index, FARL is flood attenuation by reservoirs and lakes, ALLUV is proportion of the catchment covered by **alluvial** deposits. ARTDRAIN is an arterial drainage factor and S1085 is the mainline slope in m per km. This method is considered to work well for the large catchments of the Suir, Nore and Barrow as these river catchments have quite number of the gauges within the respective catchments that were used to derive the above empirical equations based on least squares regression analysis. This method also provides for adjustment using where available a suitable pivotal site to improve the reliability of the method and adjust the parameters. The pivotal site available for the Suir is Newbridge station (16008, catchment area 1090km2), for the Nore it is Brownsbarn gauge (15006,

catchment area 2418 km$^2$) and for the Barrow it is Levitstown gauge (14019, catchment area 1697km$^2$).

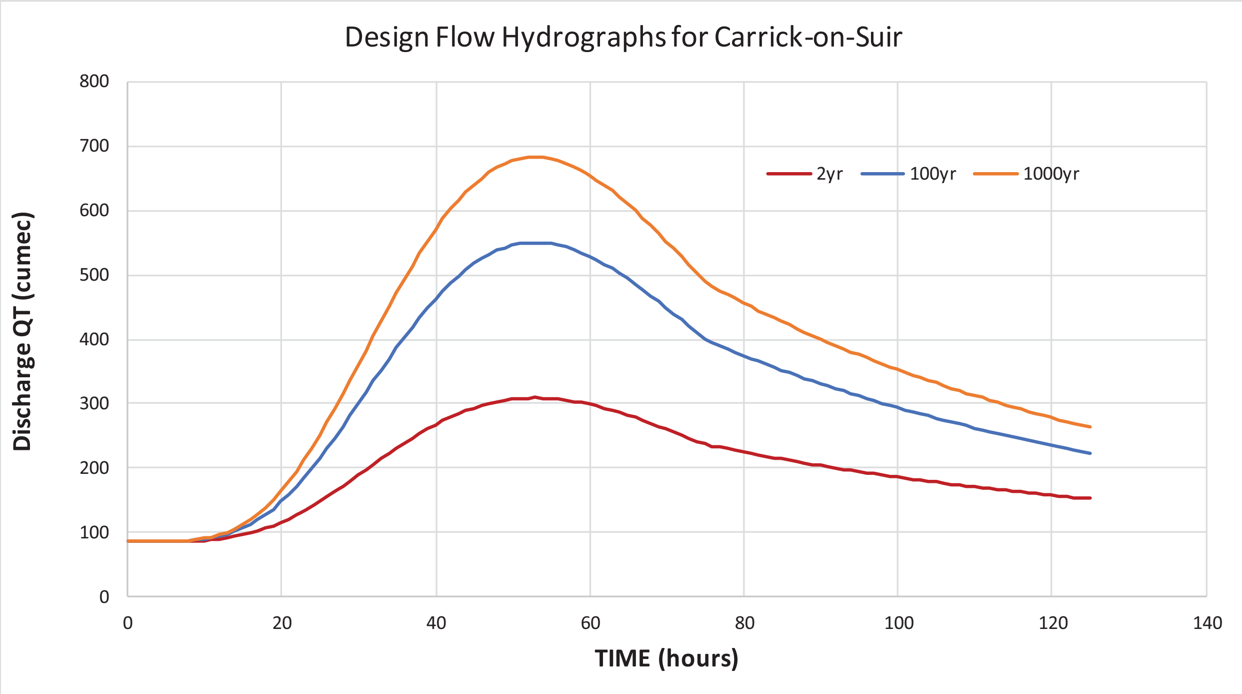


**Figure 1** **2, 100 and 1000year Design Flow hydrographs for River Suir at Carrick-on-Suir using FSU Method**

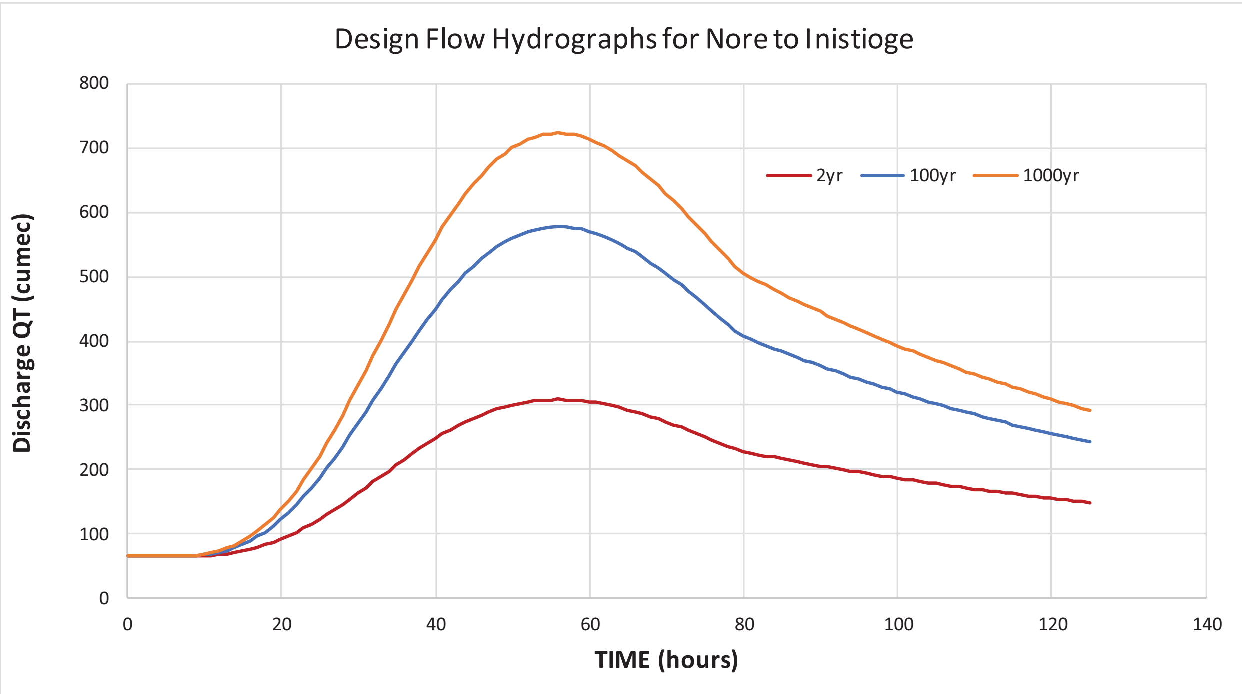


**Figure 2** **2, 100 and 1000year Design Flow hydrographs for River Nore at Inistioge using FSU Method**

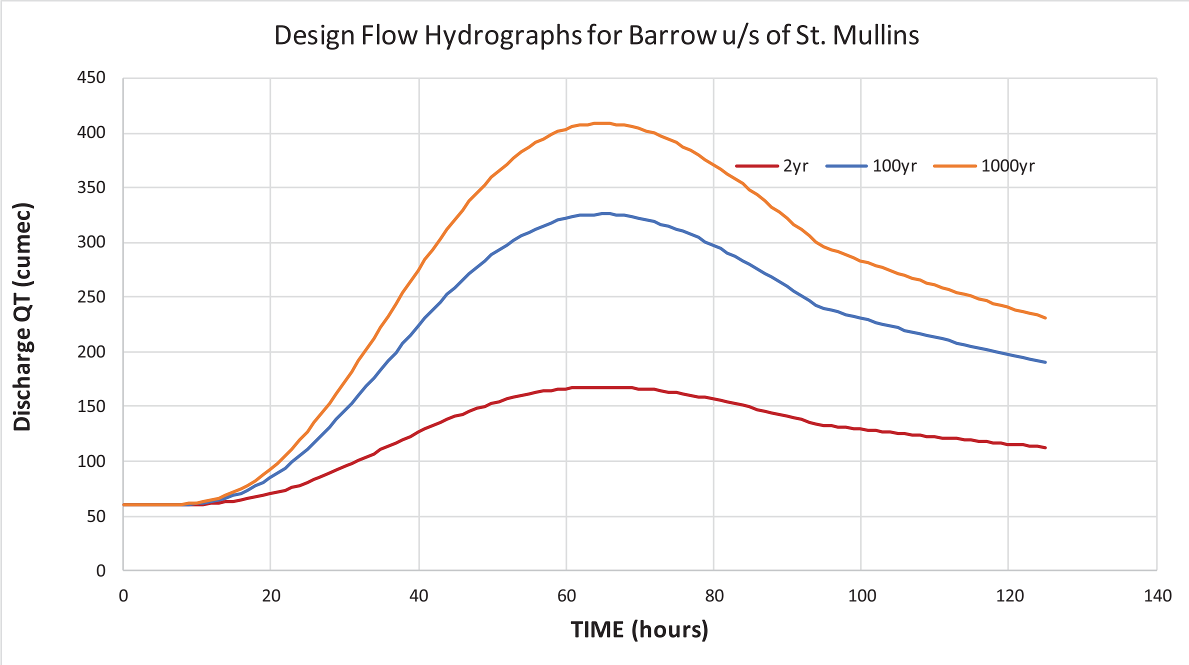


**Figure 3** **2, 100 and 1000year Design Flow hydrographs for River Barrow near St. Mullin's using FSU Method**

These design flood hydrograps were scaled based on catchment area to provide for lateral inflow from their respective downstream tributaries.

## 4. Tidal Elevation Estimation

### *4.1 The Irish Coastal Protection Strategic Study*

The Irish Coastal Protection Strategic Study for South Coast – Phase 3 (May2011) included Waterford Harbour and provides return period tidal storm surge predictions. These predictions were derived by hindcasting significant meteorological and astronomical events to generate a maximum series of storm surge elevations for Irish coastal waters with calibration to various annual maxima records at the various tidal stations surrounding Ireland. A summary of the predictions for Waterford Harbour , the open sea off Dunmore (S_1) and within the Suir Estuary near Waterford City (S_5)

**Table 10** **ICPSS Estimation Points in Waterford Harbour**

| Return Period | W_1<br>Dunmore East<br>m OD | W_5<br>1.3km u/s of Rice Br<br>Waterford<br>m OD |
|---|---|---|
| t=2 | 2.12 | 2.33 |
| t=5 | 2.21 | 2.42 |
| t=10 | 2.27 | 2.49 |
| t=20 | 2.33 | 2.55 |
| t=50 | 2.41 | 2.63 |
| t=100 | 2.47 | 2.69 |
| t=200 | 2.53 | 2.76 |
| t=1000 | 2.66 | 2.90 |

### *4.2 Tidal Gauge flood level analysis*

A short continuous tidal gauge record is available for Adelphi Quay (16160) from 1999 to present (a 17year annual maxima series). The annual maxima series for this record is presented below.

**Table 11 Annual Maxima Series of gauged tidal flood levels at Adelphi Quay Waterford**

| | | | |
|---|---|---|---|
| STATION NAME | ADELPHI QUAY | | |
| STATION No. | 16160 | | |
| RIVER | SUIR ESTUARY | | |
| CATCHMENT | SUIR | | |

Annual Maximum Series of Recorded Water Levels (Tidal)

| HYDROMETRIC YEAR | WATER LEVEL (mAOD - Malin) | S.G. READING (m) | DATE |
|---|---|---|---|
| 1999 | 2.49 | 5.19 | 23/12/1999 |
| 2000 | 2.70 | 5.40 | 12/12/2000 |
| 2001 | 2.70 | 5.4 | 01/02/2002 |
| 2002 | 2.57 | 5.27 | 08/10/2002 |
| 2003 | 2.32 | 5.02 | 25/11/2003 |
| **2004** | 2.89 | **5.59** | **27/10/2004** |
| 2005 | 2.58 | 5.28 | 30/03/2006 |
| 2006 | 2.59 | 5.29 | 08/10/2006 |
| 2007 | 2.87 | 5.57 | 10/03/2008 |
| 2008 | 2.33 | 5.03 | 12/01/2009 |
| 2009 | 2.44 | 5.14 | 19/11/2009 |
| 2010 | 2.48 | 5.18 | 08/10/2010 |
| 2011 | 2.43 | 5.13 | 29/11/2011 |
| 2012 | 2.77 | 5.47 | 17/10/2012 |
| 2013 | 3.02 | 5.72 | 03/02/2014 |
| 2014 | 2.59 | 5.29 | 06/11/2014 |
| 2015 | 2.55 | 5.25 | 28/10/2015 |
| median | 2.58 | | |
| Statistical error | 0.048 | | |

Statistical Frequency Analysis of this relatively short 17 year record indicates that an EV1 (Gumbel) type probability distribution fits well the data and that the return period tidal flood events at Adelphi Gauge are likely to be considerably higher than the IPCSS/CFRAM estimates.

**Table 12 Estimated return period tidal flood levels for Adelphi Quay, Waterford using at-site EV1 frequency analysis**

| Return Period | Yvariate | Ht | 67% confidence Interval | |
|---|---|---|---|---|
| | | | Ht-s.e. | Ht+s.e. |
| t=2 | 0.37 | 2.58 | 2.52 | 2.63 |
| t=5 | 1.50 | 2.76 | 2.67 | 2.85 |
| t=10 | 2.25 | 2.88 | 2.76 | 3.00 |
| t=20 | 2.97 | 2.99 | 2.85 | 3.14 |
| t=50 | 3.90 | 3.14 | 2.96 | 3.33 |
| t=100 | 4.60 | 3.26 | 3.04 | 3.47 |
| t=200 | 5.30 | 3.37 | 3.12 | 3.61 |
| t=1000 | 6.91 | 3.62 | 3.31 | 3.94 |

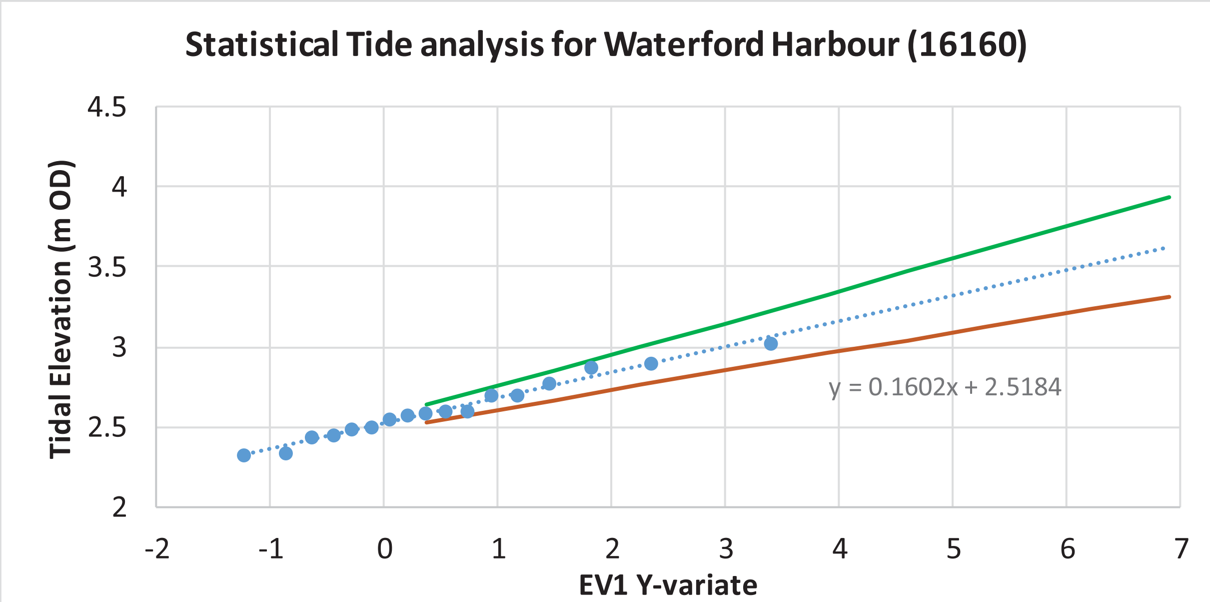


**Figure 4** **EV1 statistical analysis of 17 years annual maximum elevations for Adelphi Gauge including 67% confidence interval.**

The recorded annual maximum record for Aldelphi Quay shows two events October 2004 and February 2014 (both tidal events) having recorded flood levels at and above the ICOSS 1000year estimate and a further event not featuring as an annual maxima occurring on the 3rd January 2014 at 2.88m OD.

The hydraulic modelling shows that the river fluvial flow contribution in the Suir Estuary near Adelphi Quay is relatively minor with the highwater tide level only increasing as a result of the fluvial flows by 0.14 for the 2year fluival flood inflow and 0.2m for the 100year Fluvial Flood. The natural tidal steepening between Dunmore East gauge and the Adelphi Waterford Gauge is 0.12m. At the Carrick on Shannon gauge the estimated tidal steepening and increase in highwater under low flow conditions is simulated at 0.29m increase in tidal highwater level between Adelphi and Carrick-on-Suir and highwater occurs 1.25hours latter.

**Table 13** **Hydraulic Modelling Results for Spring Tide and different fluvial flow events**

| | Open Sea at Dunmore East S01 m OD | Adelphi Quay Section S40 m OD | Difference m |
|---|---|---|---|
| 95-percentile Low flow | 2.25 | 2.369 | 0.119 |
| 50 percentile Flow | 2.25 | 2.385 | 0.135 |
| 2year fluvial flood | 2.25 | 2.508 | 0.258 |
| 100year Fluvial Flood | 2.25 | 2.564 | 0.314 |

The 95-percentile low flow is estimated at 2l/s per $km^2$.

A longer record of combined fluvial and tidal annual maximum flows is available for Carrick-on-Suir (44 year annual maxima record). This is a combined record with significant fluvial and tidal events recorded. A statistical analysis of this combined record gives the following Return period estimates:

**Table 14 Estimated return period tidal flood levels for Carrick-on-Suir using at-site EV1 frequency analysis**

| Return Period | Yvariate | Ht | 67% confidence Interval | |
|---|---|---|---|---|
| | | | Ht-s.e. | Ht+s.e. |
| t=2 | 0.37 | 2.93 | 2.89 | 2.96 |
| t=5 | 1.50 | 3.10 | 3.05 | 3.15 |
| t=10 | 2.25 | 3.22 | 3.15 | 3.29 |
| t=20 | 3.20 | 3.36 | 3.27 | 3.45 |
| t=50 | 3.90 | 3.47 | 3.36 | 3.58 |
| t=100 | 4.60 | 3.58 | 3.45 | 3.70 |
| t=200 | 5.30 | 3.69 | 3.55 | 3.83 |
| t=1000 | 6.91 | 3.94 | 3.75 | 4.12 |

The difference in return period elevations between Carrick-on-Suir and Waterford gauges is 0.35 to 0.32m for the 2, 10, 200 and 1000year estimates respectively indicating a reasonable consistent relationship between the statistical results of the two sites, notwithstanding the difference in record length. The hydraulic modelling predicted a difference under spring tides of 0.29m which reasonably agrees with the above.

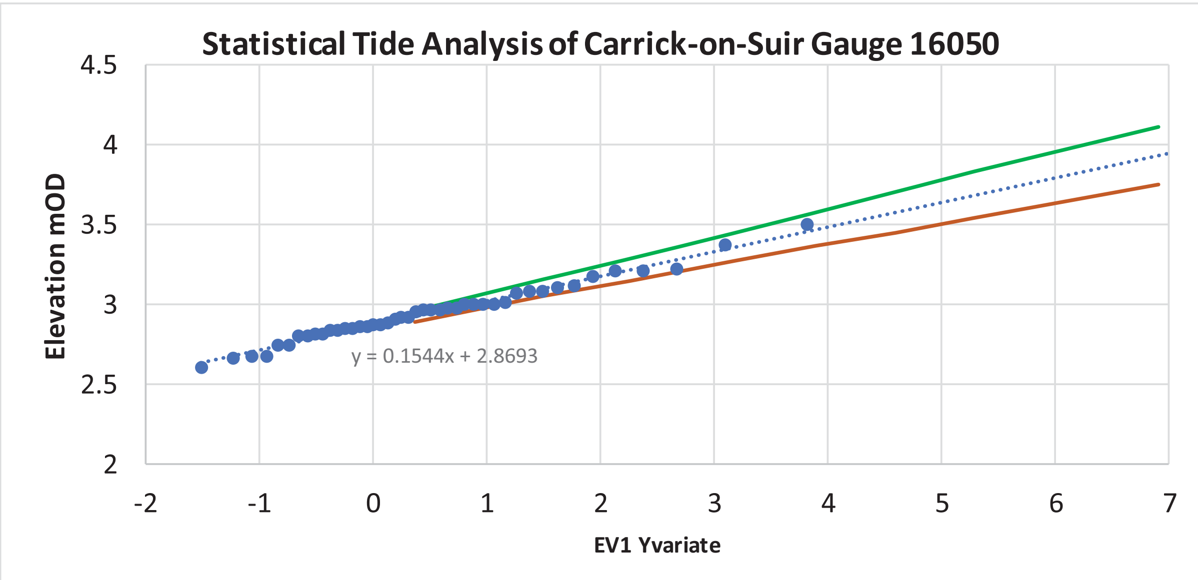


**Figure 5 EV1 statistical analysis of 44 years annual maximum elevations for Adelphi Gauge including 67% confidence interval.**

In conclusion, the ICPSS predictions, which are also used in the CFRAM study, clearly underestimate the return period tidal conditions in Waterford Harbour, given that three recent tide levels equalled or surpassed the 1000year estimate.

The results from the statistical analysis of the Adelphi Quay Gauge presented above provide the more reliable estimates and are consistent with results from a longer 44year record available for the Carrick-on-Suir gauge. The recommended design tide/flood levels for Waterford Harbour in the vicinity of the Adelphi Quay and the SDZ is a 10year return period flood level of 2.88mOD, a 200year return period water elevation of 3.37m OD and a 1000year water elevation of 3.62m OD Malin, these are 0.35m and 0.6m above the recent historical maximum tide level of 3.02m OD recorded on the 3rd February 2014.

To allow for tidal steepening between the open sea boundary at Dunmore East and fluvial flow contribution the 200year Design Tide at the open sea boundary is specified as 3.12m OD and 3.36m OD for the 1000year events respectively.

The design tide hydrograph is developed by taking a duration of high Spring tides and lifting a 24hour period which includes two highwaters such that the high tide level on the two highwaters equals the required highwater level of 3.12m OD for 100year and 3.36m OD for the 1000year at Dunmore East.

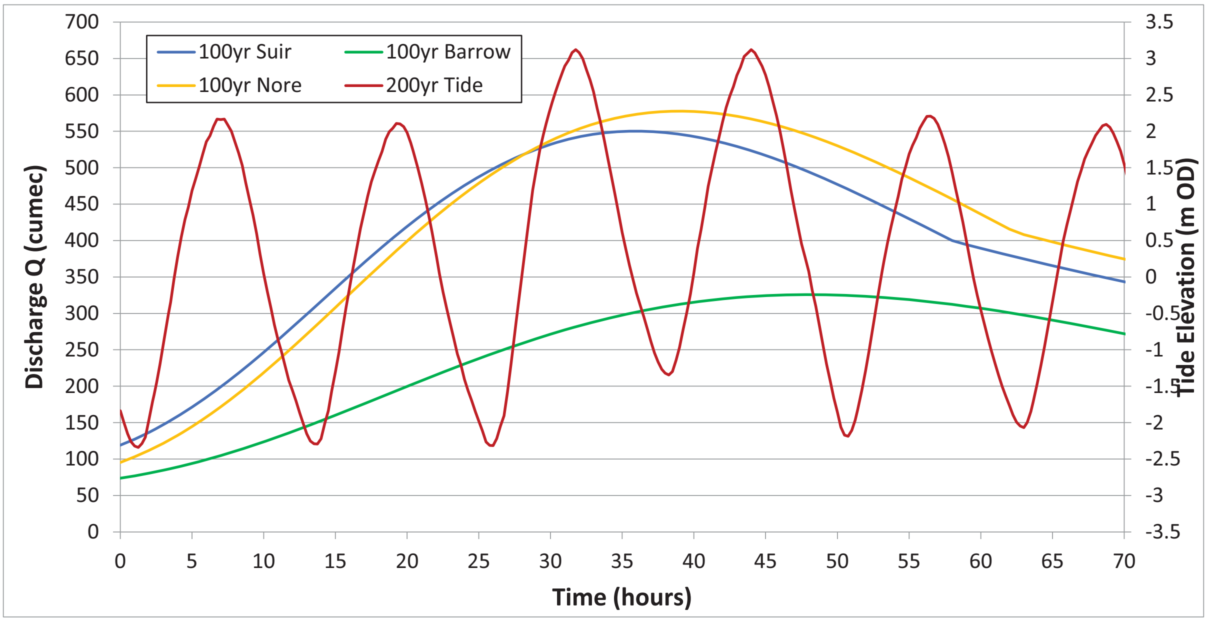


**Figure 6** **Example of lifting twin spring tide highwater and low water period to achieve the predicted storm surge highwater level of 3.12m OD Malin at Dunmore East.**

The fluvial Flood peaks are timed to coincide with the Storm Surge event.

**APPENDIX D**
*Hydraulic modeling report*

ROUGHAN & O'DONOVAN

Comhairle Cathrach
& Contae Phort Láirge
Waterford City
& County Council

# Hydraulic Flood Modelling Report

## 1. Introduction

In order to carry out a detailed site specific Flood Risk Assessment of the SDZ lands on the north bank at Waterford a sufficiently detailed hydraulic model of the existing Suir Estuary and the Proposed SDZ development is necessary to determine the design flood level for the SDZ lands and to quantify the potential flood impact of developing the SDZ lands. In the hydraulic modelling for the proposed SDZ case it is assumed that the SDZ lands are completely infilled and no longer provide conveyance or flood storage to the Suir. The proposed development case also includes a bridge crossing of the Suir Estuary channel with instream piers to support the proposed draw bridge section and the fixed bridge deck.

## 2. Model description

A 1D river model using HEC-RAS hydraulic software was considered to be the most suitable modelling approach for this particular flood risk assessment. The mode was developed of Waterford Harbour and its full estuarine reaches of the Suir, Barrow and Nore Rivers. A range of survey information was utilised in the constructing the model which is described below:

- OPW CFRAM river cross-section survey of the Suir, Nore and Barrow river chanels
- Apex cross-sections River Survey of the Suir at Waterford
- Infomar Sea bed Survey of Waterford Harbour
- Admiralty Chart of Waterford Harbour
- Apex Topographical Survey of the SDZ site and adjacent lands
- 2m Lidar Survey of Waterford City

## 3. Model Structure

River Section and overbanks were defined for approximately 115km of river reach along the main river/estuarine channels of the Suir, Nore and Barrow. The complete estuarine reaches which extend many kilometres upstream along the SUIR, Barrow and Nore were included in the model so that the simulations accurately accounted for the large tidal exchange volume that generate significant ebbing and flooding flows through Waterford Harbour. The model domain is presented in Figure 1 and the HEC-RAS model schematic showing cross-section locations is presented in Figure 2.

The model domain extends from the open sea off Dunmore East to 1km upstream of Carrick-On-Suir on the Suir, to 3km north of St. Mullin's Village on the River Barrow and to Inistioge on the Nore. A total of 249 river sections were included from the various surveys. Survey information was not available for a 19km length in the upstream middle section of the Suir Estuary from Woodstown to the west of Waterford to Piltown southeast of Carrick-on-Suir. This un-surveyed reach length was represented by simple liner interpolation between the nearest available upstream and downstream surveyed section so as to account for the tidal exchange volume and is sufficiently remote from the area of interest in Waterford Harbour not to materially affect the computed hydrodynamics.

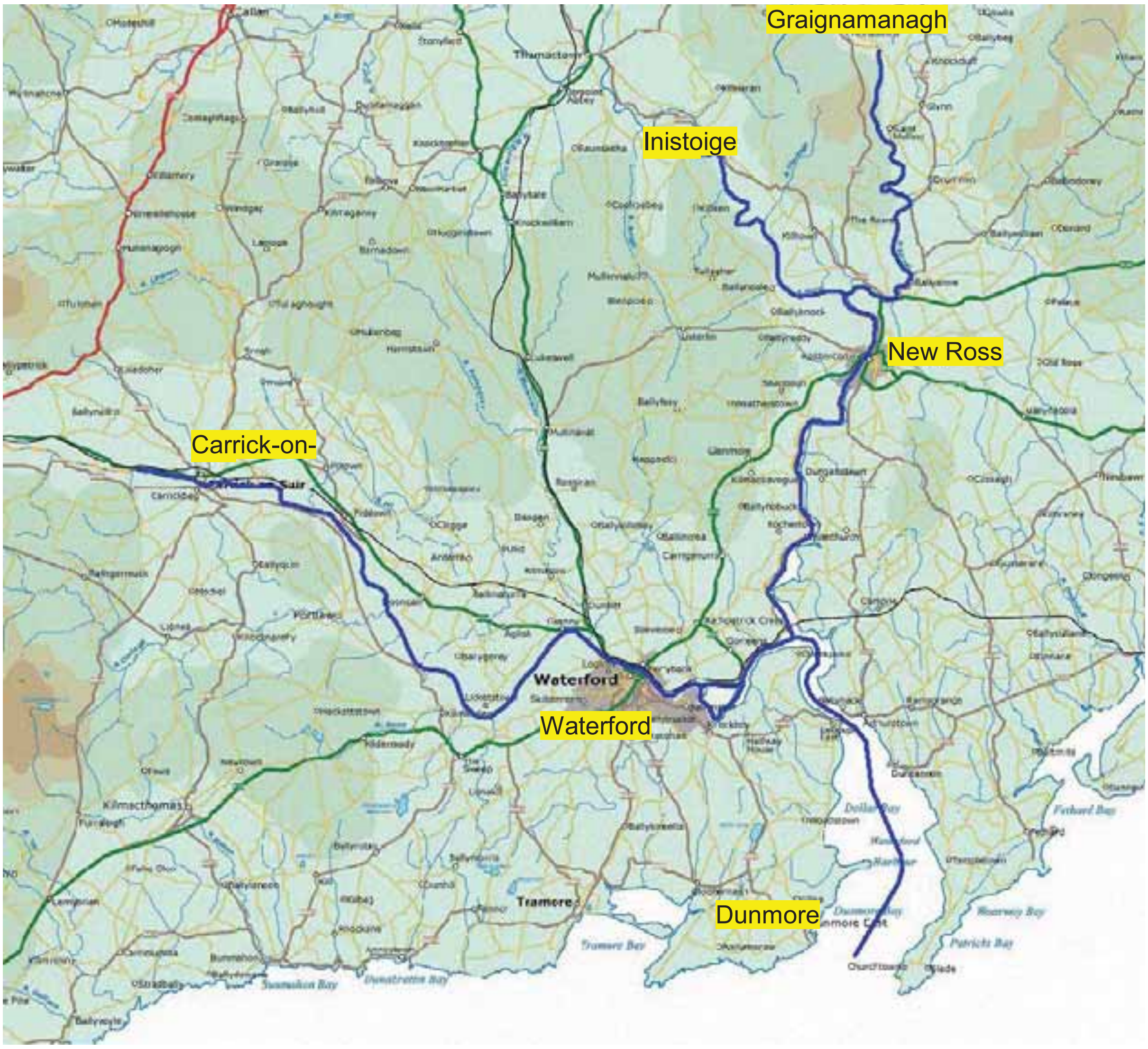


**Figure 1** **Extent of Waterford Harbour Estuarine Model**

A Manning's bed roughness coefficient n of 0.028 was used for the various estuarine reaches and a lower roughness coefficient of 0.024 for the wider and deeper Waterford Harbour reach. These roughness coefficients are considered to be appropriate for the wide deep and reasonably regular estuarine reaches through Waterford.

The model set-up included the loop configuration around King's island in Waterford Harbour. The existing draw bridge structure at Rice Bridge located immediately upstream of the SDZ lands was included in the model based on the CFRAM bridge survey cross-section.

The survey section included the flood protection along the South Quays and the modelled river channel overbank sections extended through the SDZ lands along the north bank. The Estuarine Sections off Dunmore East are over 4km wide, whereas the estuarine sections Near Cheekpoint at the Barrow confluence were c. 800m wide and c. 220m in the Suir adjacent to the SDZ Lands.

**Figure 2 HEC-RAS Model Schematic**

## 4. SDZ Development

A model of the existing estuarine system was constructed and this was modified to include the proposed bridge linking the SDZ lands on the north bank to the Waterford south quay area. In the model all lands on the SDZ Site were raised so as to be taken out of the flood zone. The modelled SDZ bridge crossing is presented below and the pier support pile groups were modelled as wide solid piers extended down to channel bed.

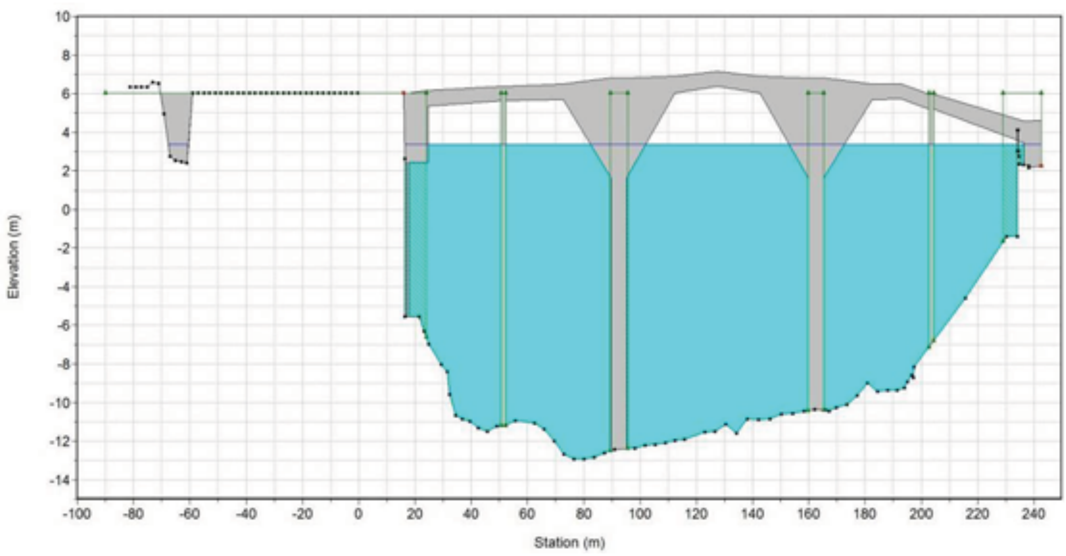


**Figure 3 Proposed SDZ Bridge Crossing of Suir Estuary**

## 5. Model Boundary Conditions

Design flood flow hydrographs derived using the new FSU flood flow estimation method were specified at the upstream boundaries of the Suir, Nore and Barrow Rivers respectively. To account for the various downstream inflow tributaries inflow hydrographs (also derived using the FSU method) were specified as lateral inflows at key tributary locations upstream of the Waterford Harbour reach. The downstream open sea boundary off Dunmore East was specified as a tidal boundary condition derived using recorded spring tidal measurements from the Adelphi Quay Gauge and adjusted appropriately. Example of flow and tidalboundary hydrographs specified in the various flood simulation model runs are presented below in Figures 4 to 7 and show the timing of the Fluvial Flood Peak coinciding with the tidal storm surge or highwater spring tides.

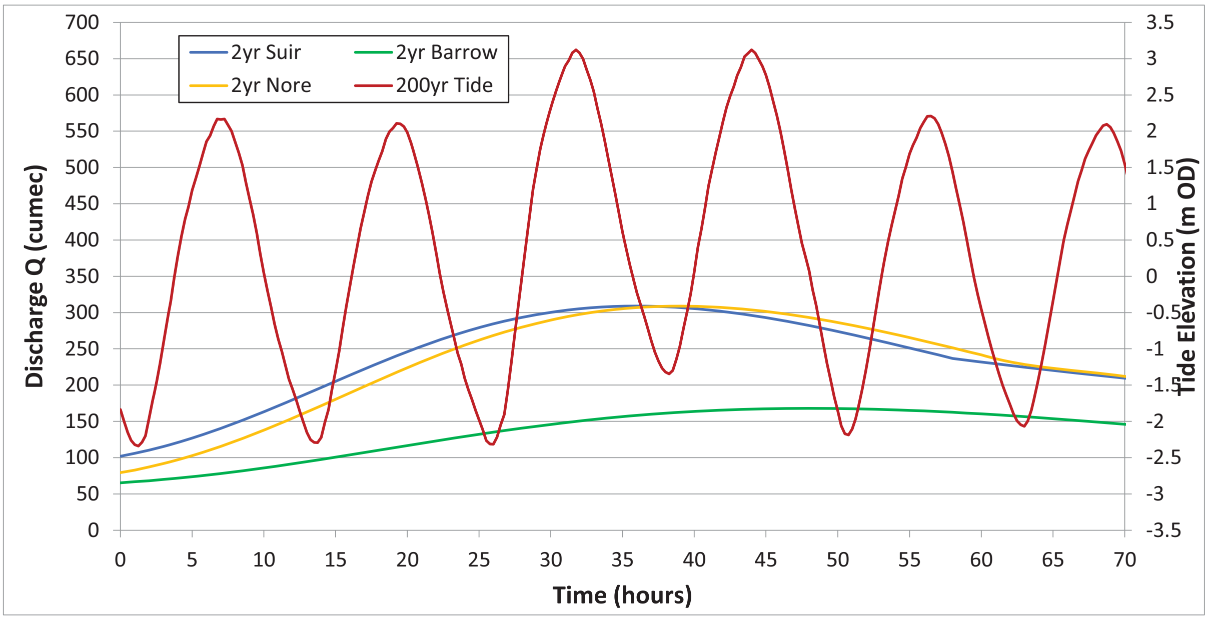


**Figure 4** 2year Fluvial Event combined with 200year Storm Surge Tide

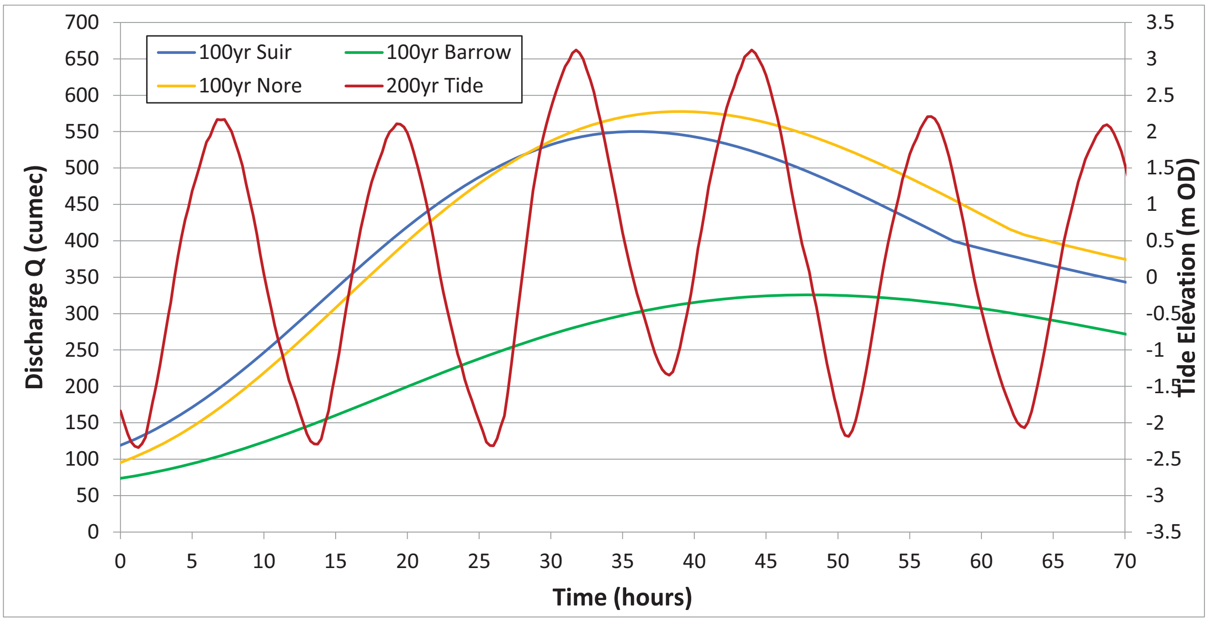


**Figure 5** 100year Fluvial Event combined with 200year Storm Surge Tide

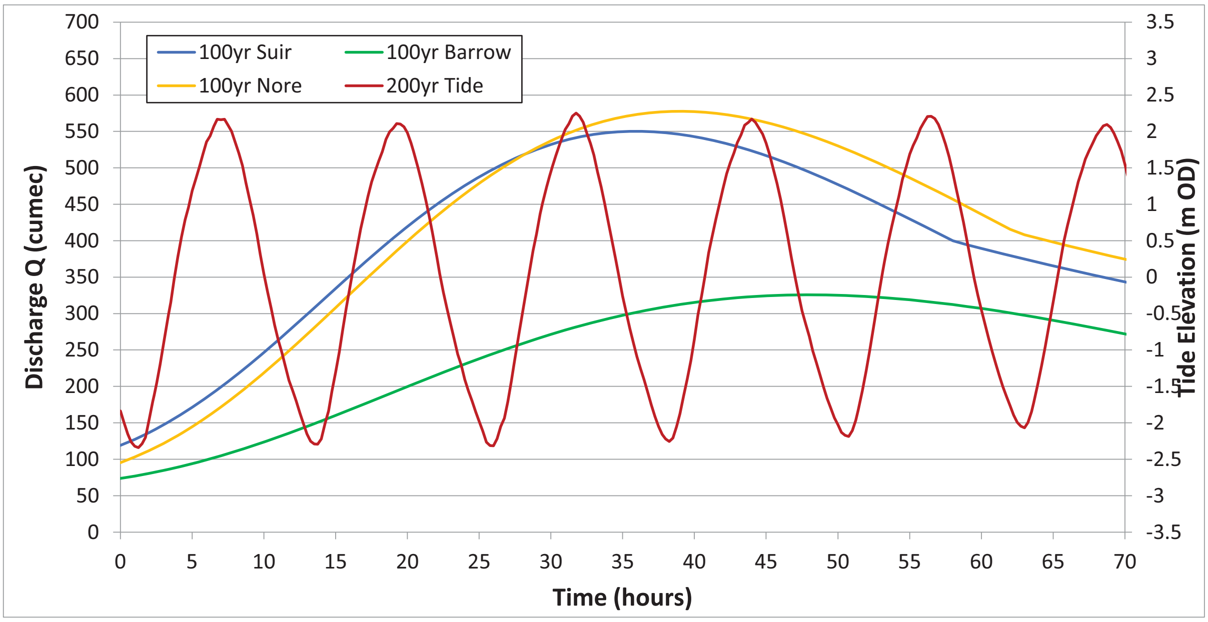


**Figure 6 100year Fluvial Event combined with Spring Tide Conditions**

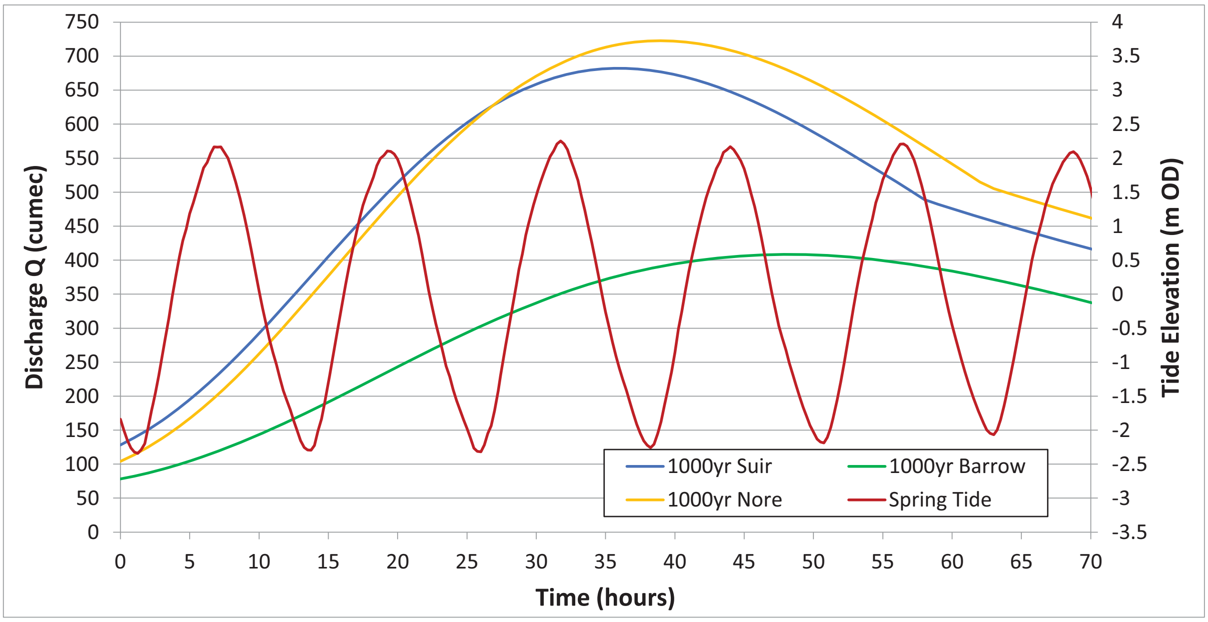


**Figure 7 1000year Fluvial Event combined with Spring tides**

## 6. Flood Simulations

Tidal analysis presented earlier in the Hydrology Chapter indicates that the appropriate 200 year and 1000year flood levels for present day scenario (without Climate Change) are 3.37m OD and 3.61m OD Malin respectively for the SDZ reach. These flood level estimates are considered to represent combined 200year and 1000year flood levels, but as can be clearly seen from the modelling results presented in this appendix the design tide plays the dominant influence on generating the peak flood levels with the fluvial contribution relatively small and of only minor influence.

The following combined fluvial and tidal hydraulic simulation events considered are presented as follows:

- Simulation 1 50percentile River Flow combined with 200year Storm Surge Tide Event

- Simulation 2 Event — 2year Fluvial Flood Event combined with 200year Storm Surge Tide
- Simulation 3 Event — 100year Fluvial Flood Event combined with 200year Storm Surge Tide
- Simulation 4 — 100year Fluvial Flood Event combined with Spring Tide Event
- Simulation 5 — 1000year Fluvial Flood Event combined with Spring Tide Event

In all cases the model was run for the existing scenario (i.e. without the SDZ Development) and also for the proposed SDZ development including the Bridge Crossing. For all simulations the impact on flood levels both locally upstream and downstream were found to be miniscule and less than the modelling tolerance of 4mm. To assist demonstrating the time varying simulation results within the model domain, various reference nodes were selected for more detailed output, graphically and in tabular format. The location of these Reference Nodes is presented below in Figure 8.

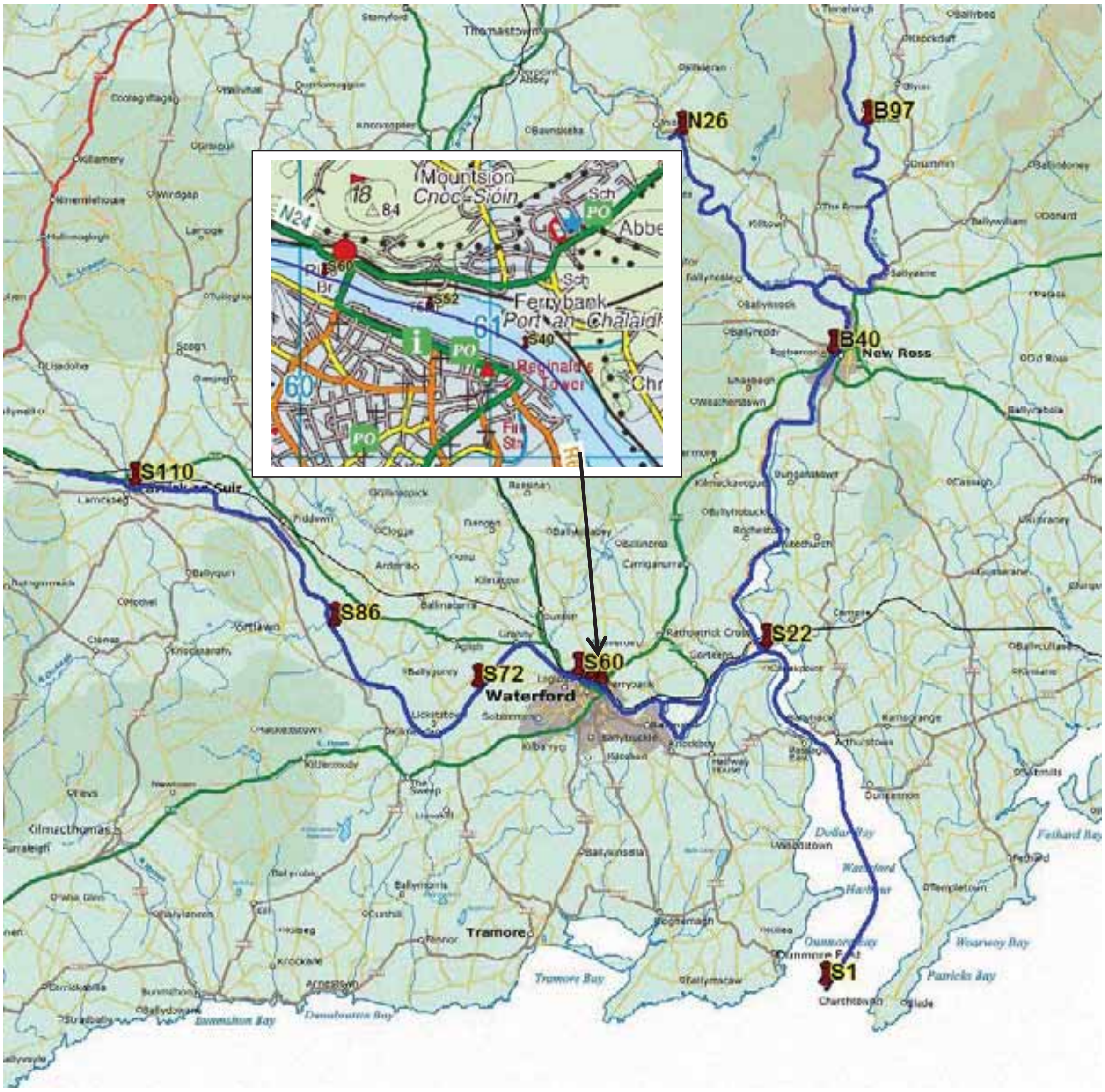


**Figure 8 Model Output Reference Nodes**

## *6.1 Simulation 1 – 200year tide combined with 50-percentile fluvial river flow (i.e. Suir 49cumec, Nore 32cumec and Barrow 30cumec)*

This simulation is the 200year storm surge tide combined with a non-flood conditions in the Nore,Suir and Barrow rivers which are set to the 50-percentile flow (a flow rate that is exceeded 50%of the time, annually). For this 200year design tide simulation of 3.12m OD Malin in the open sea off Dunmore East the mean flooding (incoming) tidal flow in the Suir estuary at Section S23 at Cheekpoint just upstream of the Barrow confluence is 2,366cumec over a 5.75hour flood tide period. This represents s an inflow volume of 48.98 million $m^3$ of water up the Suir Estuary. The ebbing tide characteristics of this simulation give an ebb flow period of 6.75hours, and average flow rate of 2,113cumec and a total outflowing volume of 51.42million $m^3$.

The Barrow and Nore Estuarine system at Section B5 just upstream of the Suir confluence near Cheekpoint has an incoming flood tide flow rate over 5.5hours of 2,159cumec producing an incoming volume up the Barrow Estuary of 42.74million $m^3$ on a single tidal excursion. On the outgoing ebbing tide which lasts for almost 7hours of the 12.5hour tidal cycle, the average ebb flowrate is 1,791cumec over the 7hours representing a total outflow volume of 44.35 million $m^3$.

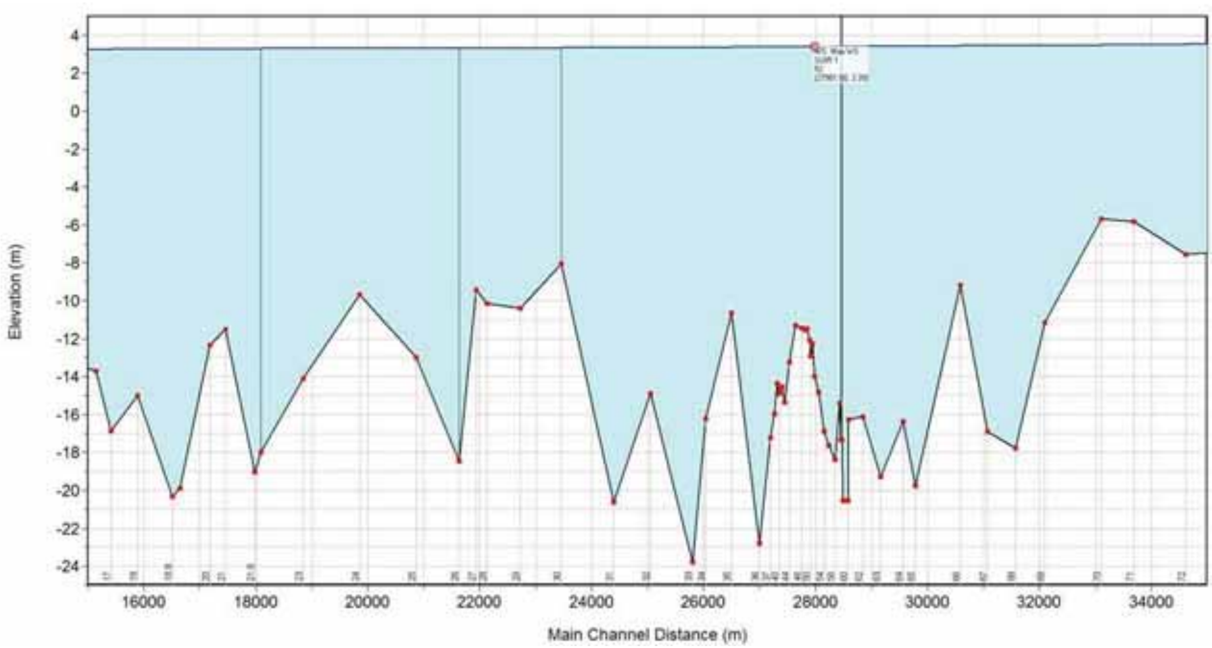


**Figure 9 Flood profile for Simulation 1 showing maximum computed water level profile in section of Suir adjacent to the Waterford SDZ – maximum highwater flood level typically 3.21m OD Malin in this section**

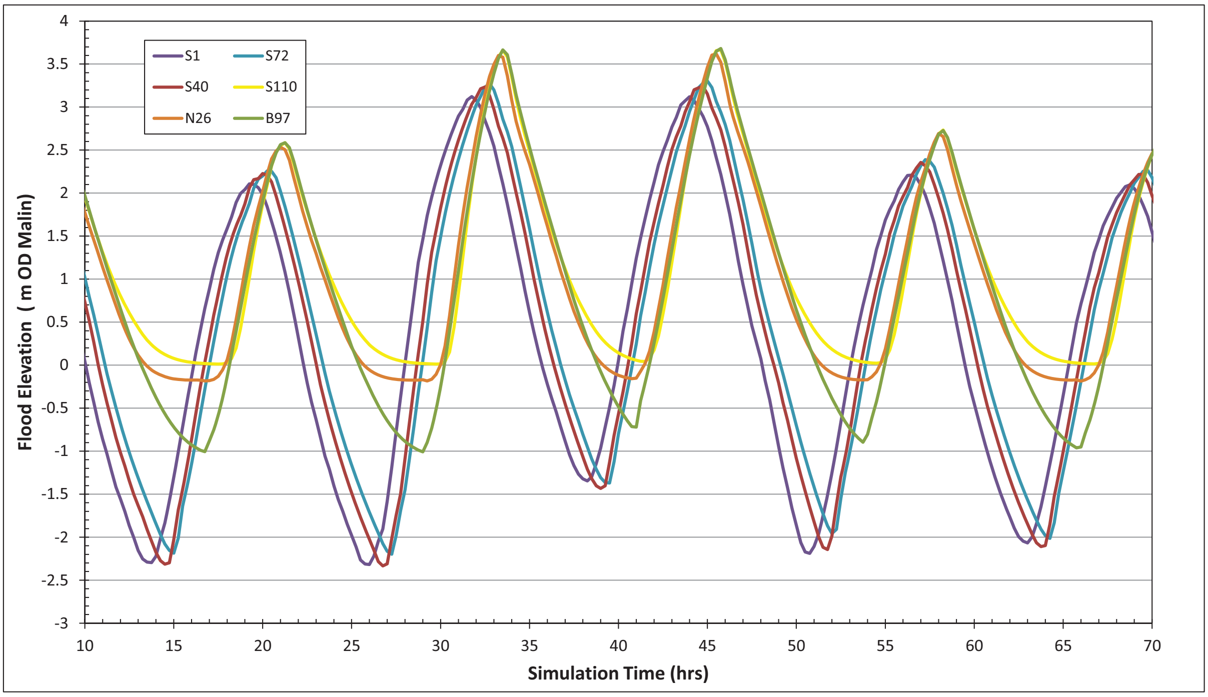


**Figure 10** Computed Water Level Hydrographs at selected reference nodes (refer to Figure 8 for locations of reference sites)

**Table 1** Maximum Flows and Flood Levels at Reference Sites for Simulation 1 (200yr Tide plus 50-percentile River flow)

| Reference Site | Water level m OD | Max ebb | Max Flood |
|---|---|---|---|
| | | Flow cumec | Flow cumec |
| **S110** | 3.665 | 131 | -28 |
| **S86** | 3.444 | 771 | -889 |
| **S72** | 3.304 | 1520 | -1694 |
| **S60** | 3.258 | 2011 | -2292 |
| **S52** | 3.249 | 2036 | -2327 |
| **S40** | 3.242 | 2071 | -2379 |
| **S22** | 3.240 | 5897 | -7168 |
| **S1** | 3.122 | 20907 | -26631 |
| **B40** | 3.353 | 982 | -1144 |
| **B97** | 3.681 | 139 | -61 |
| **N26** | 3.618 | 53 | 12 |

Opposite the Waterford Strategic Development Zone at Section S52 the flow characteristics can be summarised as an average flood tide flow rate of 1,590cumec over a 5.5hour period producing an inflow volume of 31.48 million $m^3$ and an average ebb tide flow rate of 1,351cumec over a 7hour period representing a total outflowing volume of 32.97million $m^3$ at a maximum flood level of 3.249m O.D. These are significant ebbing and flooding flows and the available cross-sectional area within the Suir estuartine channel for the reach adjacent to the SDZ (sections 42 to 57) is 2790$m^2$ (flow area).

The potential loss of overbank flow area by developing the SDZ is very minor at 27.8$m^2$ and this represents only 1.01% of the total cross-sectional area and the modelling shows no

discernible impact on flood levels. The flood storage volume available on the site at the peak flood level of 3.249m OD flood level, based on the Apex topographical survey, is 36,005m$^3$. This is only a small fraction of the 32.97million m$^3$ outgoing flood volume passing the site (0.11%) during this tidal flood event.

## *6.2 Simulation 2 – 200year tide combined with 2year (median) fluvial flood flow in the Nore, Suir and Barrow Rivers*

This simulation is the 200year storm surge tide combined with the 2year (median) fluvial flood flow in the Suir, Nore and Barrow rivers, and which is likely to represent a combined event that exceeds a 200year return period event. Flood flow conditions in these large rivers generally represent the winter season (November to February period). For this simulation the high tide in the open sea off Dunmore East is set at 3.12m OD Malin. Under these conditions the computed mean flooding (incoming) tidal flow in the Suir estuary at Section S23 just upstream of the Cheekpoint and the Barrow confluence is 2,157cumec over a 5.25 to 5.5hour flood (incoming) tide period. This represents an inflow volume of 41.8 million m$^3$ of water up the Suir Estuary. The ebbing (outflowing) tide characteristics give an ebb flow period of 7 to 7.25hours, and average outflow rate of 2,270cumec and a total outflowing volume of 58.22million m$^3$.

The Barrow and Nore estuarine system at Section B5 just upstream of the Suir confluence near Cheekpoint has an average inflow rate over 5.25hours flooding tide of 1,688cumec and an incoming volume of 32.71million m$^3$. On the outgoing ebbing tide which lasts for 7.25hours of the 12.5hour tidal cycle, the average ebb flow is 2,083cumec representing a total outflow volume of 53.46million m$^3$.

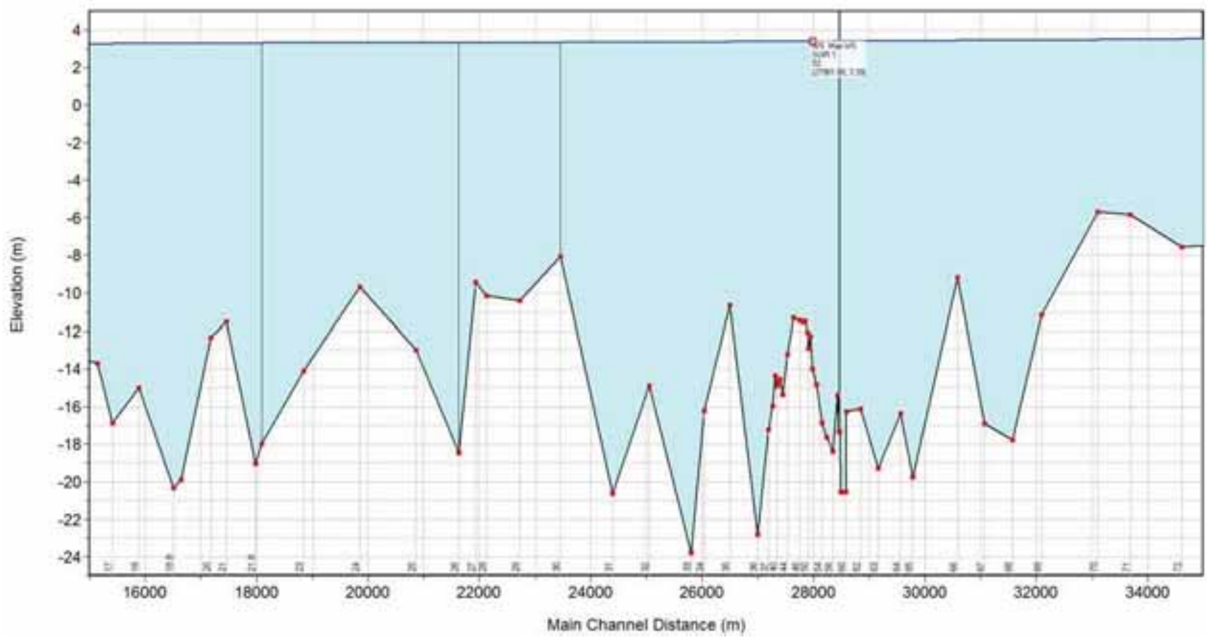


**Figure 11 Flood profile for Simulation 2 showing maximum computed water level profile in section of Suir adjacent to the Waterford SDZ - flood level typically 3.36 to 3.39m OD Malin**

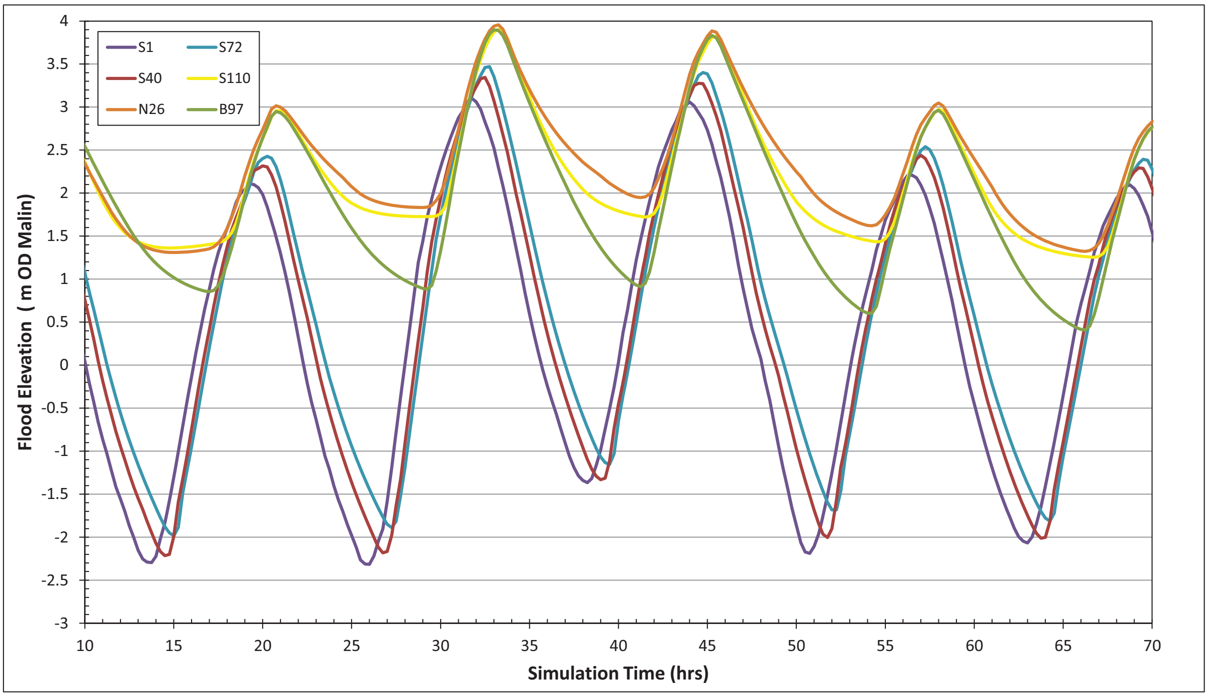


**Figure 12** **Computed Water Level Hydrographs at selected reference nodes for simulation 2 (refer to Figure 8 for node reference locations)**

**Table 2** **Maximum Flows and Flood Levels at Reference Sites for Simulation 2 (200yr Tide plus 2year Fluvial Flood event)**

| Reference Site | Water level m OD | Max ebb Flow cumec | Max Flood Flow cumec |
|---|---|---|---|
| S110 | 3.936 | 345 | 105 |
| S86 | 3.681 | 879 | -580 |
| S72 | 3.508 | 1612 | -1511 |
| S60 | 3.403 | 2211 | -2051 |
| S52 | 3.393 | 2236 | -2087 |
| S40 | 3.381 | 2272 | -2139 |
| S22 | 3.292 | 6283 | -6674 |
| S1 | 3.122 | 20911 | -26070 |
| B40 | 3.620 | 1201 | -710 |
| B97 | 3.940 | 216 | 66 |
| N26 | 4.025 | 313 | 78 |

Opposite the Waterford Strategic Development Zone at Section S52 the flow characteristics can be summarised as an average incoming flood tide flow rate of 1,276cumec over 5.25hour flood flow period producing an inflow volume of 24.12 million $m^3$ and an average ebb tide flow of 1,536cumec over a 7.25hour period representing a total outflowing volume of 40.10million $m^3$ at a maximum flood level of 3.393m O.D. These represent significant ebbing and flooding flow rates in the estuarine channel adjacent to the SDZ land (model sections 42 to 57) and the available cross-sectional area within the estuarine channel adjacent to the SDZ is 2784$m^2$ (flow area).

The potential loss of overbank section area by developing the SDZ is 38.5m$^2$ and only 1.36% of the total cross-sectional flow area) and hydraulic model shows no discernible impact on flood levels. The flood storage volume available on the site at the peak flood level of 3.393m OD based on the Apex topographical survey is 46,048m$^3$. This is only a small fraction of the 40.10million m$^3$ outgoing flood volume passing the site (0.115%).

## *6.3 Simulation 3 – 200year tide combined with 100year fluvial flood flow in the Nore, Suir and Barrow*

This simulation is the 200year storm surge tide combined with the 100year flood flow in the Suir, Nore and Barrow Rivers. Such a combination is likely to represent a probability well in excess of 200year return period. Under these conditions the computed mean flooding (incoming) tidal flow in the Suir Estuary at Section S23 just upstream of Cheekpoint near the Barrow confluence is 1,862cumec over a 5.25hour flood tide period. This represents an inflow volume of 35.19 million m$^3$ of water up the Suir Estuary. The ebbing tide characteristics of this simulation give an outflowing ebb flow period of 7.25hours, an average ebb flow rate of 2,399cumec and a total outflowing volume of 62.60million m$^3$.

The Barrow and Nore Estuarine system at Section B5 just upstream of the Suir confluence near Cheekpoint has an average flow rate over a 4.5hours flooding tide of 1,321cumec and an incoming volume of 22.08million m$^3$. On the outgoing ebbing tide which lasts for almost 8hours of the 12.5hour tidal cycle, the average ebb flow is 2,084cumec representing a total outflow volume of 60.00 million m$^3$.

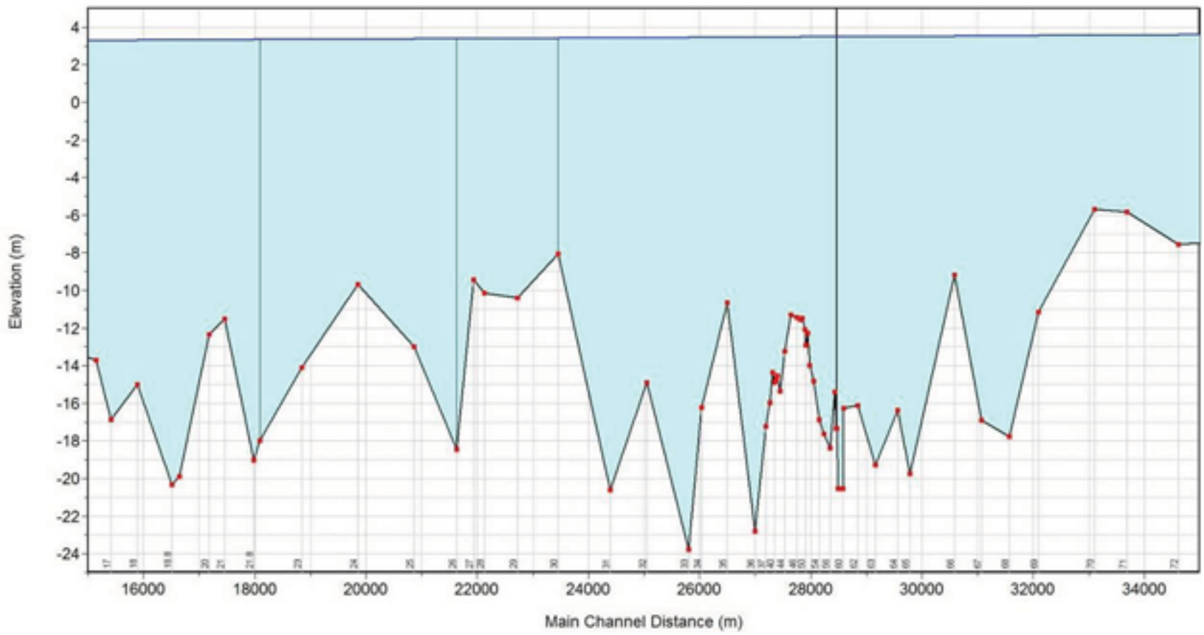


**Figure 13 Flood profile for Simulation 3 showing maximum computed water level profile in section of Suir adjacent to the Waterford SDZ - flood level typically 3.47m OD Malin**

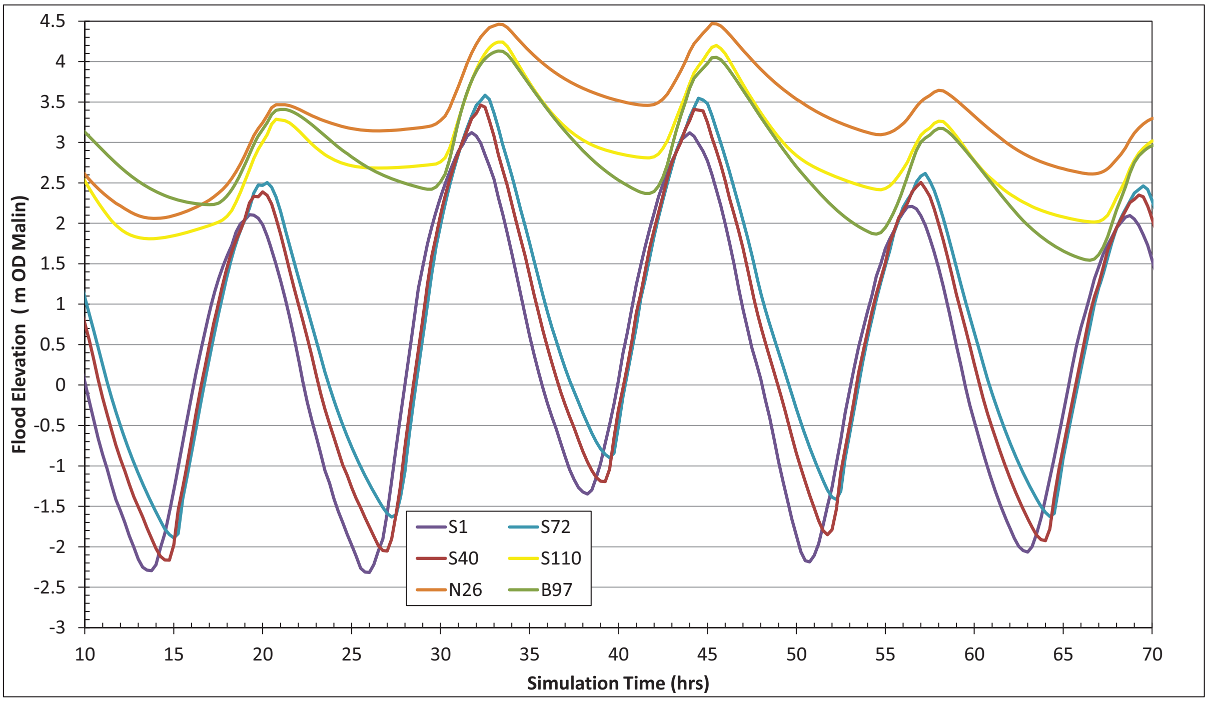


**Figure 14** **Computed Water Level Hydrographs at selected reference nodes for simulation 3 (refer to Figure 8 for node reference locations)**

**Table 3** **Maximum Flows and Flood Levels at Reference Sites for Simulation 3 (200yr Tide plus 100year Fluvial Flood event)**

| Reference Site | Water level m OD | Max ebb Flow cumec | Max Flood Flow cumec |
|---|---|---|---|
| S110 | 4.241 | 568 | 114 |
| S86 | 3.707 | 994 | -535 |
| S72 | 3.584 | 1634 | -1272 |
| S60 | 3.477 | 2241 | -1771 |
| S52 | 3.471 | 2264 | -1808 |
| S40 | 3.462 | 2296 | -1861 |
| S22 | 3.330 | 6239 | -5964 |
| S1 | 3.122 | 20956 | -25322 |
| B40 | 3.603 | 1394 | -406 |
| B97 | 4.130 | 340 | 77 |
| N26 | 4.470 | 579 | 95 |

Opposite the Waterford SDZ at Section S52 the flow characteristics can be summarised as an average incoming flood tide flow rate of 986cumec over a 4.75hour period producing an inflow volume of some 16.85 million $m^3$. The average outflowing, ebb tide flow rate is 1,663cumec over a 7.25hour period and represents a total outflow volume of 45.65million $m^3$ at a maximum flood level of 3.471m O.D. These represent significant ebbing and flooding flow rates in the estuarine channel adjacent to the SDZ land (model sections 42 to 57) and the available cross-sectional area within the estuarine channel adjacent to the SDZ is 2843$m^2$ (flow area). The potential loss of overbank section area by developing the SDZ is 44$m^2$ and represent only 1.52% of the total cross-sectional flow area at highwater. Such a small change in available flow area is shown by the hydraulic modelling to have no

discernible impact on peak flood levels in the Suir. The flood storage volume available on the site at the peak flood level of 3.471m OD, based on the Apex topographical survey, is 51,659m$^3$. This is only a small fraction of the 45.65million m$^3$ flood volume passing the site (0.113%) on the ebbing tide.

## *6.4 Simulation 4 – Spring tide combined with 100year fluvial flood in the Nore, Suir and Barrow*

This simulation is a mean spring high tide combined with the 100year fluvial flood flow in the Barrow, Nore and Suir. Such a combination investigates the significance of the fluvial flood event under normal spring tide conditions in Waterford Harbour.

Under these conditions the computed incoming (flooding) tidal flow in the Suir estuary at Section S23 just upstream of Cheekpoint near the Barrow confluence is 1,404cumec over a 5.25hour flood tide period. This represents an inflow volume of some 25.87 million m$^3$ of water into the Suir Estuary. The ebbing tide characteristics of this simulation give an outgoing ebb flow period of 7.25hours, an average ebb flow rate of 2,037cumec and a total outflowing volume of 54.07million m$^3$.

The Barrow and Nore Estuarine system at Section B5 just upstream of the Suir confluence near Cheekpoint has an average incoming flow rate over a 4.25hours flood tide period of 875cumec and an incoming volume of some 13.80million m$^3$. On the outgoing ebbing tide which lasts for 8.25hours of the 12.5hour tidal cycle, the average ebb flow is 1,790cumec representing a total outflow volume of 52.33 million m$^3$.

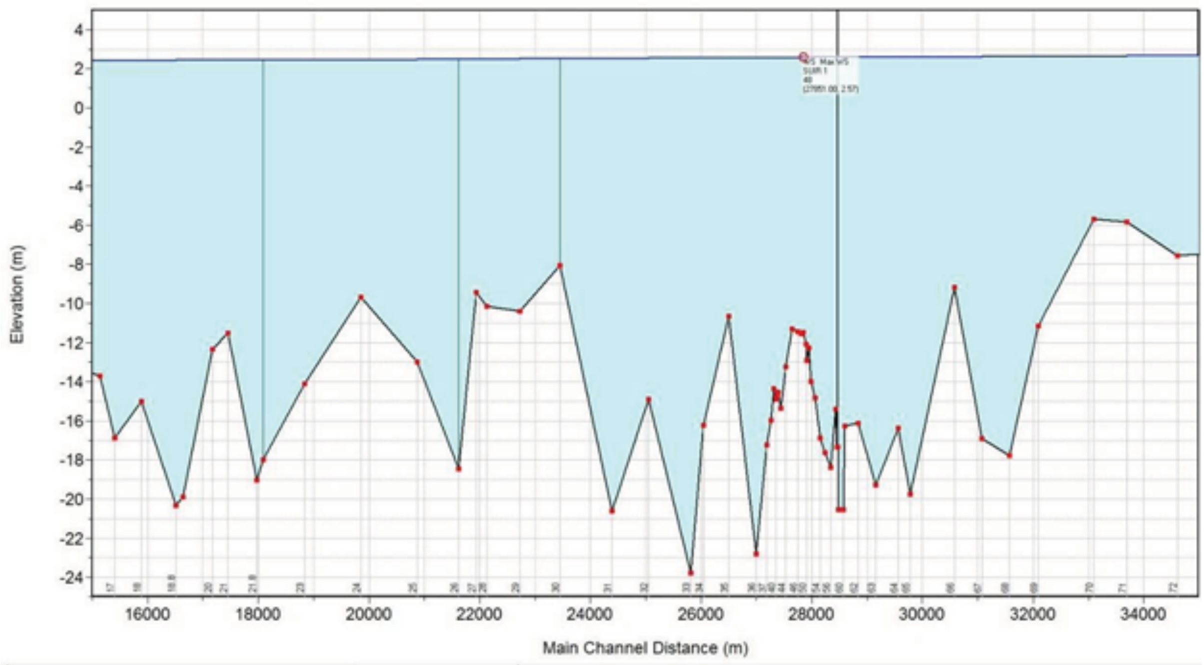


**Figure 15 Flood profile for Simulation 4 showing maximum computed water level profile in section of Suir adjacent to the Waterford SDZ - flood level typically 2.57m OD Malin**

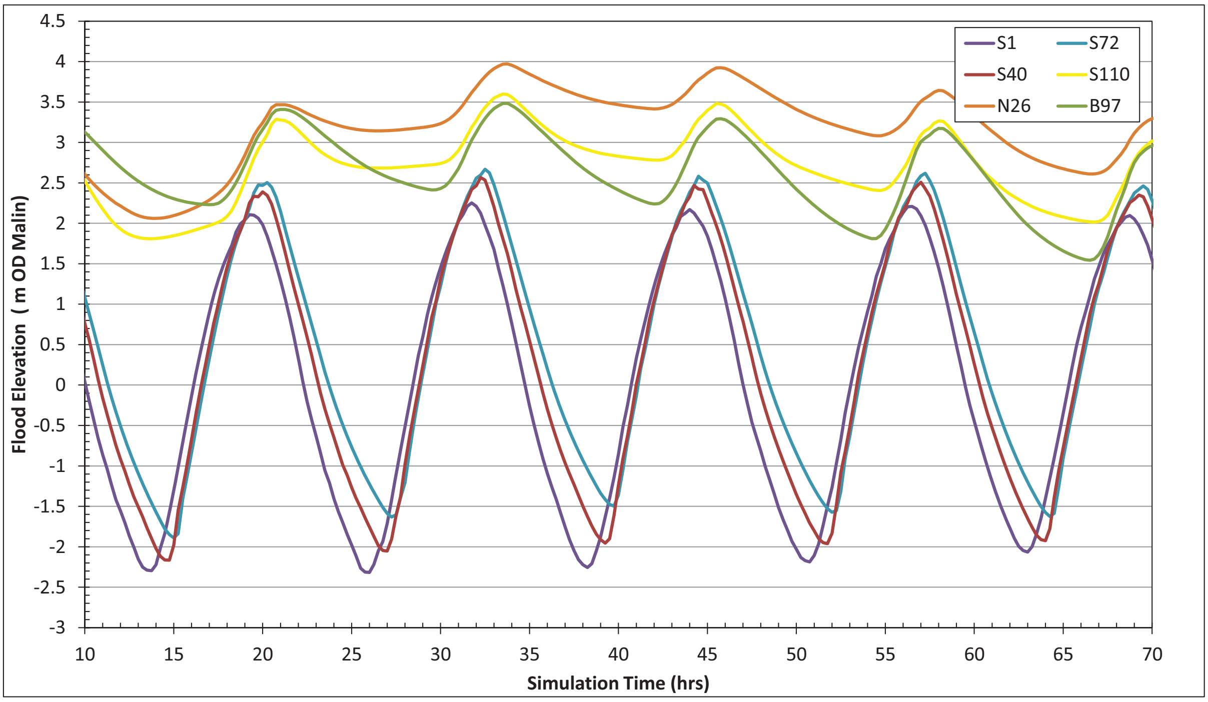


**Figure 16** **Computed Water Level Hydrographs at selected reference nodes for simulation 4 (refer to Figure 8 for node reference locations)**

**Table 4** **Maximum Flows and Flood Levels at Reference Sites for Simulation 4 (Spring Tide plus 100year Fluvial Flood event)**

| Reference Site | Water level m OD | Max ebb | Max Flood |
|---|---|---|---|
| | | Flow cumec | Flow cumec |
| S110 | 3.599 | 558 | 114 |
| S86 | 2.780 | 869 | -535 |
| S72 | 2.668 | 1449 | -1272 |
| S60 | 2.574 | 1998 | -1694 |
| S52 | 2.571 | 2022 | -1724 |
| S40 | 2.566 | 2056 | -1768 |
| S22 | 2.446 | 5546 | -5081 |
| S1 | 2.252 | 19340 | -19445 |
| B40 | 2.731 | 1247 | -406 |
| B97 | 3.483 | 338 | 77 |
| N26 | 3.971 | 579 | 95 |

Opposite the Waterford Strategic Development Zone at Section S52 the flow characteristics can be summarised as an average incoming flood tide flow rate of 697cumec over a 4.25hour period producing an inflow volume of 10.66 million $m^3$. The average outflowing, ebb tide flow rate is 1,380cumec over an 8.25hour period representing a total outflow volume of some 39.73million $m^3$ at a maximum flood level of 2.57m O.D. These flows represent significant ebbing and flooding flowrates in the estuarine channel adjacent to the SDZ land (model sections 42 to 57). However the available cross-sectional area within the estuarine channel adjacent to the SDZ at a flood level of 2.57m OD is significant at 2614$m^2$ (flow area). The potential loss of overbank section area by developing the SDZ at a flood level of 2.57m OD is only c. 2$m^2$, which is only 0.07% of the total cross-sectional flow area and such

a small change has no discernible impact on peak flood levels in the Suir. The flood storage volume available on the SDZ site at the peak flood level of 2.57m OD, based on the Apex topographical survey, is 6,573m$^3$. This is only a small fraction of the 39.38million m$^3$ outgoing flood volume passing the site (0.017%).

### *6.5 Simulation 5 – Spring tide combined with 1000year fluvial flood flow in the Nore, Suir and Barrow*

This simulation is a mean spring high tide combined with the estimated 1000year fluvial flood flow in the Barrow, Nore and Suir. Such a combination investigates the significance of the fluvial flood event under normal spring tide conditions in Waterford Harbour.

Under these conditions the computed incoming (flooding) tidal flow in the Suir estuary at Section S23 just upstream of Cheekpoint near the Barrow confluence is 1,262cumec over a 4.75hour flood tide period. This represents an inflow volume of 21.02 million m$^3$ of water into the Suir Estuary. The ebbing tide characteristics of this simulation give an outgoing ebb flow period of 7.75hours, an average ebb flow rate of 2,068cumec and a total outflowing volume of 56.75million m$^3$.

The Barrow and Nore estuarine system at Section B5 just upstream of the Suir confluence near Cheekpoint has an average flow rate over a 3. 5hours flooding tide of 628cumec and an incoming volume of 8.22million m$^3$. On the outgoing ebbing tide which lasts for 9.0hours of the 12.5hour tidal cycle, the average ebb flow is 1,812cumec representing a total outflow volume of 57.04 million m$^3$.

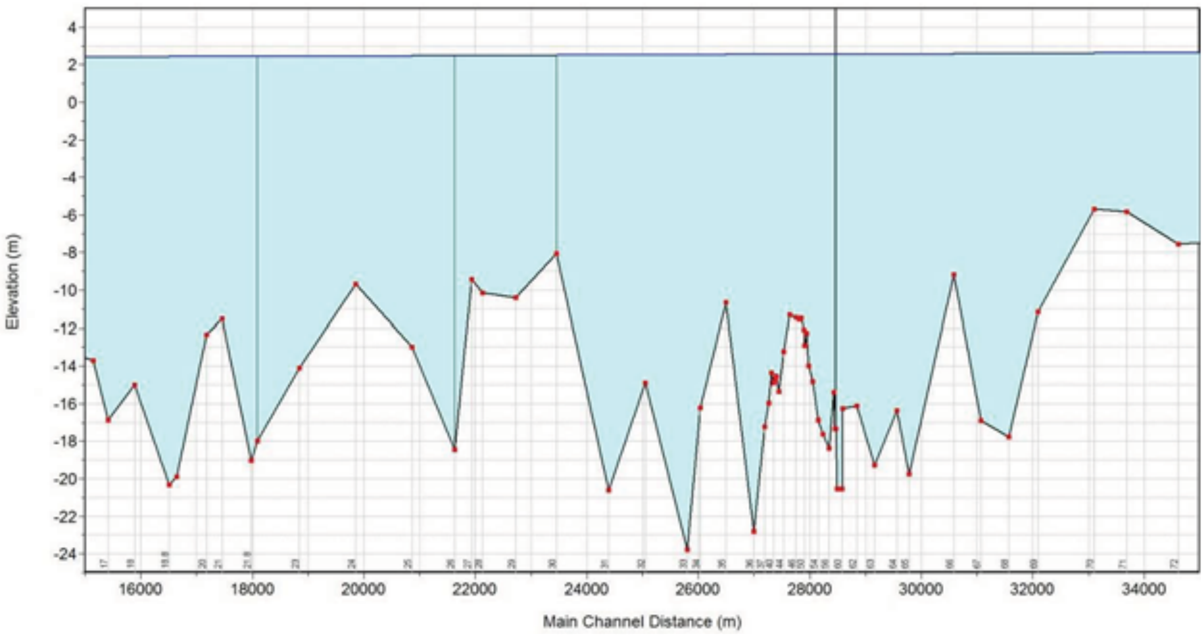


**Figure 17 Flood profile for Simulation 5 showing maximum computed water level profile in section of Suir adjacent to the Waterford SDZ - flood level typically 2.55m OD Malin**

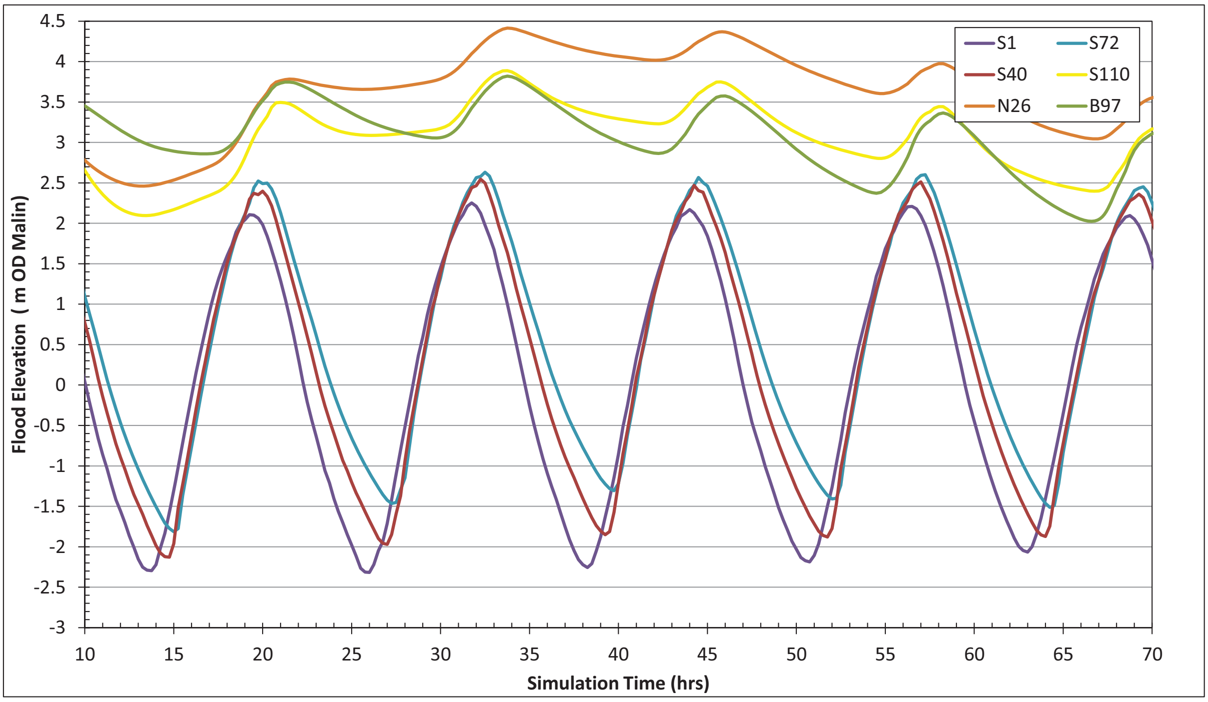


**Figure 18** **Computed Water Level Hydrographs at selected reference nodes for simulation 5 (refer to Figure 8 for node reference locations)**

**Table 5** **Maximum Flows and Flood Levels at Reference Sites for Simulation 5 (Spring Tide plus 1000year Fluvial Flood event)**

| Reference Site | Water level m OD | Max ebb Flow cumec | Max Flood Flow cumec |
|---|---|---|---|
| S110 | 3.888 | 688 | 129 |
| S86 | 2.766 | 949 | -504 |
| S72 | 2.631 | 1488 | -1261 |
| S60 | 2.552 | 2044 | -1680 |
| S52 | 2.548 | 2067 | -1710 |
| S40 | 2.545 | 2100 | -1754 |
| S22 | 2.443 | 5642 | -5008 |
| S1 | 2.252 | 19474 | -19396 |
| B40 | 2.781 | 1414 | -311 |
| B97 | 3.820 | 417 | 83 |
| N26 | 4.414 | 724 | 105 |

Opposite the Waterford Strategic Development Zone at Section S52 the flow characteristics can be summarised as an average incoming flood tide flow r ate of 509cumec over a 4hour period producing an inflow volume of 7.13million $m^3$ and an average outgoing, ebb tide flow of 1,419cumec over a 8.5hour period representing a total outflow volume of 43.07million $m^3$ at a maximum flood level of 2.55m O.D. These flows represent significant ebbing and flooding flowrates in the estuarine channel adjacent to the SDZ land (model sections 42 to 57). However the available cross-sectional area within the estuarine channel adjacent to the SDZ at a flood level of 2.55m OD is significant at approximately 2612$m^2$ (flow area). The potential loss of overbank section area by developing the SDZ at a flood level of 2.548m OD is c. 2$m^2$ , which is only 0.07% of the total cross-sectional flow area and such a small change

has no discernible impact on peak flood levels in the Suir. The flood storage volume available on the SDZ site at the peak flood level of 2.55m OD, based on the Apex topographical survey, is 6,401$m^3$. This is only a small fraction of the 43.07million $m^3$ outgoing flood volume passing the site (0.015%).

## 7. Discussion

The critical event for generating maximum flood levels within the Suir Estuary study reach at Waterford is a storm surge event combining with high Spring Tide period. The coinciding of such tidal events with Fluvial flood flows in the Suir, Nore and Barrow provides little effect on highwater flood levels in the estuary at Waterford, with a 100year fluvial flood providing only a 0.08m rise over a 2year fluvial flood event and 0.22m increase over a median (50-percentile) river flow at high tide. Fluvial Flood Events combined with Spring tides are not critical and do not cause flooding in the Suir estuarine reach at Waterford.

### *7.1 Flood Impact*

The effect of the SDZ development in terms of loss of potential flood storage and the presence of the proposed Bridge and support piers is found to have no perceptible impact on Flooding.

### *7.2 Flood Zones*

The Flood Zones A, B and C for the study area are determined using the OPW lidar data and the Apex topographical Survey for the SDZ Site (Site Contour Map presented in Figure 19).

These flood zones are determined using a combined 200year Flood level of 3.37m OD and a 1000year combined flood level of 3.61m OD. A Flood Zone map is presented in Figure 20 and shows virtually the entire SDZ site to be located within the High flood Risk Zone A except for stock piles of building rubble.

### *7.3 Recommended Minimum Development Level*

The Recommended Development level for setting finish floor levels is the 200year tide combined with the 100year fluvial Flood 3.47m OD plus 0.5m freeboard (for uncertainty including local wave wake effects) and medium range sea level rise plus isostatic land tilt adjustment of 0.550m. This gives a minimum development level of 4.42m O.D at the medium range sea level rise and 4.92m OD at the high range sea level rise.

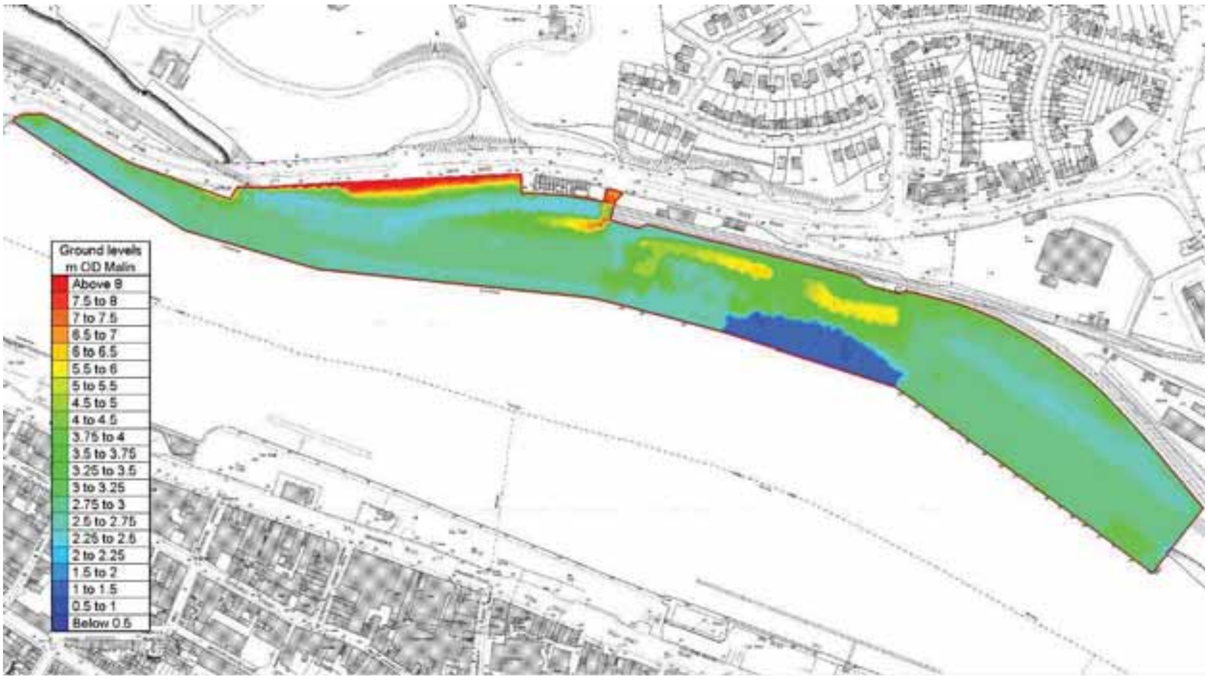


**Figure 19 Topographical contour Map of SDZ lands on the North Bank**

**Figure 20 Flood Zone Mapping for SDZ Site and surrounding lands (Blue is Flood Zone A, Cyan is Flood Zone B and Orange is Flood Zone C)**

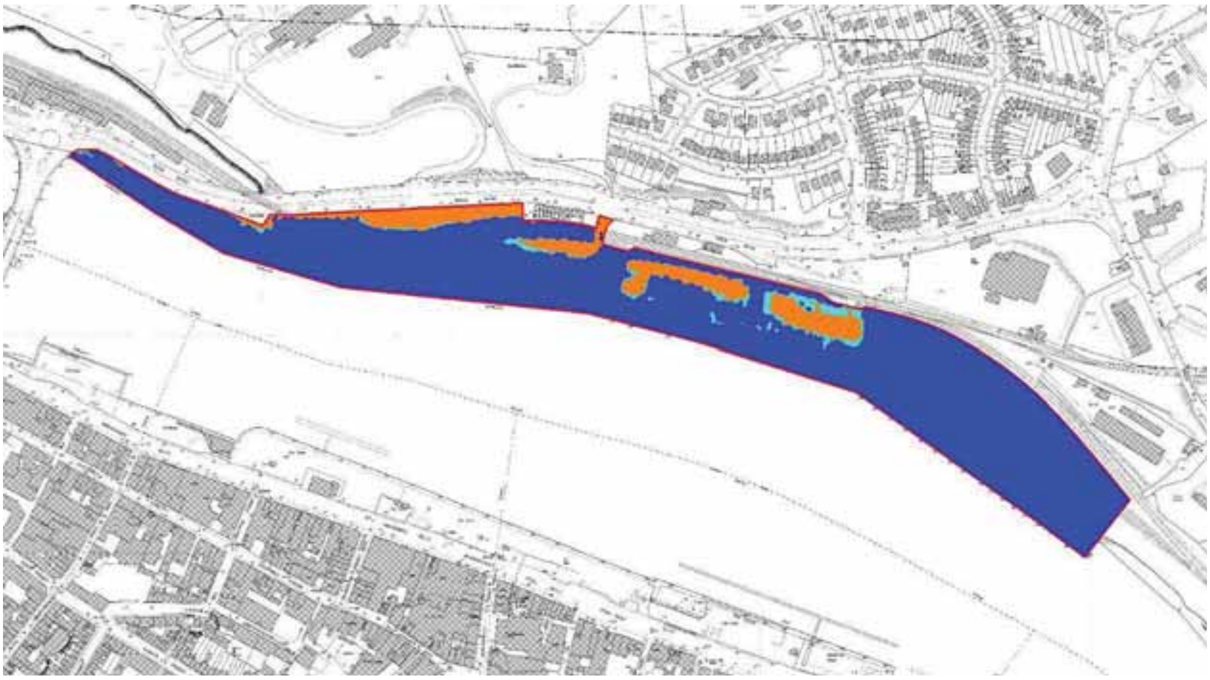

**Figure 21 Flood Zone Mapping at SDZ Site (Blue is Flood Zone A, Cyan is Flood Zone B and Orange is Flood Zone C)**

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