6. Model calibration

6.1 Introduction

The first step of the calibration process is to calibrate the model to an in-bank event in order to demonstrate the ability of the 1D component of the model to reproduce water levels in the main River Corrib. This gives confidence that the 1D schematisation, structure representation, head losses and Manning's parameters in the 1D model are correctly represented. The second step of the process is to calibrate the model to an out-of-bank event in order to demonstrate the ability of the full model to reproduce water levels across the entire floodplain. When a good calibration is achieved against both in-bank and out-of-bank events it gives confidence that the model is able to reproduce the mechanisms of flooding.

As noted in Section 2.5 three historic events have been selected as calibration/validation events and these are listed in the following table.

Table 15 Events used to calibrate the Galway City model

Date	Flood source	Peak flow/level (severity)	Data
Fluvial: Feb-Mar 2020	Fluvial in bank event (~1 in 10)	$343m^3/s$ – all gates open	Gauge data (in bank) at 3 gauging stations (waterlevel.ie).
Fluvial: February 2022	Fluvial in bank event (<1 in 2)	$230m^3/s$ - all gates open	Gauge data (in bank) at 5 gauging stations (waterlevel.ie).
Tidal: Feb 2014	High tide, storm surge & wave overtopping (~1 in 20)	3.59m AD - all gates open	Gauge data at 3 gauging stations (waterlevel.ie) Photographs, wave data, tide data, flood extents, threshold & topo surveys of affected areas around Claddagh, Father Griffin, Spanish Arch and Docks (JBA flood event report)

6.2 Calibration model boundary conditions

6.2.1 Upstream boundaries – Calibration inflows

Data recorded at Dangan gauge during all three calibration events has been used as the upstream flow boundary for the River Corrib in the calibration modelling. The inflows were applied at the upstream boundary of the model at the outfall of Lough Corrib which is located approximately 5km upstream of the Dangan gauge.

Checks have been completed to ensure the peak flows and shape of hydrograph is maintained as it travels from the Lough to the gauge. An example of this is presented in Figure 6.2.1 which considers the February 2020 event. It can be seen from the plot that the shape and peak of the hydrograph is maintained between the two sections of the model i.e., at the upstream boundary where the Dangan gauged data is applied and at the gauge itself. There is a slight phase lag on the rising limb of the hydrograph.

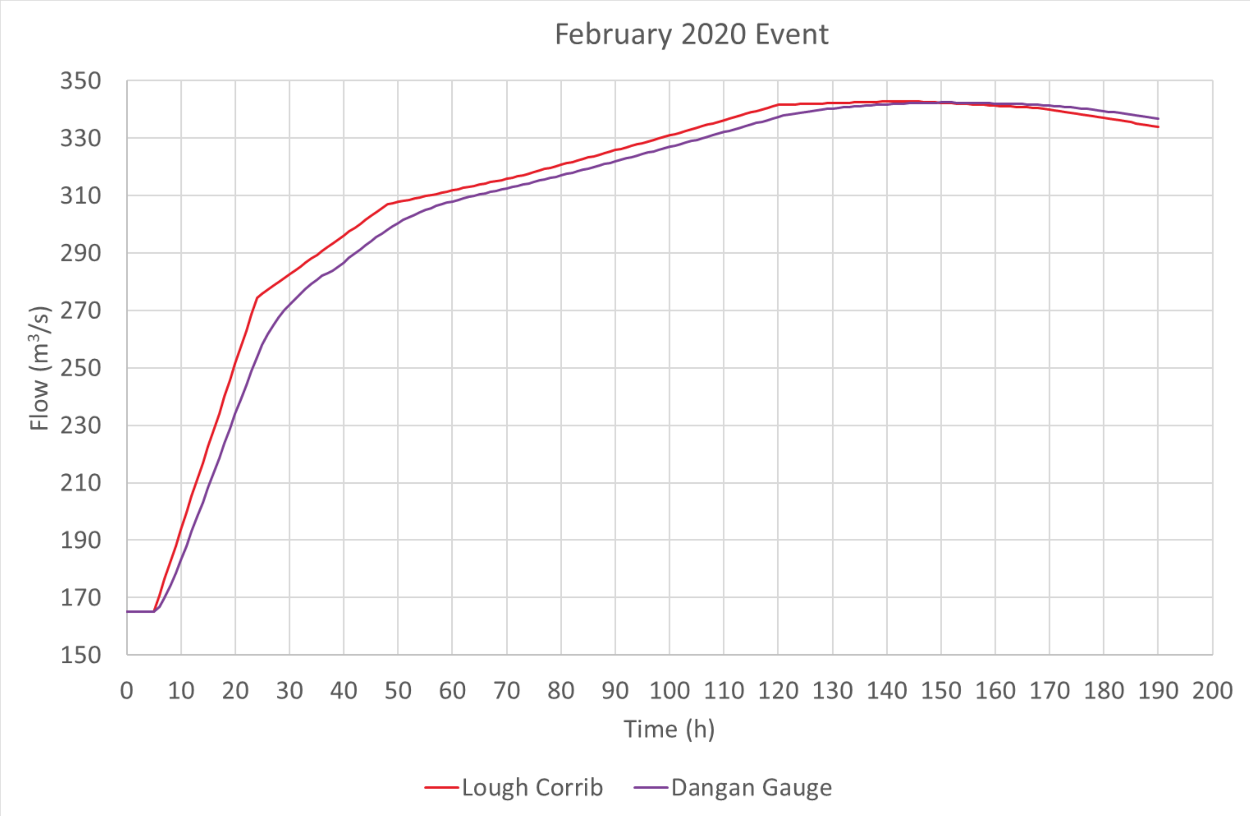

Figure 6.2.1 February 2020 event hydrograph from the Dangan gauge in the model at the upstream boundary node (Lough Corrib), and at the location of the Dangan gauge in the model

6.2.2 Downstream boundary – Galway Bay water levels

Data recorded at Galway Port during each of the calibration events has been used as the downstream water level boundary of the calibration model. Data from this gauge is deemed suitable for use given its close proximity to the location of the downstream boundary.

6.3 Overview of the adjustments made to the model as part of the calibration process

The project brief sets out the required accuracy of calibrated model. It states that the calibration "shall aim to achieve vertical accuracies of +/-100mm, and no greater than +/-200mm when compared to recorded flood event point data". Furthermore, it is noted that the Scottish Environment Protection Agency (SEPA) guidance document on hydraulic modelling states that "high confidence" in the hydraulic modelling of "local scale or detailed studies" is achieved when the "tolerances for peak water level are in the order of +/-150 mm".[22] This criterion is also considered as part of this study.

The model was calibrated by adjusting the following set of parameters:

- Manning's number within the river channel;
- Adjusting Salmon Weir discharge coefficient;
- Salmon Weir Bridge pier width, ineffective flow areas and calibration coefficient.

All the above adjustments are described in detail in Section 5.4.

Due to hydrograph shape the peak flow of each of the calibration events is in effect steady for a number of days.

[22] https://www.sepa.org.uk/media/219653/flood_model_guidance_v2.pdf

It is therefore useful to consider both the average and maximum differences between the modelled and recorded water level as part of the calibration assessment. The average is calculated for the period shown on the calibration plots.

6.4 In bank calibration - February 2020 event

The February 2020 event approximates to a return period of circa 10 years on the River Corrib. The peak flow in the Corrib reached 343m^3/s and the peak tidal level reached 2.51m AOD.

Figure 6.4.1 presents the modelled and recorded water level at the Dangan gauge for the event as well as the differences between them. The grey dashed line also depicts the modelled water levels from the initial run undertaken with the model i.e., before the various calibration adjustments were applied to the model. It can be seen from the figure that the Arup model post calibration (blue line) is well matched to the recorded data at Dangan (orange line) across the full duration of the hydrograph. The difference between the model and the recorded data varies from 43-190mm across the simulation (shown in dotted blue line on the secondary axis). The average difference is circa 126mm which is circa 26mm above the specified vertical accuracy of the brief.

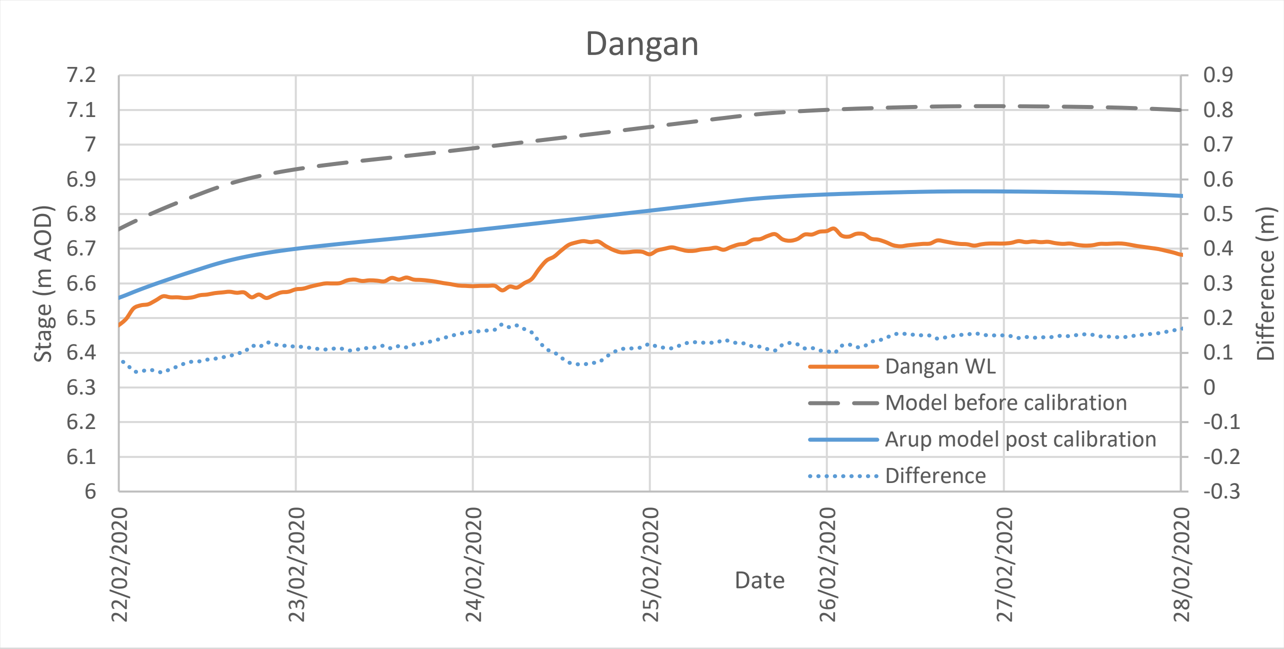

Figure 6.4.1 February 2020 event - Dangan Gauge

Figure 6.4.2 presents the modelled and recorded water level at the Barrage U/S gauging station for the event as well as the differences between them. It can be seen from the figure that the Arup model post calibration (blue line) is very well matched to the recorded data at Barrage U/S (orange line) across the full duration of the hydrograph. The dotted grey line shows the difference between the modelled and recorded values. The difference varies from 6-117mm and the average difference across the event is 73mm. This falls below the 100mm vertical accuracy specified by the Project brief.

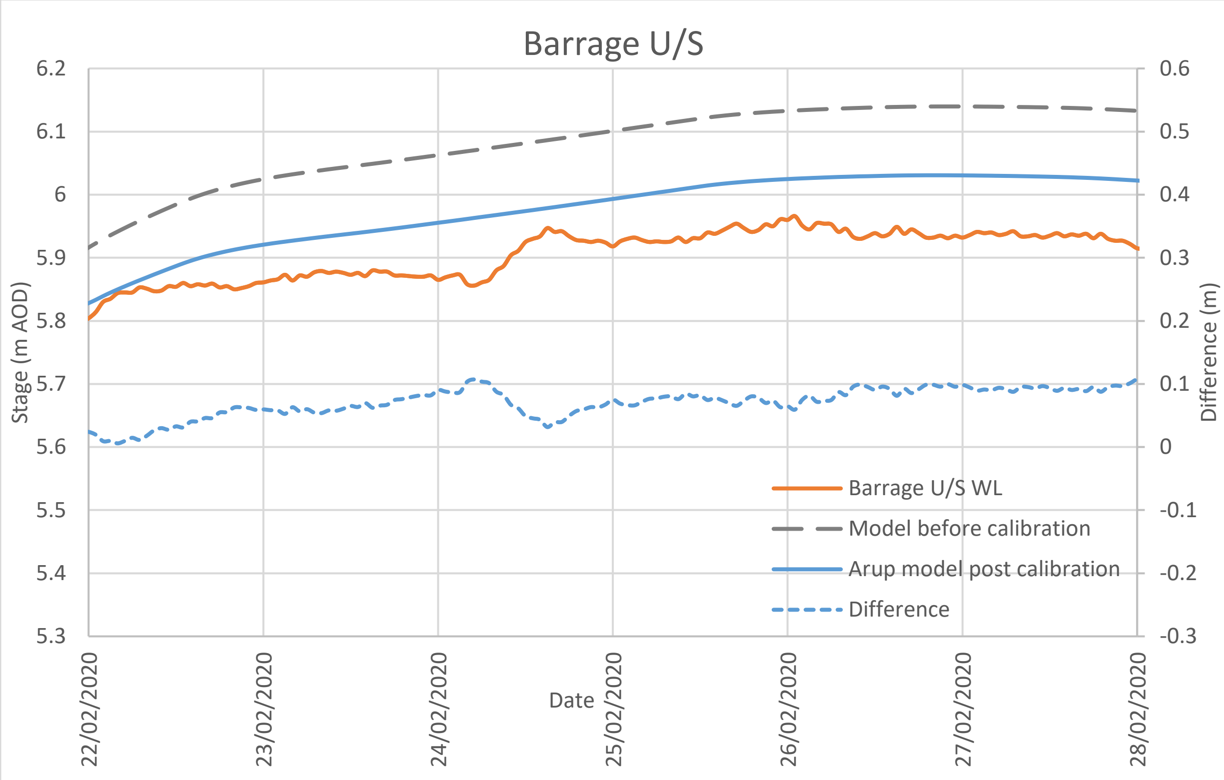

Figure 6.4.2 February 2020 event – Barrage U/S Gauge

Figure 6.4.3 presents the modelled and recorded water level at Wolfe Tone Bridge tidal gauge for the event and the difference between them. It is noted that the Wolfe Tone bridge gauge records are somewhat noisy as they are subject to surface wave actions and turbulence downstream of the bridge. Despite this, it can be seen from the figure that the post calibration model (blue line) follows the recorded tidal signal quite well and that the high-water peaks are reasonably well matched.

The difference in the water level at high tide varies across the different peaks from 0mm to circa 200mm. The average difference at peaks is circa 58mm which falls below the 100mm specification of the brief.

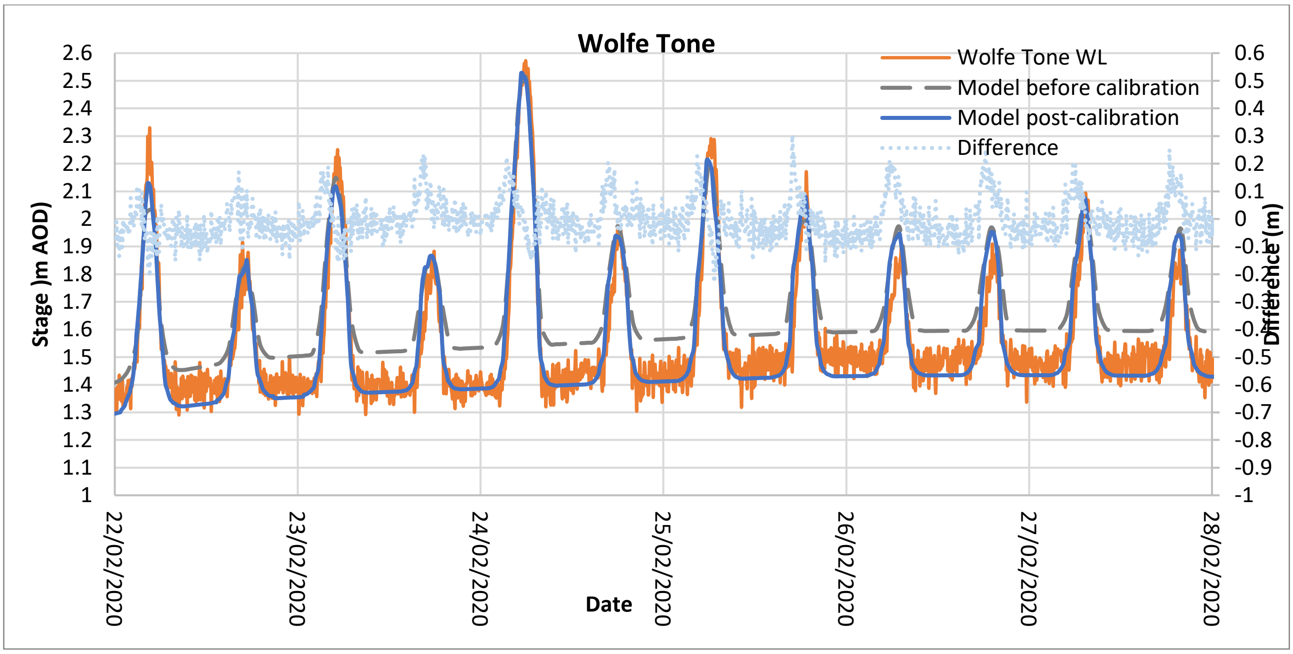

Figure 6.4.3 February 2020 event – Wolfe Tone Bridge Gauge

It can be seen from the results that the modelled water levels compare well with the recorded data for the February 2020 event at the various gauging stations.

6.5 In bank calibration - February 2022 event

The February 2022 event happened after the installation of two new gauges in the River Corrib as part of the Galway City FRS. Although the event is relatively minor (circa 2-year event on the Corrib) it is a very useful calibration as it allows for modelled water levels to be compared at five different gauges through the reach: Dangan, Quincentennial Bridge, Barrage U/S, Barrage D/S and Wolfe Tone Bridge gauges.

Figure 6.5.1 presents the modelled and recorded water level at Dangan gauging station for the event as well as the differences between them. It can be seen from the figure that the Arup model post calibration (blue line) is well matched to the recorded water levels. The modelled data follows the overall pattern of the recorded data with a small phase lag between them. The difference between the recorded and modelled levels ranges from 17-104mm. The average difference in levels is 73mm.

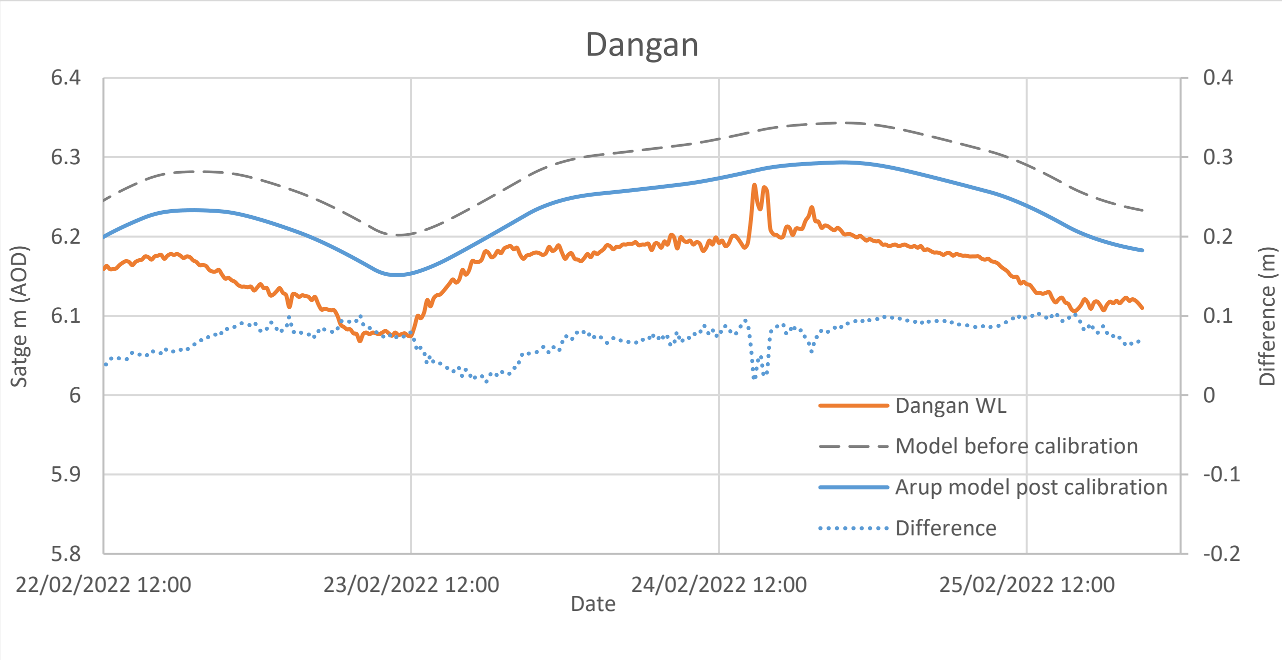

Figure 6.5.1 February 2022 event - Dangan Gauge

At the other gauge station downstream (the Quincentennial Bridge and Barrage U/S) the difference between the model and the recorded data is less than 100mm. At Quincentennial Bridge gauge (presented in Figure 6.5.2) the differences range between 0-48mm and the average difference is circa 11mm. At Barrage U/S gauge (presented Figure 6.5.3) the differences between the recorded and modelled levels ranges from 0-59mm and have an average difference in levels of circa 15mm.

At both these gauges, the model is in very good agreement with the recorded water levels and is well below the 100mm tolerance as specified by the project brief.

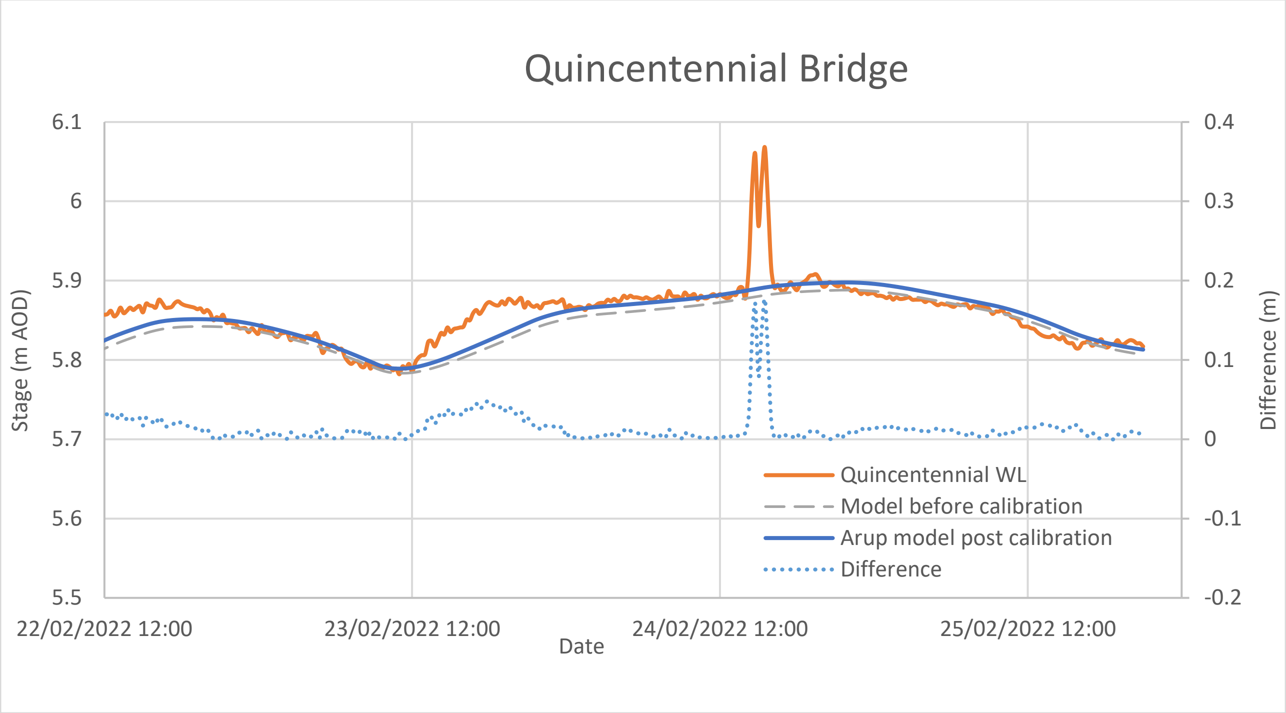

Figure 6.5.2 February 2022 event – Quincentennial Bridge Gauge

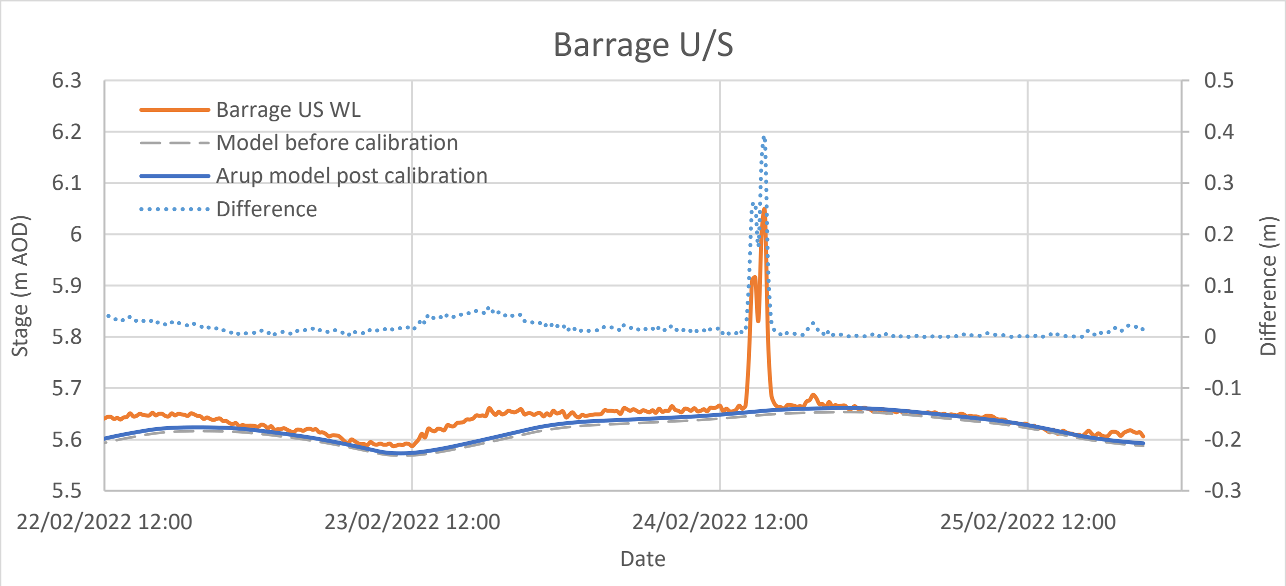

Figure 6.5.3 February 2022 event – Barrage U/S Gauge

Downstream of the Salmon Weir, at Barrage D/S gauging station the difference between the model and the recorded data ranges from 41mm to 213mm (refer to Figure 6.5.4) as the model is underestimating the design water levels through the reach. The average difference is 108mm which is marginally above the specified tolerance in the brief.

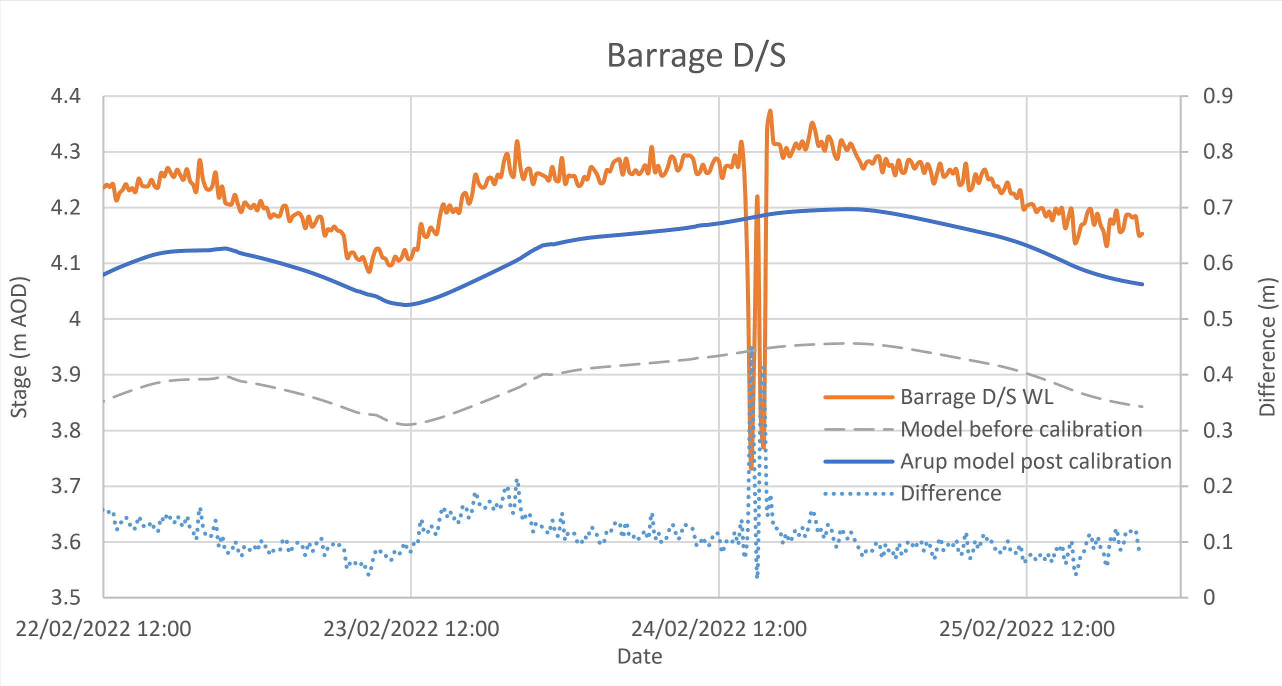

Figure 6.5.4 February 2022 event – Barrage D/S Gauge

Overall, the model performs very well and is well calibrated to the February 2022 event. At the majority of the gauging stations the differences between recorded and modelled levels falls below the 100mm tolerance as specified in the brief. The only station where it exceeds the tolerance is as the Barrage D/S and in this case, it is only 8mm above it which is deemed to be marginal. This provides confidence in the ability of the model to reproduce in bank flows along the River Corrib.

6.6 Out of bank calibration (February 2014 event)

Once a very good in-bank calibration was achieved, the February 2014 tidal event was simulated with the 1D/2D fluvial/tidal hydraulic model.

Figure 6.6.1 presents the maximum modelled flood extent overlaid on the observed flood extents along with the location of all the properties that were observed to be flooded. The modelled flood extent is generally in agreement with the observed properties flooded. This is most prominent along Father Griffin Road, Raven Terrace, Dock Road, Quay Street, Flood Street and Merchants Road Lower.

There is however a notable difference between the modelled extent and the observed extent as the modelled extent inundates a larger area. As discussed in Section 2.5.5, the observed flood extents were derived from on-site records and observations following on from the event and are therefore subject to uncertainty. And as also discussed in Section 2.5.5, when the observed flood extent is compared with the flood extent that would likely result from a peak tidal water level of 3.5mOD (i.e. the water level that was recorded at Wolfe Tone Quay during the event) it was seen that the observed extent is very likely to be underestimated. It is therefore not deemed valid to compare the modelled extent to the observed extent.

It is instead considered more appropriate to compare the modelled flood extents with the extent that is derived by taking a horizontal cut of 3.5m AOD through the Lidar dataset as presented in Figure 2.5.7 in 2.5.5 and also presented in Figure 6.6.2 below. When the modelled extent is compared to this extent it can be seen that they are well correlated which offers further confidence in the model. [23]

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[23] Use of the word "probable" on the figure refers to areas that were likely to have been flooded during the event but for which the CFRAM consultant were unable to confirm with absolute certainty due to lack of evidence.

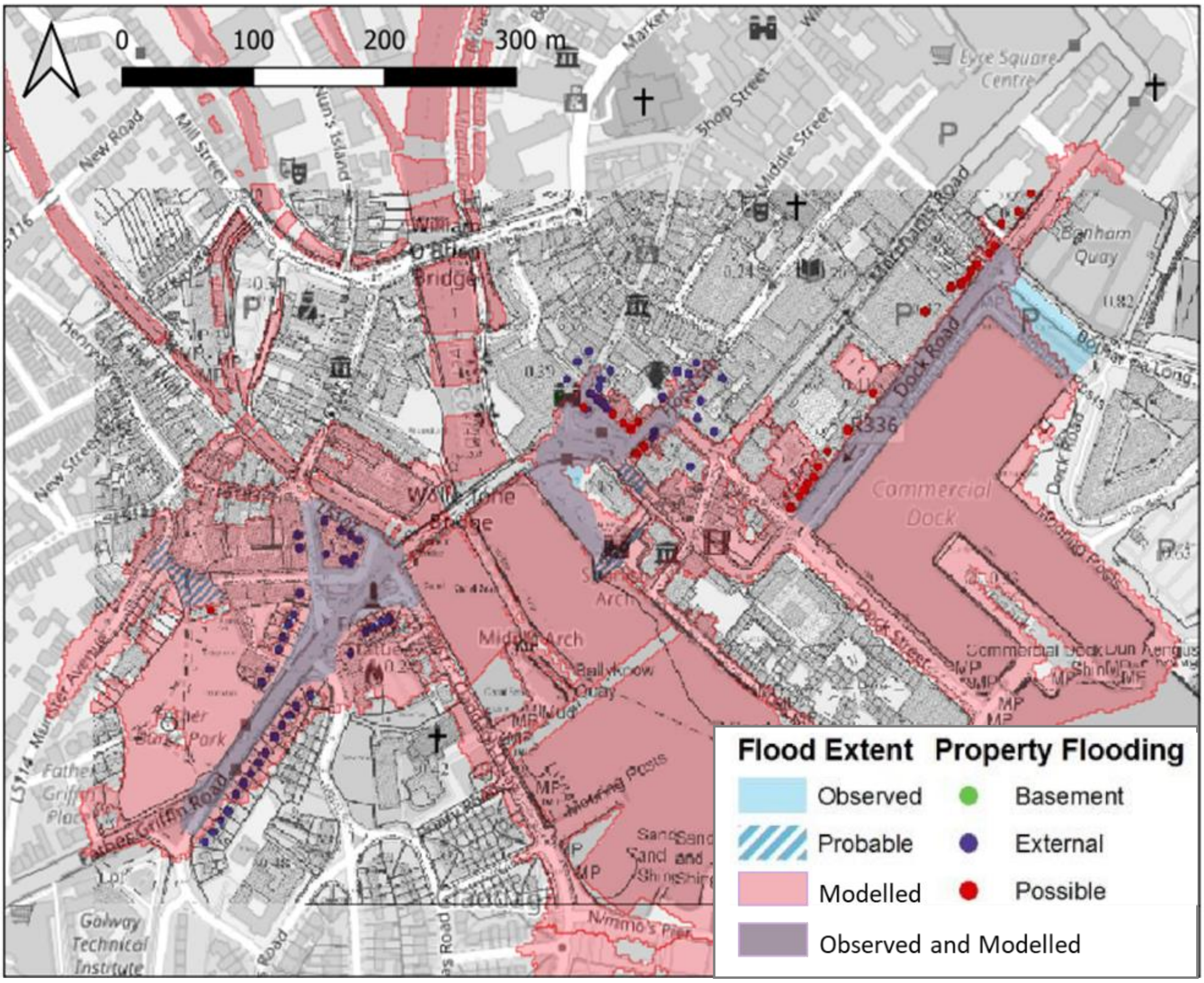

Figure 6.6.1 Arup modelled extent overlaid on JBA recorded flood extents, February 2014

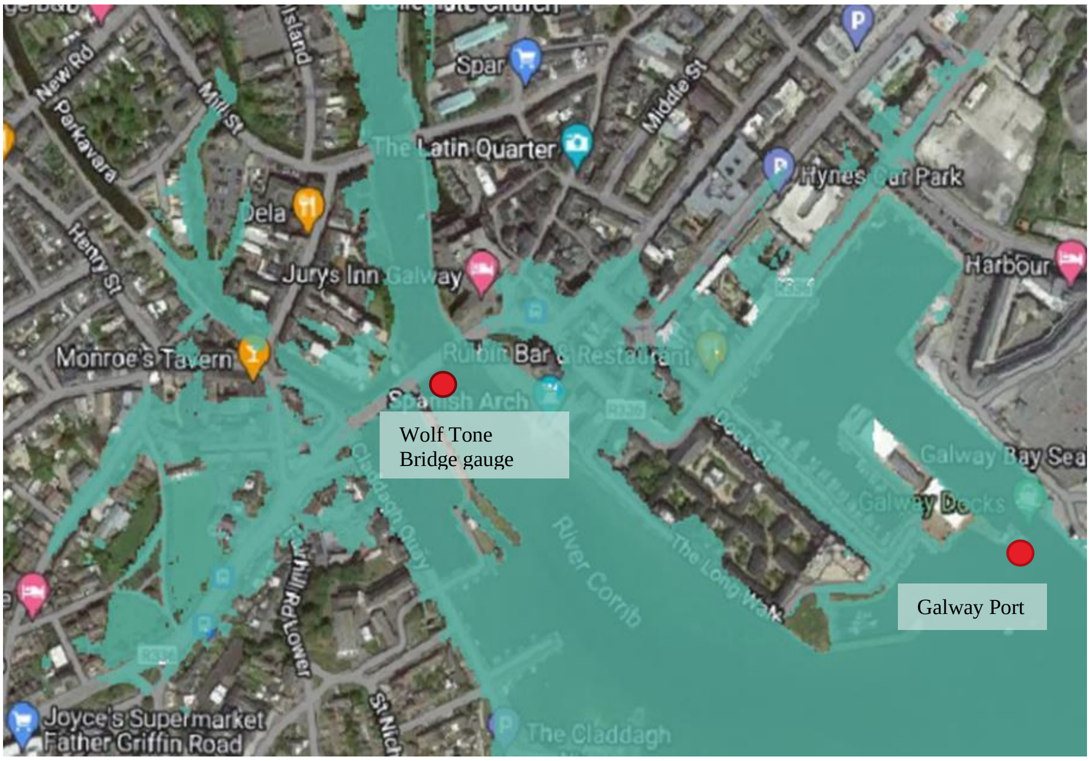

Figure 6.6.2 Lidar extents below the 3.5m AOD level

6.7 Conclusion of the hydraulic model calibration

The 1D/2D fluvial/tidal hydraulic model has been calibrated against recorded water level data for two separate in-bank events from 2020 and 2022. The model has also been validated against the tidal out-of-bank flood event from February 2014.

In assessing the overall performance of the model, the accuracy tolerances as detailed in the project brief needs to be considered. This states that the model “shall aim for the calibrated models to have vertical accuracies of +0.1m, but not greater +0.2m, when compared to recorded flood event point data”.

It is also useful to consider model tolerances as specified by SEPA. This states that high confidence in the hydraulic modelling is achieved when the tolerances for peak water level are in the order of +/-150 mm.

The model is able to reproduce the general shape of the hydrographs very well across all the gauges for the two in-bank events. The models overpredicts the flood levels at Dangan gauge by on average 126mm and 73mm respectively for the 2020 and 2022 events which exceeds the lower tolerance as specified by the brief, but which is less that the higher tolerance (see Figure 6.4.1 and Figure 6.5.1). Both of the differences are lower the high confidence tolerance of the SEPA guidance.

The overprediction however does not carry through to the downstream locations. At Quincentennial Bridge, the average difference is reduced significantly to 12mm during the 2022 event and to 15mm at the Barrage U/S gauge which demonstrate a very close match between the model and the data.

The Barrage U/S gauge overpredicts the 2020 event by circa 73mm which is also less than the specified tolerance. Downstream the Salmon Weir, at Barrage D/S gauge the model underpredicts the levels during the February 2022 event by on average 108mm which is only marginally above the tolerance of 100mm. At Wolfe Tone Bridge, the model simulates the tidal water levels very well and matches the high-water peaks very closely. The average difference in the peaks is circa 58mm for the 2020 event. Both of the differences are lower than the high confidence tolerance specified by the SEPA guidance.

The model is shown to be well calibrated to the observed flooded properties during the 2014 tidal event. While the model does not closely match the recorded extent of the flood as reported by Western CFRAM consultants, it is noted that this recorded extent is likely to be underestimated. As part of the calibration, we have approximated the 2014 extent derived by considering the recorded peak tidal water from the Wolfe Tone gauge. When this extent is compared with the model it can be seen that they are well matched.

When all of the calibration runs are considered, it is evident that the 1D/2D fluvial/tidal hydraulic model is able to reproduce maximum flood extents and maximum water levels within the specified tolerances across the study area for small and large flood events. The model is therefore deemed suitable to simulate design model runs as part of the study.

The standalone 2D coastal model has not been calibrated to any historic event due to (a) a lack of suitable data with which to derive calibration boundary conditions, and (b) the overall uncertainly associated with WOT methods. This however does not impact on the findings of the coastal model as the model has been developed following the best practice internationally: high-quality data has been used to define the geometry of the model and the realism of the model has been assessed in the detail. Further we note that the design run coastal model results (presented in the following chapters) are comparable with the results of the fluvial/tidal 1D/2D model in the common area of the models. This allows us to draw further confidence on the performance of the coastal model particularly given that the 1D/2D model has been calibrated against recorded data.

7. Design runs – Fluvial dominated

7.1 Design model runs

The calibrated fluvial/tidal model was used to simulate the design model runs for the study. A total of 8 model runs have been simulated for the fluvial dominated current scenario as listed in Table 16. The peak upstream inflow on the Corrib and the peak tidal water level downstream used for each of the fluvial dominated runs are also shown in Table 16. The approximate return period of the tidal boundary has been calculated through a Joint probability analysis, please refer to the Hydrology report for more details.

Additional runs were also undertaken as part of the sensitivity analysis and for the assessment of the impact of climate change. These are described in Section 10 of the report.

The flood extents, depth and velocity maps can be found in GIS format within the GIS deliverables package, in Appendix A. A list of the GIS deliverables is included in Appendix A.

Table 16 Fluvial design model runs

Model Run Name	Scenario	Design Event	Upstream Peak Flows (m^3/s)	Downstream tidal boundary in Galway Bay (m AOD)
Q2	Fluvial	50% AEP	255.8m^3/s (50% AEP)	2.10m AOD (<1 in 1 year event)
Q5	Fluvial	20% AEP	304.0m^3/s (20% AEP)	2.28m AOD (<1 in 1 year event)
Q10	Fluvial	10% AEP	335.7m^3/s (10% AEP)	2.42m AOD (<1 in 1 year event)
Q20	Fluvial	5% AEP	366.4m^3/s (5% AEP)	2.56m AOD (<1 in 1 year event)
Q50	Fluvial	2% AEP	406.0m^3/s (2% AEP)	2.74m AOD (<1 in 1 year event)
Q100	Fluvial	1% AEP	435.7m^3/s (1% AEP)	2.87m AOD (<1 in 1 year event)
Q200	Fluvial	0.5% AEP	465.4m^3/s (0.5% AEP)	3.01m AOD (<1 in 1 year event)
Q1000	Fluvial	0.1% AEP	533.8m^3/s (0.1% AEP)	3.33m AOD (25% AEP)

7.2 Flood extents and nodes

Flood extents are presented in shapefile format as a digital deliverable accompanying this report. The shapefiles are in compliance with Appendix G (I) of the OPW FRS Engineering Spatial Data Specification[24] as per the instruction in the project brief. Defended runs are presented.

Maximum water levels and flow rates at each of the nodes in the 1D model for the full range of return periods events are presented in tables in Appendix B-1. Longitudinal maximum water levels for the primary reaches are also presented in Appendix B-1.

It should be noted that the flow reported is extracted from the 1D nodes only and does not include any flow on the floodplain.

The results for each AEP event for the current scenario are discussed in the following sections of the report.

7.3 Discussion of the fluvial flood risk - Current scenario

The baseline design model runs assume that blockages do not occur at any of the culverts or bridges in the model. A blockage sensitivity and their impact on flood risk will however be assessed as part of the optioneering and be discussed in the Options report.

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[24] Office of Public Works (September 2021), *Flood Relief Scheme Engineering Spatial Data Specification,* online gov.ie - Technical Specifications and Guidance Notes (www.gov.ie)

The baseline runs are also defended runs as they include the existing formal defences of the study area. The ineffective flow area at the Salmon Weir bridge (as discussed earlier in the report) has been accounted for in the model by removing the first of the arches from the bridge geometry in the model.

Following a detailed review of the flood extents from the Sruffnacashlaun stream/culvert, it was agreed by the Steering Group to exclude the catchment from the Flood Relief Scheme for Galway. Flood risk within this particular small and heavily urbanised catchment is a function of the drainage system and therefore falls outside of the scope of this flood relief scheme. A localised drainage-specific study that considers all of the various components of the drainage network (i.e. all the manholes, pipes, gullies etc.) is needed and GCC has noted that this item of work will be progressed separately to the scheme. As such, the produced flood maps for CgC FRS (extents, depths and velocities) does not include the flood extents from the Sruffnacashlaun stream/culvert. As flows from the Sruffnacashlaun catchment still need to be accounted for as part of the hydraulic modelling, given its connection to Distillery Channel and River Corrib, the Sruffnacashlaun Stream/culvert was maintained in the model.

The Menlo area has been modelled in 1D-only. Flood extents and depths for this area have been added to the GIS deliverables. Notable results are discussed in the following sections.

The following sections of the report present a discussion on the baseline design runs. Images of the inundated flood extents have been included along with the text to aid the reader. The reader is however referred to the accompanying GIS files for the entire modelled flood extents. The description of flood risk is discussed from downstream of the Study area at Galway City Centre to the upstream reach towards the Dangan area.

The number of properties inundated by the design runs is approximate and will be updated when the damages assessment has been completed. A table listing the finalised and confirmed number of both residential and commercial properties inundated by both fluvial and tidal flooding will be presented in the final version of the hydraulics report.

7.4 50% AEP (Q2) event

There is no out of bank flooding around the River Corrib or its mill races and canals for the Q2 event. Some out of bank flooding is expected to the west of the Dyke Road embankment in the green area that lies between the embankment and the left bank of River Corrib. The embankment itself is not overtopped for any event up to the 1% AEP.

Out of bank flooding is observed around the Coolough lakes and in the vicinity of Jordan’s cut (west of Jordan’s island). No properties are however at risk from this.

7.5 20% AEP (Q5) event

The Q5 maximum modelled extent is very similar to the Q2 maximum extent along the Corrib. The additional volume of water associated with the Q5 event increases water levels and hence flood depths above the Q2 event, but it does not lead to any significant increase in the maximum flooded extent.

The maximum flooded extents in the undeveloped areas west of the Dyke Road embankment and around the Coolough lakes (Figure 7.5.1) are greater when compared to the Q2 event due to the relatively flat gradient of the areas i.e., the greater water level associated with the event inundate a larger area. No properties are however at risk of flooding from the Q5 event in this area.

Figure 7.5.1 Q5 fluvial flood extents around the Dyke Road embankment

7.6 10% AEP (Q10) event

The Q10 maximum modelled extent is similar to the Q5 maximum extents. There are however small increases in the extents west of the Dyke Road embankment and around the Coolough lakes. No properties are at risk in this area.

7.7 5% AEP (Q20) event

The model results indicate that the Q20 events stays in bank in Galway City Centre. There is small increase in the maximum flooded extent on the undeveloped land on Jordan's island and the RB of River Corrib east of Corrib Village. Water gets out of bank on the right-hand side of the river Corrib at a forested area located to the east of the ground of the University of Galway. No properties are however at risk of flooding.

7.8 2% AEP (Q50) event

A very minor volume of water overtops the Claddagh Quay road from the Claddagh/River Corrib for the Q50 event. This therefore represents the threshold of flooding for fluvial dominated events in the City Centre even though the flooded extent along the Claddagh Quay road is very minor (Figure 7.8.1).

Figure 7.8.1 Q50 fluvial flood extents near the Dyke Road embankment

The flood extents in the undeveloped areas near Dyke Road embankment, Jordan’s island, and the forested area near the University of Galway are increased when compared to the Q20 flood extent.

7.9 1% AEP (Q100) event

The Q100 event is the design event of the proposed scheme. Flooding in Galway City for this event results from water getting out of bank at the Claddagh Quays and along the right bank of the Eglinton Canal at Raven Terrace (Figure 7.9.1). Flood water in the event propagates from the Claddagh Quay and the Eglinton Canal to Father Griffin Road, Father Burke Park and to Munster Avenue. A commercial property is at risk of inundation on Munster Avenue and the ground floor of two residential blocks on Father Burke Road is also at risk of inundation.

Figure 7.9.1 Q100 fluvial flood extents near Claddagh Quay

Further upstream, the crest level of the Dyke Road embankment is sufficiently elevated to prevent water overtopping the structure and inundating the Terryland area from the River Corrib. The flood extents on the right bank of the River Corrib at the forested area in the vicinity of the University of Galway are increased when comparted with the Q50 extent. No properties are however at risk for the Q100 event.

While water gets close to properties in the Menlo area, no finished floor level is exceeded, so no property is considered at risk.

7.10 0.5% AEP (Q200) event

The maximum flood extents west of the Claddagh basin are notably larger for the Q200 event when compared to the Q100 extents. The majority of Father Burke park is inundated and the ground floor of several additional properties between Father Burke Road and Dominick Street Upper are also at risk of flooding (Figure 7.10.1). Several additional commercial properties on Fairnhill Road upper are also at risk. A number of residential properties are also inundated on Father Griffin Road.

Figure 7.10.1 Q200 fluvial flood extents near Claddagh Quay

Water gets out of the left bank of the Eglinton Canal for the Q200 event and inundated Atlanta House.

Both the Gaol river and St Clare river overtop their banks during the Q200 event. This event therefore represents the threshold of flooding along these watercourses. Overtopping at Gaol river (NUNS) occurs upstream of the University of Galway Old engineering building due to the limited capacity of the culverts underneath the building which causing backwatering and overtopping of the banks upstream of the building. This causes a number of properties on the left bank of the Gaol river to be inundated before floodwater re-enters the River Corrib further downstream. The St Clare river (GMRA) is overtopped upstream of St. Josephs Patrician (The 'Bish') School penstocks and leads to a number of residential properties along Presentation Road and Mill Street to be inundated. Flood water flows down Mill Street to Parkavara Street before re-entering the canal system at Parkavara Stream (Figure 7.10.2).

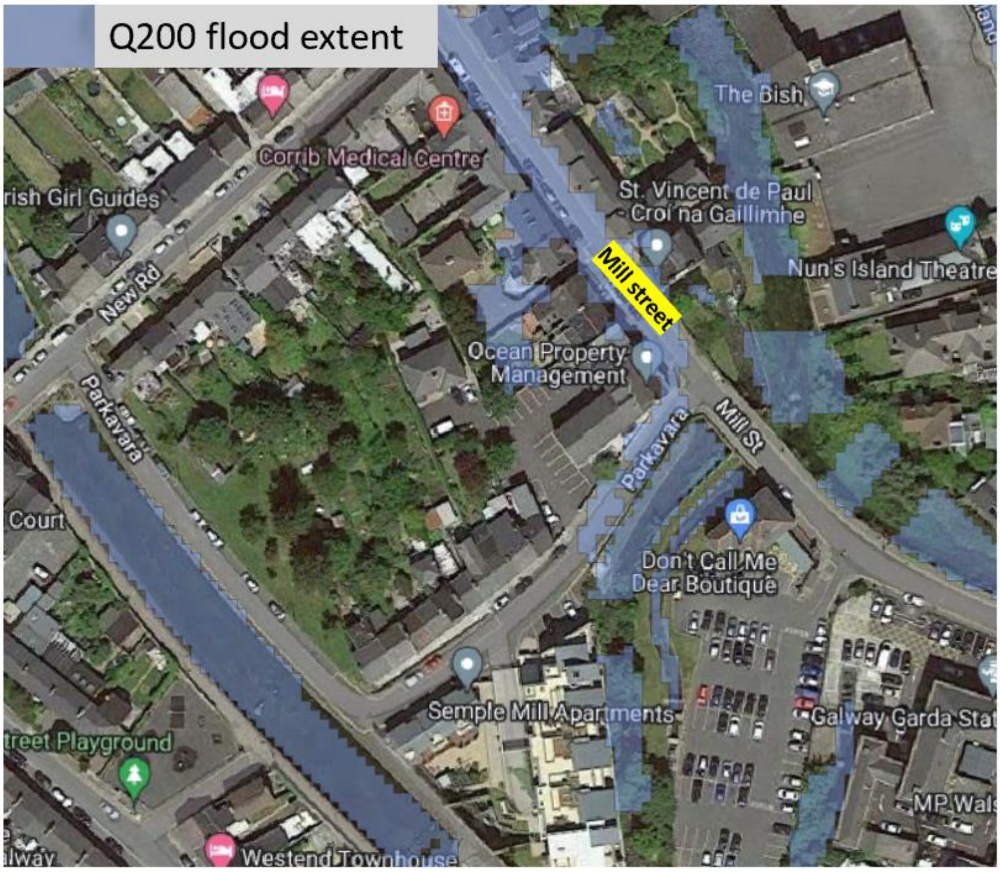

Figure 7.10.2 Q200 fluvial flood extents near Mill street

Flooding occurs along the right bank of the Eglinton canal and at its upstream confluence with the River Corrib. The Corrib Rowing and yacht club car park and building are inundated by this mechanism.

The lowest elevated sections of the Dyke Road embankment are overtopped in the Q200 event which therefore represents the threshold of flooding of the embankment. The overtopping is restricted to an 80m length of the embankment and the peak flow overtopping the embankment is 0.5m3/s which is insufficient to cause any properties within the Terryland area to be inundated.

The area in the vicinity of a small number of residential properties at Menlo to the north of the city is inundated by the Q100 event. The properties are not however at risk as we have confirmed from threshold survey data that the FFL of the properties is elevated above the Q100 design water.

7.11 0.1% AEP (Q1000) event

The Q1000 leads to extensive flooding of the City Centre. Overtopping of the right bank of the Eglinton Canal inundates large areas and multiple properties between Munster Avenue and Claddagh Quay. Flooding along the left bank of the Eglinton Canal is also extensive and leads to the inundation of a number of properties on both sides of Dominick Street Lower (Figure 7.11.1).

Figure 7.11.1 Q1000 fluvial flood extents near Claddagh Quay

The left bank of the River Corrib is overtopped at the Spanish Arch quays in the Q1000 event and leads to the surrounding roads such as Spanish Parade and Merchants Road Lower to be inundated.

The Middle River overtops its left bank and leads to a number of properties to be inundated such as the Spanish Arch MSCP, the Leonardo Hotel and properties along Kirwan's Lane. Wolfe Tone bridge is overtopped and overland flow paths from the bridge cause flooding of Quay Street, Quay Lane and Flood Street and the surrounding buildings (Figure 7.11.2). Further upstream, the Middle River overtops its left bank and leads to the inundation of Bowling Green and the surrounding properties. The Docks are also overtopped and leads to minor flooding along Dock Street.

There is extensive flooding in the Q1000 event around Presentation Road, Mill Street and Nuns island from overtopping of the St Clare River (GMRA) and Gaol River (NUNS) upstream of St. Josephs Patrician (The 'Bish') School Penstocks and the Old engineering building, respectively.

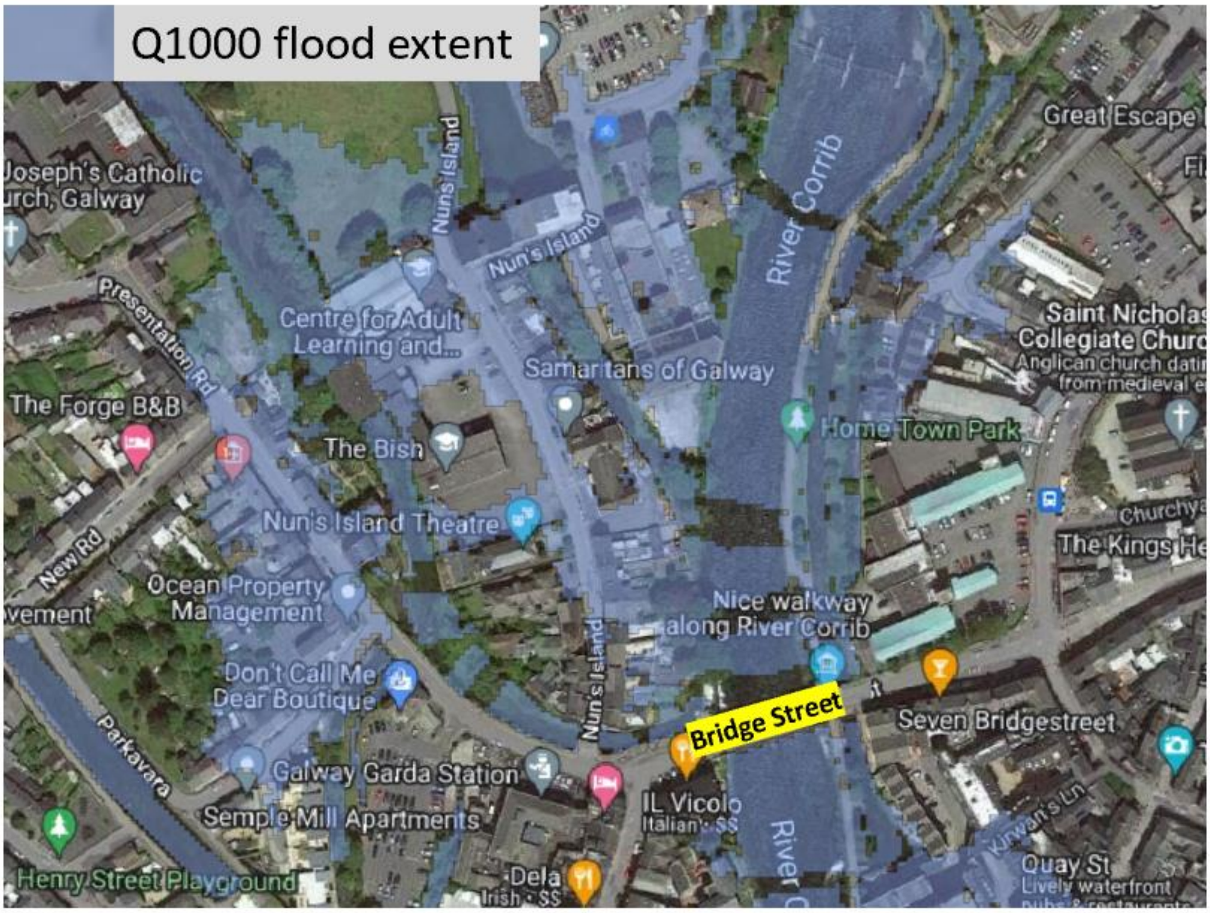

Figure 7.11.2 Q1000 fluvial flood extents near Bridge street

The Dyke Road embankment is overtopped in the Q1000 event and leads to the inundation of a large area of the Terryland catchment the majority of which is undeveloped natural floodplain. A number of commercial properties located west of Headford Road are however at risk of inundation from this. Approximately 14 commercial properties are at risk within the Terryland area from this event.

As with the Q100 event, the area in the vicinity of a small number of residential properties at Menlo is at inundated by the Q1000 event. One of the properties is at risk from the event as the FFL of the other properties are elevated above the design Q1000 water level.

7.12 Summary of results

The maximum fluvial flood extent in Galway City for the design Q100 event are not significant as the flows are largely contained within the river channels and canals.

The principal fluvial mechanism of flooding during the design event is water getting out of bank at the Eglinton Canal and Claddagh Basin due the influence of the tide on the total water levels. The tidal boundary used in the analysis for the Q100 is 2.87m AOD, which is less than the estimated 1 in 1 year flood event.

For the Q200 and Q1000 events, the Dyke Road embankment is overtopped which leads to extensive flooding in Terryland. The quays at Spanish Arch and the left bank of the Middle River are also overtopped for the Q200 and Q1000 events and lead to flooding of Galway City to the east of the River Corrib.

The total number of properties inundated for each AEP for the fluvial dominated case is presented in the table below (Table 17).

Table 17 Number of properties inundated for the fluvial dominated case

AEP	Residential	Commercial	Total
50% (2yr)	0	0	**0**
20% (5yr)	0	0	**0**
10% (10yr)	0	0	**0**
5% (20yr)	1	0	**1**
2% (50yr)	1	0	**1**
1% (100yr)	14	5	**19**
0.5% (200yr)	65	23	**88**
0.1% (1000yr)	190	103	**293**

The findings of the study will be brought forward to optioneering stage of the project where additional options to mitigate the risk will be developed. This work will be reported on in the Options report.

8. Design runs – Tidal dominated

8.1 Design model runs

The calibrated model was used to simulate the design model runs for the study. In total 8 design model runs have been simulated for the tidal dominated current scenario as listed in Table 18. Additional runs were also undertaken for the assessment of the impact of climate change and are described in Section 10 of the report. The upstream peak flow and downstream peak tidal level used for the tidally dominated runs are shown in Table 18. The approximate return period of the fluvial boundary has been calculated through a Joint probability analysis, please refer to the Hydrology report for more details.

The upstream flow boundary has been set to a minimum flow of 165m^3/s in order to prevent drying of the canal systems and watermills which causes the model to go unstable. These are listed in the table below.

The flood extents, depth and velocity maps can be found in GIS format within the GIS deliverables package, in Appendix A. A list of the GIS deliverables is included in Appendix A.

Table 18 Tidal design model runs

Model Run Name	Scenario	Design Event	Downstream tidal boundary in Galway Bay (m AOD)	Recommended flow from JP analysis (m^3/s)	Upstream Peak Flows used in model (m^3/s)
T2	Tidal	50% AEP	3.19m AOD (50% AEP)	0m^3/s	165m^3/s
T5	Tidal	20% AEP	3.36m AOD (20% AEP)	12.5m^3/s	165m^3/s
T10	Tidal	10% AEP	3.48 m AOD (10% AEP)	49.0m^3/s	165m^3/s
T20	Tidal	5% AEP	3.60 m AOD (5% AEP)	86.0m^3/s	165m^3/s
T50	Tidal	2% AEP	3.75m AOD (2% AEP)	134.0m^3/s	165m^3/s
T100	Tidal	1% AEP	3.87 m AOD (1% AEP)	175.0m^3/s (>50% AEP)	175.0m^3/s

Model Run Name	Scenario	Design Event	Downstream tidal boundary in Galway Bay (m AOD)	Recommended flow from JP analysis (m^3/s)	Upstream Peak Flows used in model (m^3/s)
T200	Tidal	0.5% AEP	3.98 m AOD (0.5% AEP)	207.0m^3/s (>50% AEP	207.0m^3/s
T1000	Tidal	0.1% AEP	4.25m AOD (0.1% AEP)	292.0m^3/s (<50% AEP, >20% AEP)	292.0m^3/s

8.2 Discussion of the tidal flood risk - Current scenario

The baseline design model runs assume that blockages do not occur at any of the culverts or bridges in the model. A blockage sensitivity and their impact on flood risk will however be assessed as part of the optioneering and be discussed in the Options report.

The baseline runs are defended runs, with the existing formal defences included in the model. The ineffective flow area at Salmon Weir Bridge has been accounted for in the model.

The following sections of the report present a discussion on the baseline design runs. The reader is referred to the accompanying GIS files for the modelled flood extents. The description of flood risk is discussed from downstream of the Study area at Galway City Centre to the upstream reach towards the Dangan area. The number of properties reported are indicative and will be updated when the damages assessment is completed.

8.3 50% AEP (T2) event

The results of the hydraulic model indicate that there are a few minor areas in the City Centre that are at risk of flooding from the T2 event. The areas are all immediately adjacent to the River Corrib downstream of Wolfe Tone bridge and in and around the area of the Docks. There are also open spaces around the Spanish Arch and the Long Walk and Dock Street that are at risk.

The threshold of tidal flooding for the City centre is therefore the T2 event which is deemed to be very low.

In terms of properties, the Spanish Arch building, and parts of a building within the Dock area are at risk of flooding.

8.4 20% AEP (T5) event

The modelled maximum T5 flood event inundates a wider area of the City centre than the T2 event and includes Flood Street, Spanish Parade and Merchant Road Lower (Figure 8.4.1). Most of the Long Walk and Dock Street are inundated and flooding is also expected to inundate parts of Dock Road.

Figure 8.4.1 T5 tidal flood extents near the port area

The right bank of the River Corrib downstream of Wolfe Tone Bridge and the Claddagh Quay is also overtopped by the T5 tide and inundates Claddagh Quay road, low lying parts of Grattan Road, Nimmo’s Pier and low-lying parts of South Park. Raven Terrace, Father Griffin Road, Father Burke Road, low lying parts of Munster Avenue as well as sections of Father Burke Park are also inundated by the T5 event.

A number of properties around Father Burke Road and Park are at risk of inundation by the event.

8.5 10% AEP (T10) event

The maximum extent of the T10 event along the left bank of the River Corrib is similar to the T5 flood extent. Dock Road is fully inundated from overtopping of the Galway Docks and water propagates to the western parts of Queen Street. Properties along Quay Lane, Spanish Parade, Flood Street and Dock Road are at risk of flooding (Figure 8.5.1).

Figure 8.5.1 T10 tidal flood extents near the port area

West of the Claddagh, overtopping of the Claddagh Quays and the right bank of the Eglinton Canal result in a slight increase in the flood extents that inundate the majority of Father Burke park and a series of apartments located between Dominick St Upper and Father Burke Road. The left bank of the Eglinton Canal before its confluence with the Corrib is also overtopped during the event and inundates Atlanta House and a number of other surrounding properties. Nimmos Pier is also overtopped causing extensive flooding of South Park but there are no properties at risk.

8.6 5% AEP (T20) event

Overtopping of the Docks during the T20 event leads to the inundation of a number of commercial properties along Dock Road. Some additional properties on Merchant's Road Lower are also inundated by inundation of tidal water originating from both the Spanish Parade and the Docks.

West of the Claddagh, the flood extents are generally similar to T10 extents. There is however some additional flooding on Father Burke Park and flooding of Dominick Street Upper which is caused by the overtopping of the Eglinton Canal at Dominick Str Lower and as well as from Father Burke Road.

8.7 2% AEP (T50) event

The T50 tidal event leads to the inundation of properties along Dock Road, Queen Street and Flood Street. The extent also impacts residential properties situated along the Long Walk.

On the right bank of the Eglinton Canal, flooding on Dominick Street Upper and Dominick Street Lower extends to the surrounding properties, with approximately 15 additional properties included within the flood extent when compared to the T20 (Figure 8.7.1). The Claddagh Hall and other buildings within South Park adjacent to Nimmos Pier are also inundated by the T50 event.

Figure 8.7.1 T50 tidal flood extents near the port area

8.8 1% AEP (T100) event

The maximum modelled T100 flood extents are similar to the T50 flood event given that the increase in the tidal water level associated with the T100 event is largely bounded by the existing ground levels. The flood depths are however greater.

There is however an increased extent to the east of the Galway docks due to existing ground levels in this area being flatter than to the West of the Corrib. The increased extent leads to a number of additional properties being inundated: 3 properties along Queen Street, 1 property along Spanish Parade, 2 additional properties on Quay Street and a single property on Druid Lane.

The T100 extents are also slightly larger compared to the T50 west of the Claddagh basin with an additional 3 properties at risk of inundation along Claddagh Quay and a number of properties along Munster Avenue also at risk (Figure 8.8.1).

Figure 8.8.1 T100 tidal flood extents near the port area

Flooding on the left bank of the Eglinton Canal extends as far as Dominick Street Lower and presents a risk to a number of properties on the street.

8.9 0.5% AEP (T200) event

The T200 event is the design tidal standard of the scheme. The modelled maximum T200 extent is broadly similar to the T100 extent due to the existing ground levels preventing the higher water level associated with T200 event from inundating a wider area.

The key areas at risk of flooding for this event are the area in the vicinity of Galway Docks and the lower reach of the Eglinton Canal, areas at the west of the Claddagh between Father Griffin Road and Munster Avenue (including Father Burke Park), properties along Grattan Road and South Park grounds and buildings. Approximately 300 properties in total are inundated during the T200 event (Figure 8.9.1).

Figure 8.9.1 T200 tidal flood extents near the port area

The T200 event also leads to water getting out of bank in the low-lying areas on the left bank of Jordan's Island which is further upstream on the River Corrib. This area however is mainly marshland and there are no properties at risk locally from this source of flooding.

8.10 0.1% AEP (T1000) event

The modelled maximum flood extents for the T1000 event are larger than the T200 year extent due to the much higher water level associated with the event (the T1000 peak water level is 270mm higher than the T200 peak level).

The areas between Dock Street and Long Walk are inundated during this event. As the properties in this area are however set higher than the surrounding ground levels the increased extent does not lead to any significant increase in the number of properties inundated. The Aran islands ferry car park northeast of Galway Port is overtopped by the T1000 event but no additional properties in the area are at risk (when compared to the T200 extent). A number of additional properties along New Dock Street and a row of terrace houses west of the Portershed that are not at risk in the T200 event are however inundated by the T1000 event.

Flooding along Munster Avenue propagates into the garden areas of a number of properties located to the west of the road. As the properties' threshold levels are elevated above the ground levels external to the buildings, they are not however inundated.

St Mary's Catholic Church on the Claddagh Road is inundated by the T1000 event. A number of properties on Priory Road, Claddagh Place, Claddagh, and Grattan Road are also inundated (Figure 8.10.1). Flooding along the Eglinton Canal propagates up the Parkavara (SMRN) and Madeira river (VARA) mill races and inundate parts of the Mill Street car park. The Eglinton Weir however prevents the tide from travelling further upstream along the canal.

Figure 8.10.1 T1000 tidal flood extents near South park and the city center

The T1000 event overtops the bank of the Gaol river near its confluence with the Corrib which leads to the inundation of a number of properties. The green bank between Middle River and Friar's south of Bowling Green is also overtopped by this event.

Further upstream, the T1000 event leads to flooding of the left bank of the Corrib adjacent to the Dyke Road Embankment. The extent of the flooding however does not reach the embankment. There is significant inundation around the Coolough upper and lower lakes along the left bank of the Corrib downstream of Jordan's Island.

8.11 Summary of results

Galway City is at significant risk of tidal flooding. It was seen from the results that quay walls are overtopped in the T2 event which is deemed to be very low.

The total number of properties inundated for each AEP for the tidal dominated case is presented in the table below (Table 19). It can be seen from the table that over 330 properties are at risk for the 0.5% AEP event.

Table 19 Number of properties inundated for the tidal dominated case

AEP	Residential	Commercial	Total
50% (2yr)	0	0	**0**
20% (5yr)	25	5	**30**
10% (10yr)	52	26	**78**
5% (20yr)	97	46	**143**
2% (50yr)	148	79	**227**
1% (100yr)	175	103	**278**
0.5% (200yr)	214	121	**335**
0.1% (1000yr)	341	164	**505**

9. Design runs – Wave over topping simulations

9.1 Design model runs

The standalone Tuflow Quadtree coastal model was used to simulate the design model runs for the WOT and tidal inundation analysis. In total 8 design model runs have been simulated for the current climatic scenario as listed in Table 20. Additional runs were also undertaken for the assessment for the MRFS.

It is not practical to simulate all of the JP events for each of the AEP scenarios. Following agreement with the OPW, only the worst-case JP event was therefore considered for the various AEP scenarios. The worst case was established by simulating each of the six JP events for the 0.5% AEP scenario and then assessing which of the JP's yielded the greatest flood extent depth. It was evident from this analysis that JP6 represents the worst case (i.e. gives the largest flood extent) when compared with the five other JP events. The JP6 SWL and WOT rates were therefore subsequently adopted as the worst case for all of the AEP scenarios.

It is noted however that while JP6 represents the worst case as regards the area flooded by the coastal event, it does not necessarily represent the worst case overtopping rate at the individual sections for which the WOT was calculated. An alternative approach could therefore have been adopted where the most conservative WOT rate at each location was utilised as the design WOT rate at each of the sections regardless of the JP combinations. This approach was not however deemed to be suitable given the need to ensure physical consistency in the set-up of the boundary conditions in the model i.e. it needs to be ensured that WOT rates and tidal water levels assigned to the model are consistent as regards the JP pairing even though this may, in some cases, mean that the WOT rate at a particular calculation point is not the most conservative estimate of WOT at that location.

Table 20 presents the design SWL for the different AEP events. It can be seen that the level varies from 3.29mOD for the 50% AEP scenario to 4.01 mOD for the 0.1% AEP.

Table 20 WOT design model runs

Model Run Name	Scenario	Design Event	Still water level boundary in Galway Bay (m OSGM15)
W2	WOT	50% AEP	3.29 mODM15 (50% AEP)
W5	WOT	20% AEP	3.44 mODM15 (20% AEP)
W10	WOT	10% AEP	3.55 mODM15 (10% AEP)
W20	WOT	5% AEP	3.66 mODM15 (5% AEP)
W50	WOT	2% AEP	3.80 mODM15 (2% AEP)
W100	WOT	1% AEP	3.90 mODM15 (1% AEP)
W200	WOT	0.5% AEP	4.01 mODM15 (0.5% AEP)
W1000	WOT	0.1% AEP	4.01 mODM15 (0.1% AEP)

The CWWS tidal levels differ to the tidal levels estimated as part of the hydrological study undertaken as part of the project, and which have been used to inform the fluvial and tidal hydraulic modelling as discussed in the previous chapter. A comparison of these levels is presented in the table below. It can be seen that the differences are generally most pronounced for the lower return period events. For the design event the difference is 30mm which is deemed to be minor.

The exception to this however is the 0.1% AEP event as a notable difference between the two sets of results is evident from the table (240mm). This is due mainly to the CWWS data which suggest that the T1000 water level is the same as the T200 level i.e., the growth curve is flat beyond the T200 event.

Table 21 WOT design model runs

Design Event	CWWS JP6 SWLs (m OSGM15)	Hydrology Study SWLs (m OSGM15)	Difference in levels
50% AEP	3.29 mODM15	3.19 mODM15	100mm
20% AEP	3.44 mODM15	3.36 mODM15	80mm
10% AEP	3.55 mODM15	3.48 mODM15	70mm
5% AEP	3.66 mODM15	3.60 mODM15	60mm
2% AEP	3.80 mODM15	3.75 mODM15	50mm
1% AEP	3.90 mODM15	3.87 mODM15	30mm
0.5% AEP	4.01 mODM15	3.98 mODM15	30mm
0.1% AEP	4.01 mODM15	4.25 mODM15	240mm

The flood depth and velocity maps are presented as a digital deliverable of the study. The reader is referred to the GIS deliverables package that are presented along with this report.

9.2 Discussion of the WOT flood risk - Current scenario

The Tuflow Quadtree coastal model utilises a single tidal curve input across the full extent of the open sea boundary in order to model the tidal inundation. The model also used a number of discharge lines which act as the sources of the WOT hydrographs in the model domain.

The following sections of the report present a discussion on the baseline design runs. The reader is referred to the accompanying GIS files in order to view the modelled output.

9.3 50% AEP (W2) event

The peak tidal water level for the W2 event is 3.29mODM15 which is sufficient to exceed the crest level of the embankment at the lowest points across the study area – to the immediate east of the port at Deadman's beach, the most southerly section of South Park at a few points in the docks areas of the city. The tidal flooding of the City centre in this event is however relatively minor and only a small area on the left bank of the downstream end of the Corrib around Spanish Parade is inundated.

WOT leads to flooding of the car park at the promenade in Salthill and also along a significant section of the upper Salthill road (Figure 9.3.1). As noted in the project hydrology report, this car park has regularly flooded in the past from WOT.

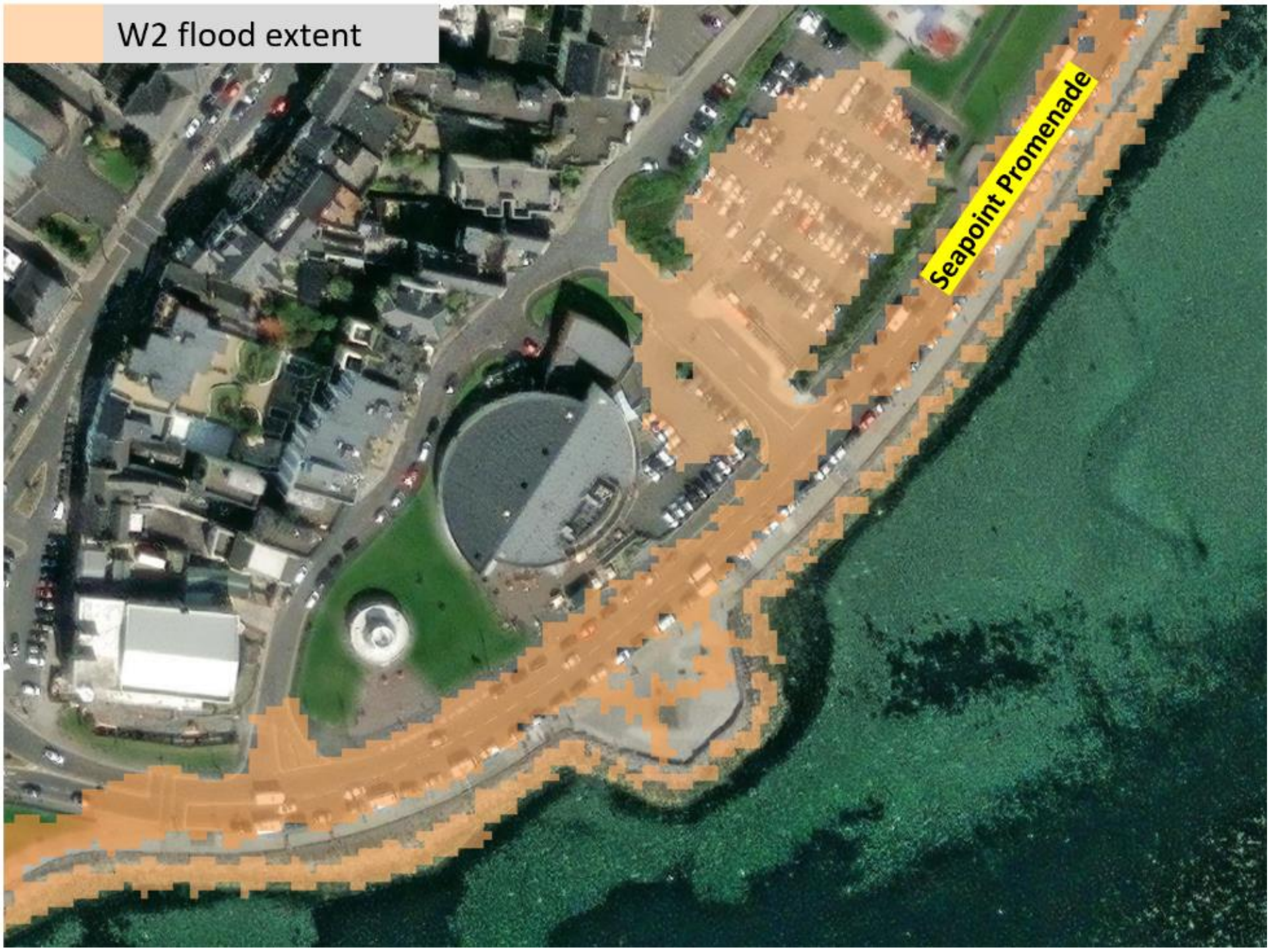

Figure 9.3.1 W2 coastal flood extents near Salthill

9.4 20% AEP (W5) event

The peak tidal water level for the W5 event is 3.44mODM15 which is sufficient to exceed the embankment at a number of locations across the site. The tidal inundation of the city centre in the W5 event extends along Fr Griffin Road on the Western side of the Corrib and as far as Spanish Parade and New Dock street on the Eastern side.

The flood extent associated with WOT for the W5 event in the vicinity of Salthill extends along Grattan Road and reaches as far as the junction with Salthill Road lower. The WOT flood extent in the vicinity of the Leisureland centre is limited to the roads in front and immediately to the East of the building.

9.5 10% AEP (W10) event

The peak tidal water level for the W10 event is 3.55mODM15 which overtops the embankment at a number of locations and leads to tidal inundation at various locations across the scheme area. The inundation of the city centre in the W10 impacts a larger area than the W5 event.

The flood extent associated with WOT for the W10 event in Salthill extends beyond Grattan Road as far as its junction with Salthill Road lower. A significant length of the Upper Salthill Road in the vicinity of the Leisureland centre is inundated by this event. The building itself is not however at risk due to the local ground levels which prevent flood water from inundating the site (Figure 9.5.1).

Figure 9.5.1 W10 coastal flood extents at Salthill

9.6 5% AEP (W20) event

The peak tidal water level for the W20 event is 3.66mODM15 which leads to the inundation of significant areas of the city centre. WOT is also a risk in the City Centre for this event such that the total risk of flooding in the centre is the sum of the risk from the two sources.

WOT at Salthill and the Seapoint Promenade for the W20 event leads to the inundation of a number of properties, public roads, and car parks. The inundated properties include the Galway Bay Hotel as indicated in the figure below. Flooding also extends all along Dr Colohan Road and along Whitestrand Avenue for this event and leads to the inundation of a small number of residential properties.

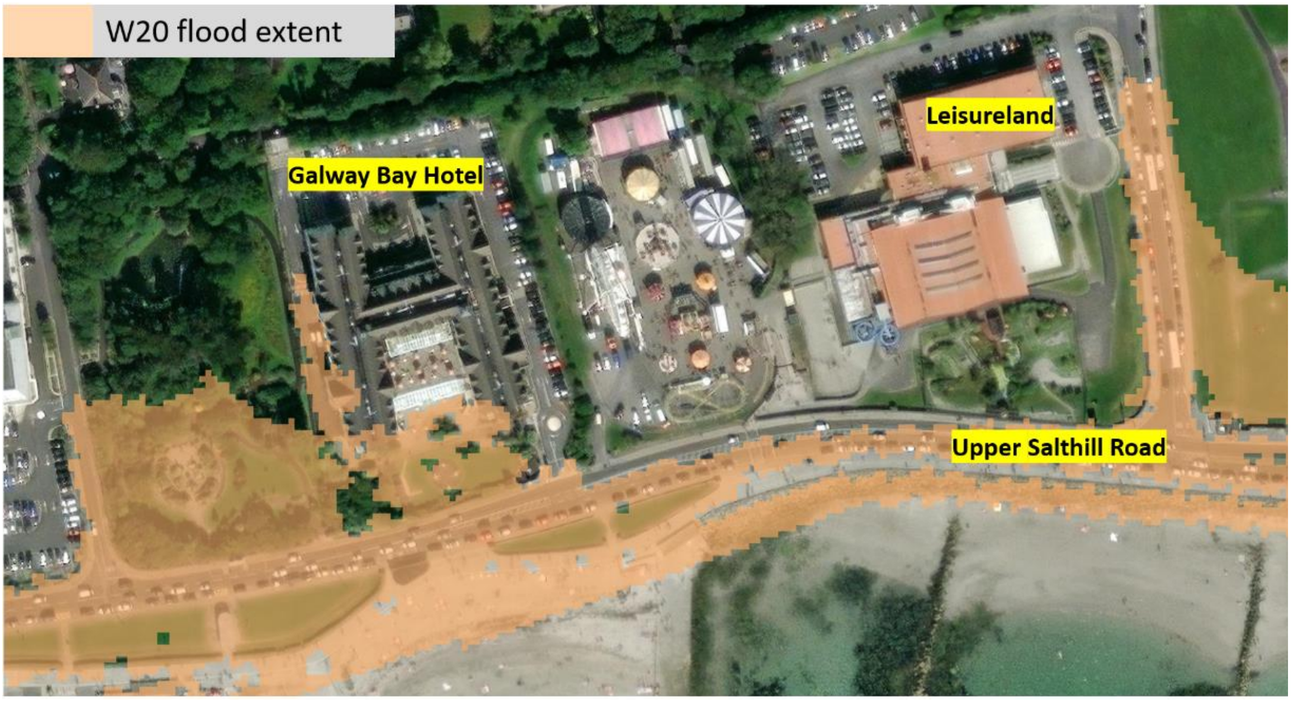

Figure 9.6.1 W20 coastal flood extents along Salthill Road

The W20 event also represents the threshold of flooding of the Galway Harbour Enterprise Park which is flooded to shallow depths by WOT from this event. No buildings are inundated however.

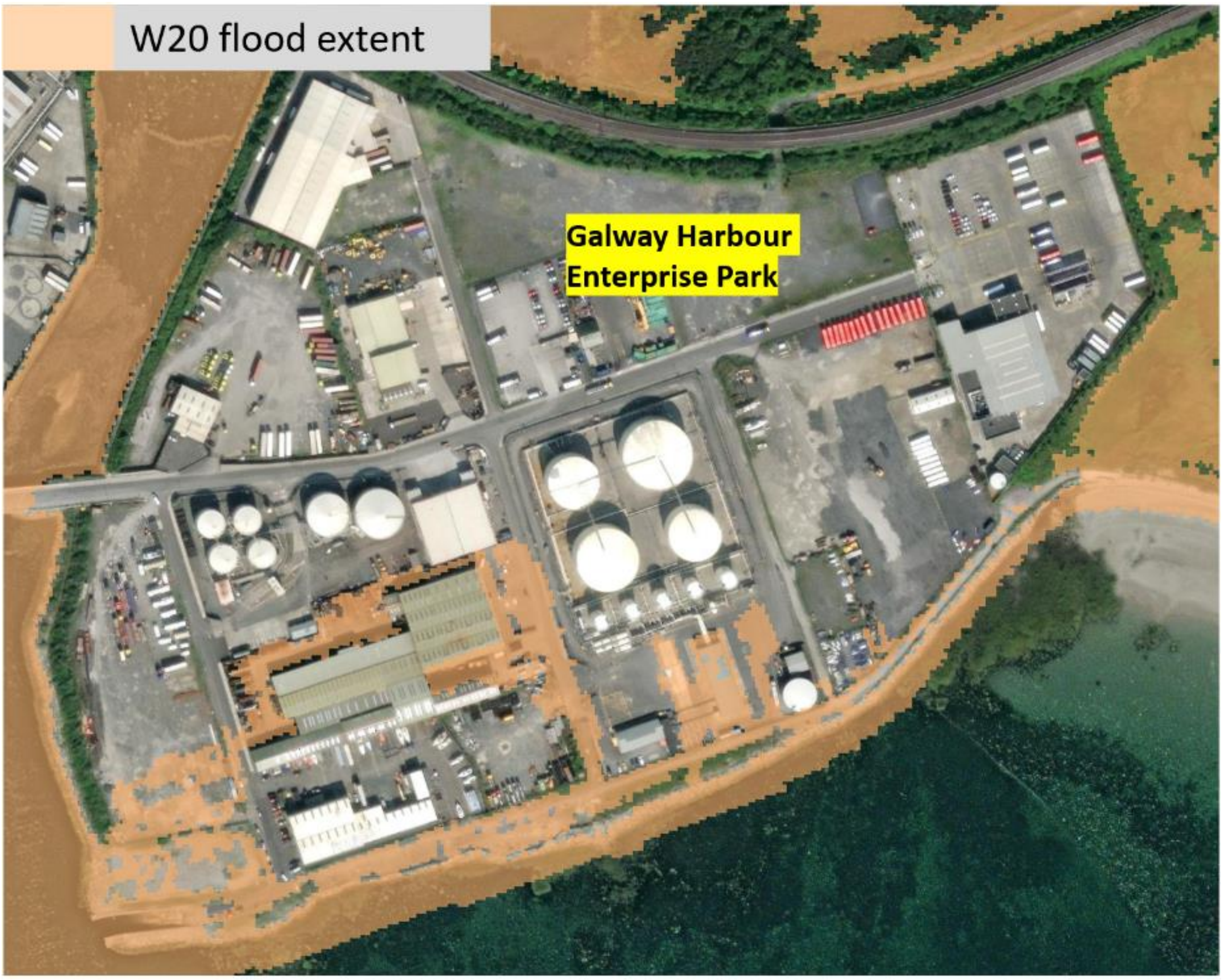

Figure 9.6.2 W20 coastal flood extents in the Galway Harbour Enterprise Park

9.7 2% AEP (W50) event

The peak tidal water level for the W50 event is 3.80mODM15 and leads to the inundation of large parts of the city centre. The flooded extent in the City Centre for the W50 event is however similar to the W20 flooded extent as the increased water level associated with the W50 event is bounded by the existing ground levels in the study area i.e., the W50 event is prevented from inundating a wider area than the W20 event by higher ground. The flood depths for the W50 event are however greater than the W20 event.

The W50 event also represents the threshold of flooding for a number of properties in the Long Walk which are inundated directly by the tidal water level.

A large area in the vicinity of Whitestrand Avenue and Dr Colohan Road is inundated by this event (Figure 9.7.1). The flooded area extends as far as Salthill Road Lower to the North as to Grattan Park to the East.

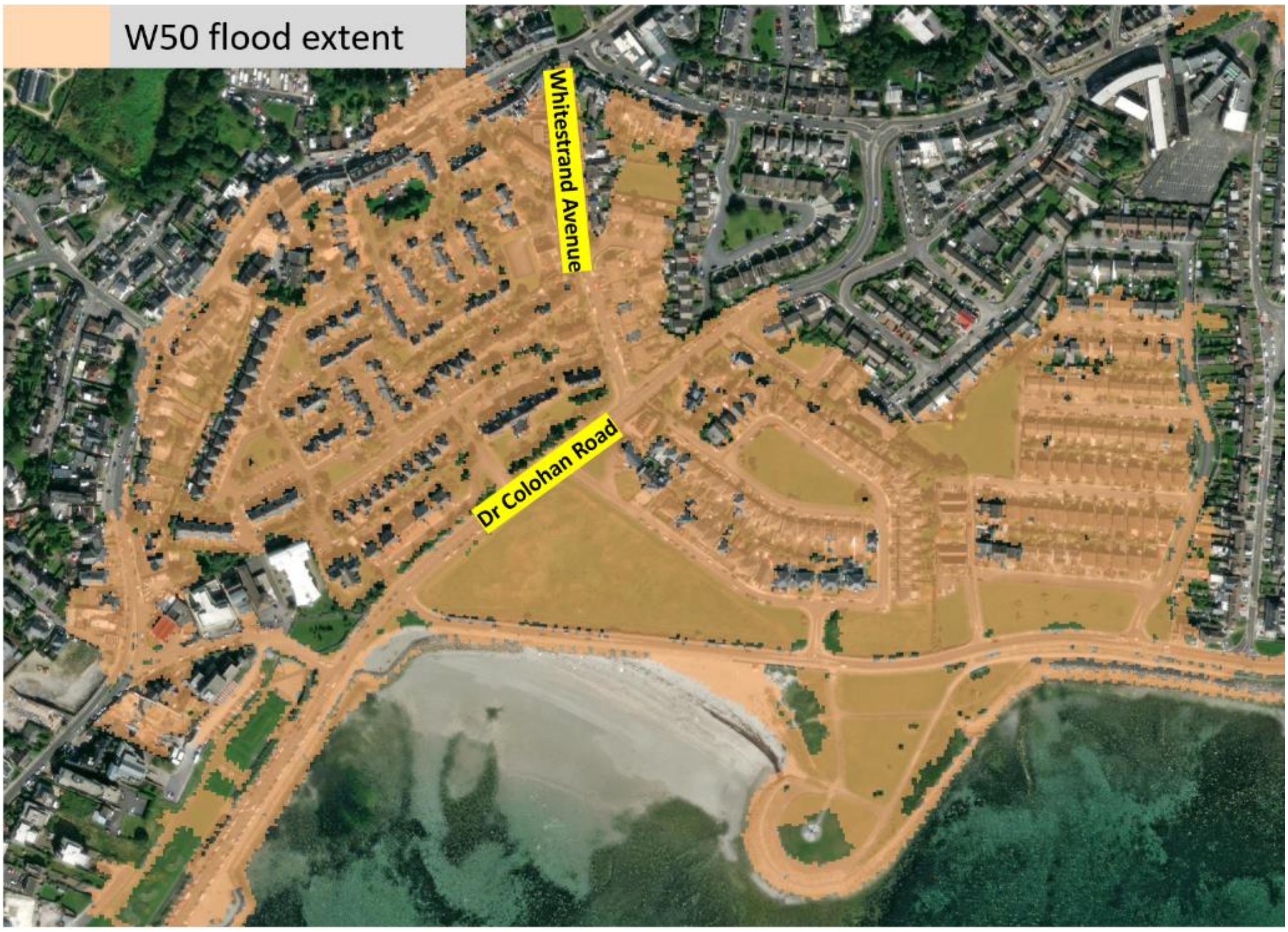

Figure 9.7.1 W50 coastal flood extents in the vicinity of Whitestrand Avenue

9.8 1% AEP (W100) event

The peak tidal water level for the W100 event is 3.90mODM15. The extent of the inundation of the City Centre is broadly the same as the W50 extent due to the existing ground levels preventing a wider area to be inundated.

The extent in the area of Whitestrand Avenue and Dr Colohan Road (Figure 9.8.1) is also broadly similar to the W50 extent but the maximum flood depths are greater. A greater flood extent along Salthill Road leads to a greater part of the site of the Galway Bay Hotel to be inundated (Figure 9.8.2). The Leisureland centre is not however at risk for this event.

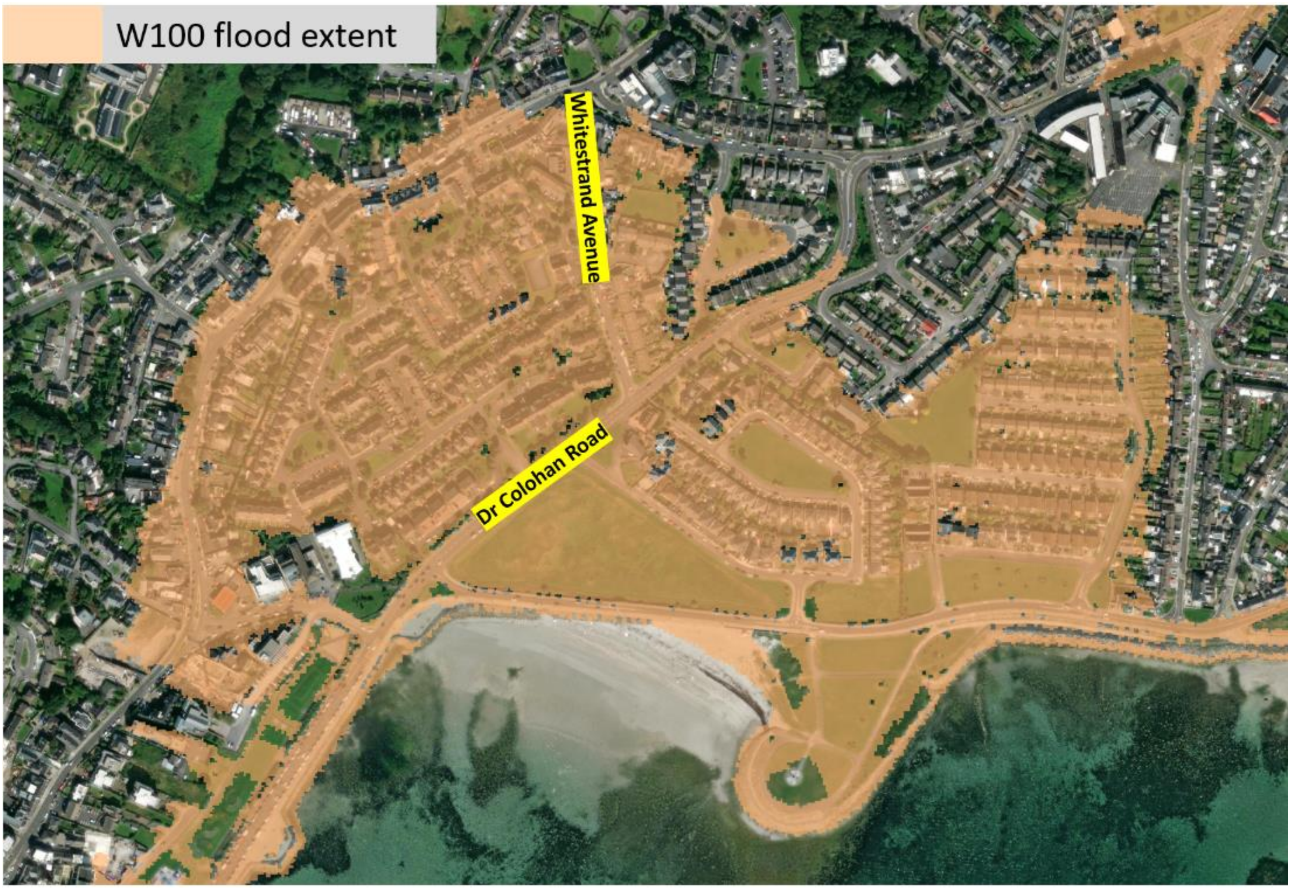

Figure 9.8.1 W100 coastal flood extents in the vicinity of Whitestrand Avenue

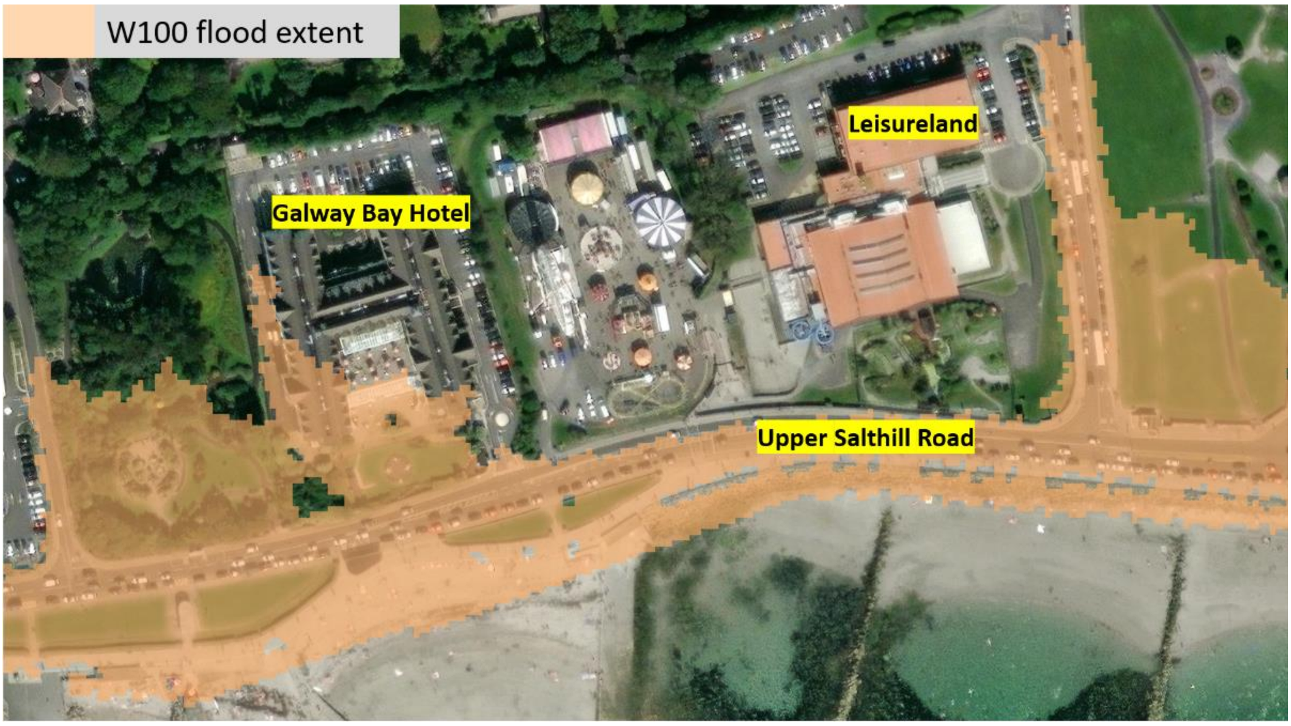

Figure 9.8.2 W100 coastal flood extents in the vicinity of Salthill Road

9.9 0.5% AEP (W200) event

The W200 event is the design standard of the scheme. It is evident from the results of the model that there are significant areas of Galway at risk from the event from both direct tidal inundation and WOT.

As the peak tidal water level of 4.01mOD exceeds the crest level of the embankment at a number of locations across the site, large areas are at risk of tidal inundation. The extent of the inundation of the City Centre is broadly the same as the W50 and W100 extents due to the existing ground levels preventing a wider area from being inundated.

The tidal inundation along Whitestrand Avenue (Figure 9.9.1) and Salthill Road Lower (Figure 9.8.2) for this event is very significant and leads to the inundation of the area located between these two roads. A large number of residential properties are consequently at risk.

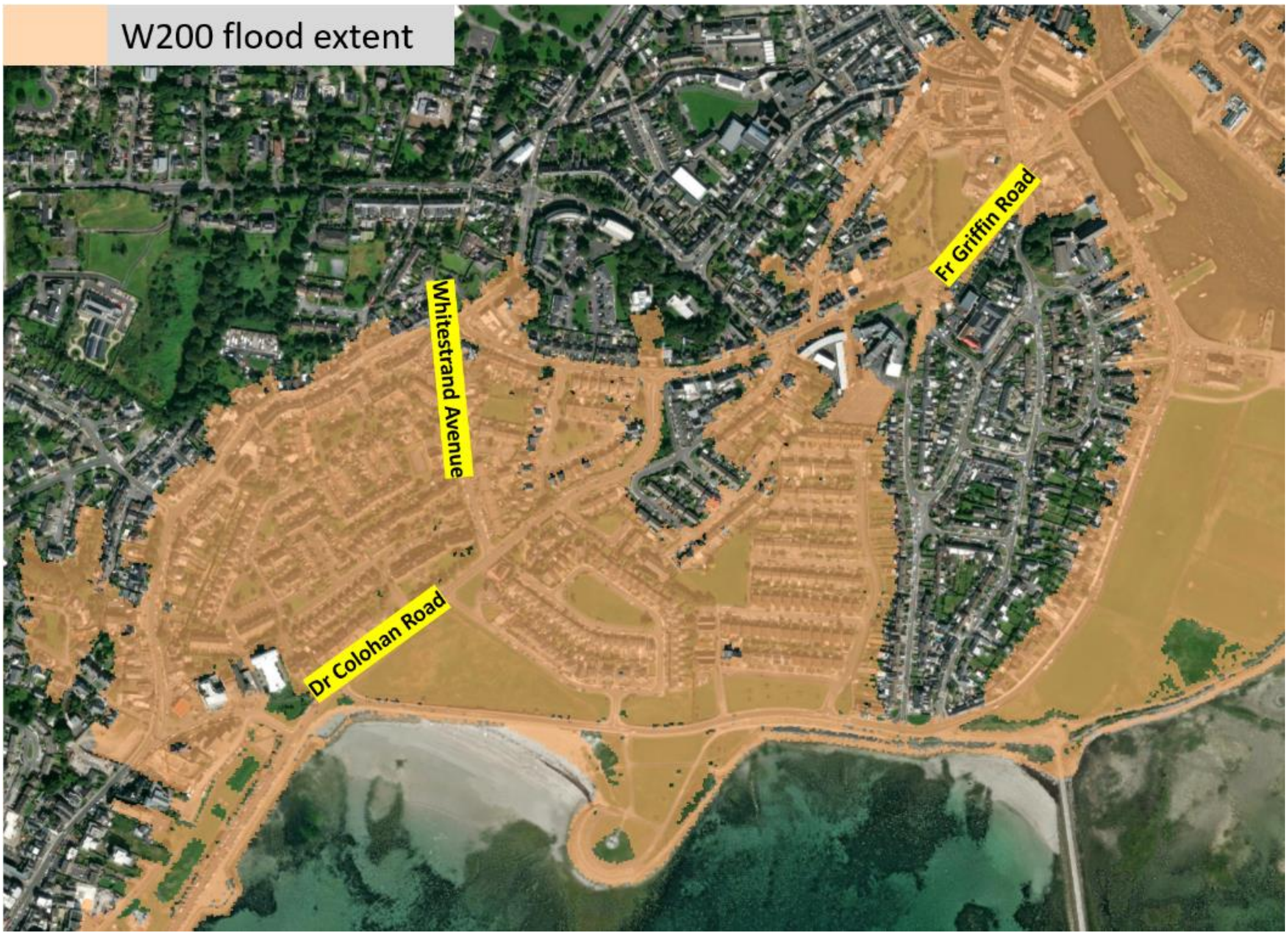

Figure 9.9.1 W200 coastal flood extents in the City Centre and in the vicinity of Whitestrand Avenue

A large area of the Galway enterprise park is inundated by this event as shown in Figure 9.9.2. A number of properties and storage units are at risk as can be seen from the figure.

Figure 9.9.2 W200 coastal flood extents in the Galway Harbour Enterprise Park

9.10 0.1% AEP (W1000) event

The W1000 event leads to very extensive flooding across the site with large areas at risk of inundation (Figure 9.9.1). The peak tidal water level for the event is 4.01mOD which is higher than the embankment at a number of locations and consequently leads to tidal overtopping and large areas being inundated by the tide. This includes the area of Salthill which is overtopped by the tidal elevations for this event.

The inundation along Whitestrand Avenue and Salthill Road Lower extends to meet the area that is inundated from by tidal flooding from the City Centre. A very significant area of mainly residential properties is inundated as a result in this event (Figure 9.10.1).

The flood extents along Lower Salthill Road are very significant in this event and lead to the inundation of the Leisureland centre (Figure 9.10.2).

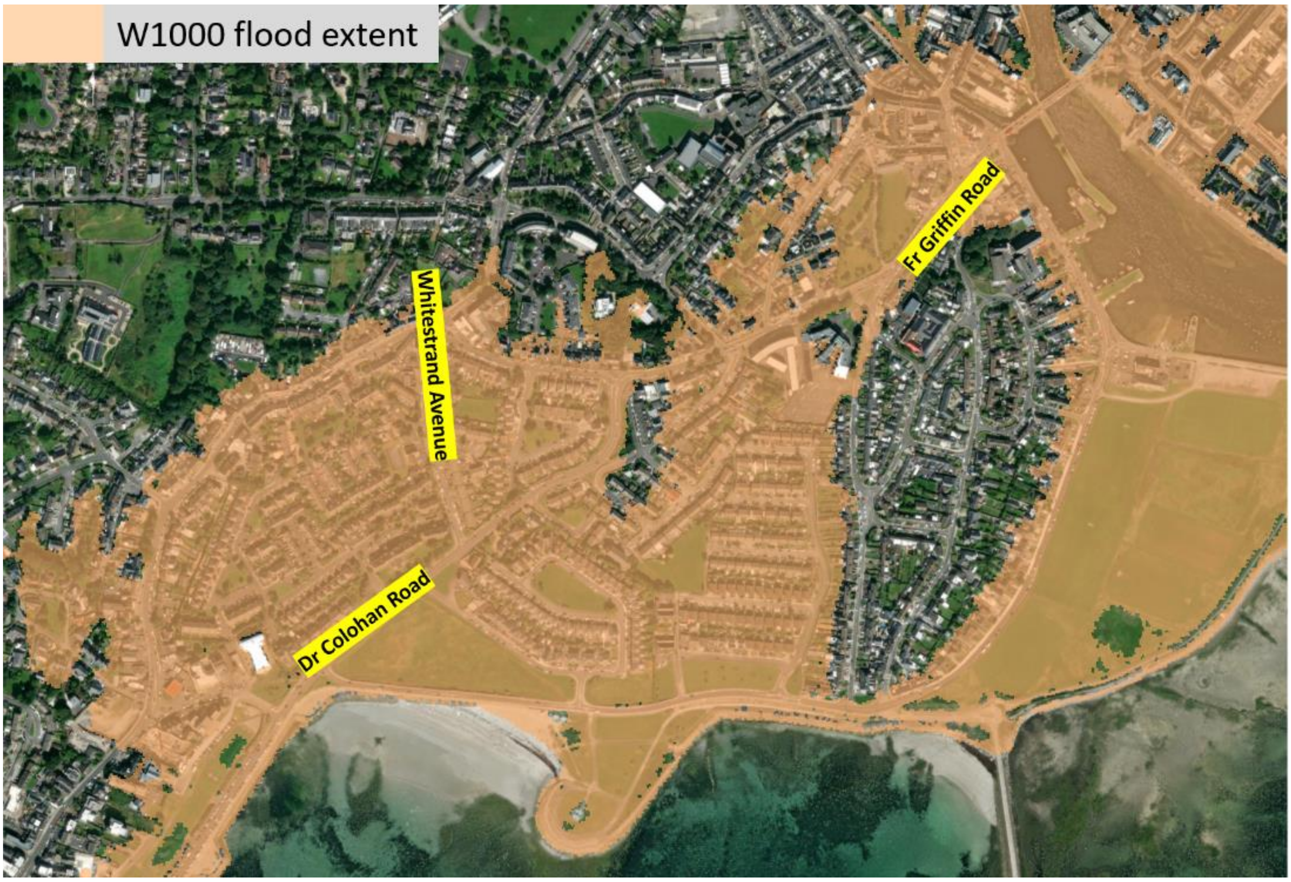

Figure 9.10.1 W1000 coastal flood extents in the City Centre and in the vicinity of Whitestrand Avenue

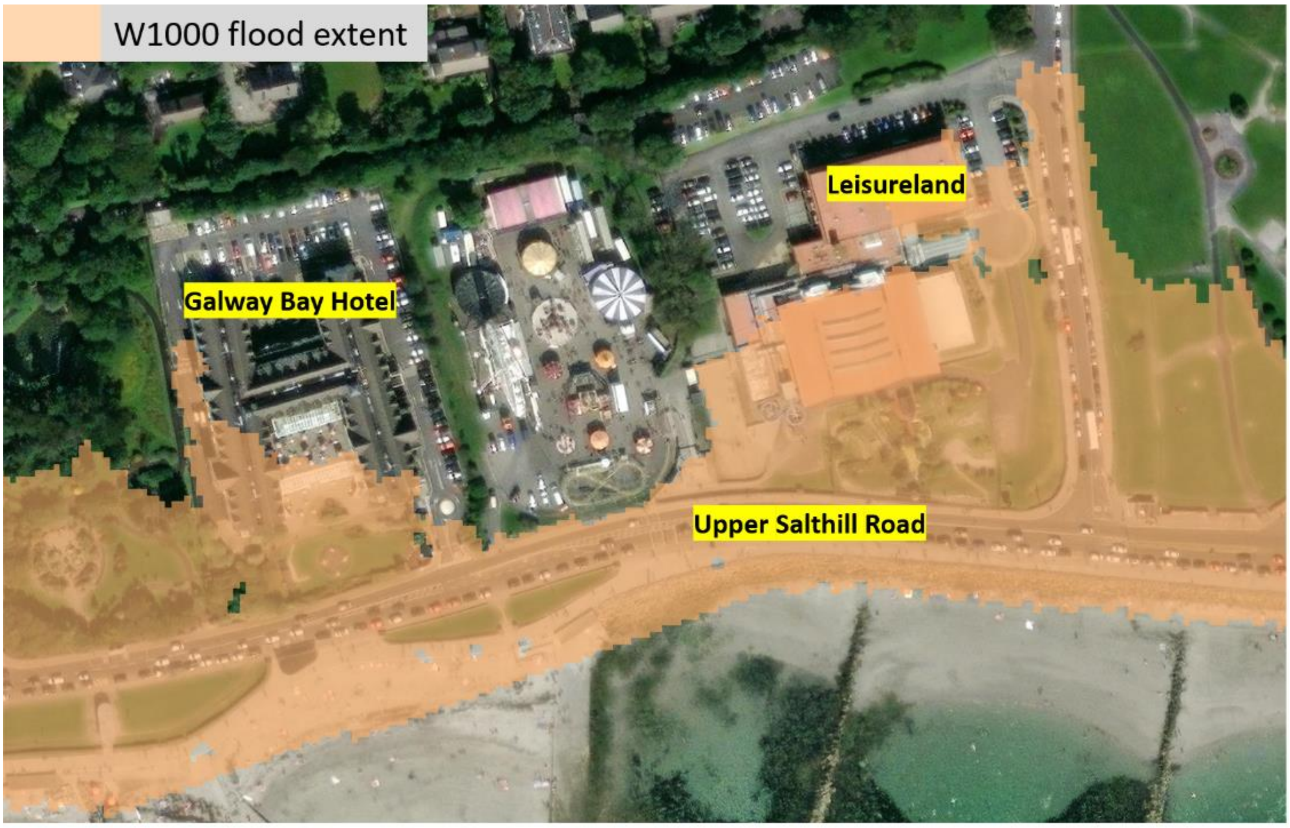

Figure 9.10.2 W1000 coastal flood extents along the Upper Salthill Road

9.11 0.1% AEP (W1000) event with wave overtopping removed

The coastal model considers the risk of both tidal inundation and wave overtopping combined. As part of the study Arup were however asked by the OPW to also consider the 0.1% AEP event with the wave overtopping component removed and to only simulate direct tidal inundation for the 0.1% AEP event (4.01mOD). The results of this simulation are presented in this section of the report and are part of the deliverables (w_521_ttt_w_c_s_1000_d_s1_c_02). Please refer to these extents for detailed information.

Figure 9.11.1-93 present both the WOT1000 and T1000 maximum flood extents for different areas of the coastal model domain. It can be seen from the figures that when the wave overtopping component of the model is removed the maximum flood events in some areas is significantly reduced while in other areas the extents are largely unchanged.

The inflows from WOT are therefore a significant contributor to coastal flooding in certain areas of the site where the crest level levels of the existing embankments/promenades are sufficiently elevated to prevent direct tidal ingress.

Figure 9.11.1 presents both flood extents for the promenade at Salthill. It can be seen from the image that the WOT maximum extent is larger than the tidal-only extent for the main area of the promenade – while the crest level of the promenade is overtopped by the still water levels, the area is also at risk from WOT which increased the flood risk to the area.

Figure 9.11.1 T1000 (no WOT) coastal flood extents in Salthill

Figure 9.11.2 presents the flood extents for the area to the East of the promenade. It can be seen that the WOT/coastal maximum flood extent is significantly larger than the tidal-only extent for the area bounded by Fr Griffin Road/Fr Burke Road to the East – as the crest level along Grattan Road is set higher than the T1000 maximum water level, this large area is not at risk from direct tidal inundation and the only source of flooding is from WOT.

In the area of the city centre however both the WOT/tidal and direct tidal maximum extents are largely identical as the area is at risk of tidal-only flooding i.e. the WOT does not add any additional flood water to this area.

Figure 9.11.3 presents both flood extents for the Galway enterprise park. It can be seen from the figure that the area of the park is only at risk from WOT/Coastal flooding.

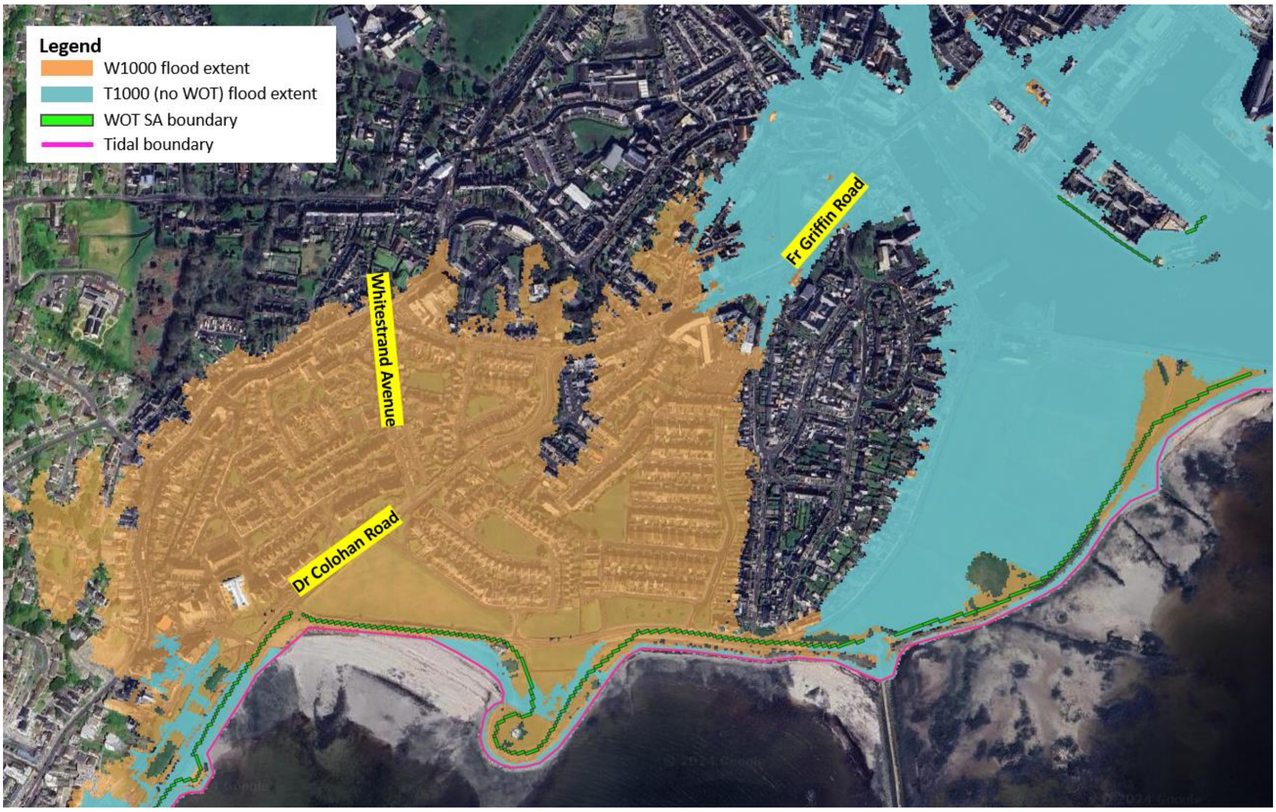

Figure 9.11.2 T1000 (no WOT) coastal flood extents in the city centre

Figure 9.11.3 T1000 (no WOT) coastal flood extents in the Enterprise Park

9.12 Summary of results

Significant areas of the scheme area are at risk from Coastal flooding i.e., both WOT and direct tidal inundation. The areas at risk include the City Centre, the area of the docks, the areas adjacent to Whitestrand Avenue and Salthill Road Lower as well as Salthill and all along the Upper Salthill road. A number of undeveloped green areas are also at risk of inundation.

The results of the model confirm what has been observed from our review of the historic record of flooding in the city: The dominant mechanism of flooding in the City Centre is direct tidal inundation while the dominant mechanism of flooding in Salthill and the areas adjacent to it along the Upper Salthill road is WOT. Both sources of flooding will therefore need to be considered as part of the optioneering.

It is noted that there are large area of the city between the Salthill and the City Centre that are only at risk from WOT.

The total number of properties inundated for each AEP for the WOT/Tidal case is presented in the table below (Table 22). It can be seen from the table that over 1000 properties are at risk for the 0.5% AEP event.

Table 22 Number of properties inundated for the WOT/Tidal dominated case

AEP	Residential	Commercial	Total
50% (2yr)	0	2	**2**
20% (5yr)	15	11	**26**
10% (10yr)	51	37	**88**
5% (20yr)	155	68	**223**
2% (50yr)	528	151	**679**
1% (100yr)	671	187	**858**
0.5% (200yr)	844	235	**1079**
0.1% (1000yr)	941	264	**1205**

As observed from the W1000 model results, the inclusion of wave overtopping inputs produces significantly larger flood extents compared to the model without wave overtopping. Neglecting wave overtopping can lead to underestimations of flood risks.

10. Sensitivity analysis

10.1 List of Sensitivity Runs

A number of sensitivity analysis runs of the 1D/2D fluvial/tidal model were undertaken to assess how the 1% AEP design fluvial water levels for the existing scenario may vary under different modelling assumptions. A complete list of the sensitivity runs is presented in the Table 23. The results of the sensitivity model runs are presented in Section 10.2.

Table 23 List of sensitivity model runs

Sensitivity Parameter	SA model no.	Model runs
Changes to operation of Salmon Weir gates during flood conditions	1	8 gates closed (50% of gates closed)
Manning's Value	2a and 2b	2a) +20% increase in the Manning's number across both the 1D and 2D model 2b) -20% increase in the Manning's number across both the 1D and 2D model

Sensitivity Parameter	SA model no.	Model runs
Bridge unit type	3a and 3b	Specification of an alternative bridge unit at key hydraulic structures. The following bridges were changed from an ARCH to an USBPR bridge unit: 3a) Salmon Weir bridge (30CORR00134D) and 3b) Wolfe Tone bridge (30CORR00072D)
Ineffective flow areas	4a and 4b	Cross sectional area of the Corrib channel was reduced at two locations in order to test the sensitivity of the model to the dimensions of the channel: 4a) Directly upstream of Salmon weir near the boat club 4b) At King's gap weir
Cell size variation	5	Cell size reduced in 2D space from 8m in RURAL space to 4m, and from 4m in URBAN space to 2m
Clifden Railway Embankment Culvert	6	Inclusion of the Clifden Railway embankment culvert in the model
Coastal model - Changes to the Manning's number	7	Modification of the manning's n of the 2D coastal model
WOT at the Enterprise Park	8	Including A WOT boundary at the South West Corner of the Enterprise Park

The standalone coastal model was also tested for manning sensitivity and is also presented in the following section.

10.2 Sensitivity Analysis Results

10.2.1 Operation of Salmon Weir gates

A scenario that tests the impact of the operation of the Salmon Weir gates during the 1 in 100-year flood was modelled. In the sensitivity run the eight easterly gates of the weir were closed and the eight westerly gates were left open.

For the Q100 baseline conditions (all weir gates open) the peak flow rates upstream of the weir is 433m^3/s and this is split in three as follows (refer to figure below as well):

- 30m^3/s passes down the Eglinton canal (7%)
- 390m^3/s passes over the weir and continues to flow down the Corrib (90%)
- 13m^3/s passes down the Middle river (3%)

Under the gate closure sensitivity run the peak flow rates upstream of the weir is reduced to 420m^3/s as some volume is lost due to the overtopping of the Dyke road embankment (see below). In this scenario the division in the flow is as follows:

- 55m^3/s passes down the Eglinton canal – an increase of 25m^3/s (13%)
- 345m^3/s passes over the weir and continues to flow down the Corrib – a reduction of 45m^3/s (82%)
- 20m^3/s passes down the Middle river – an increase of 7m^3/s. (5%)

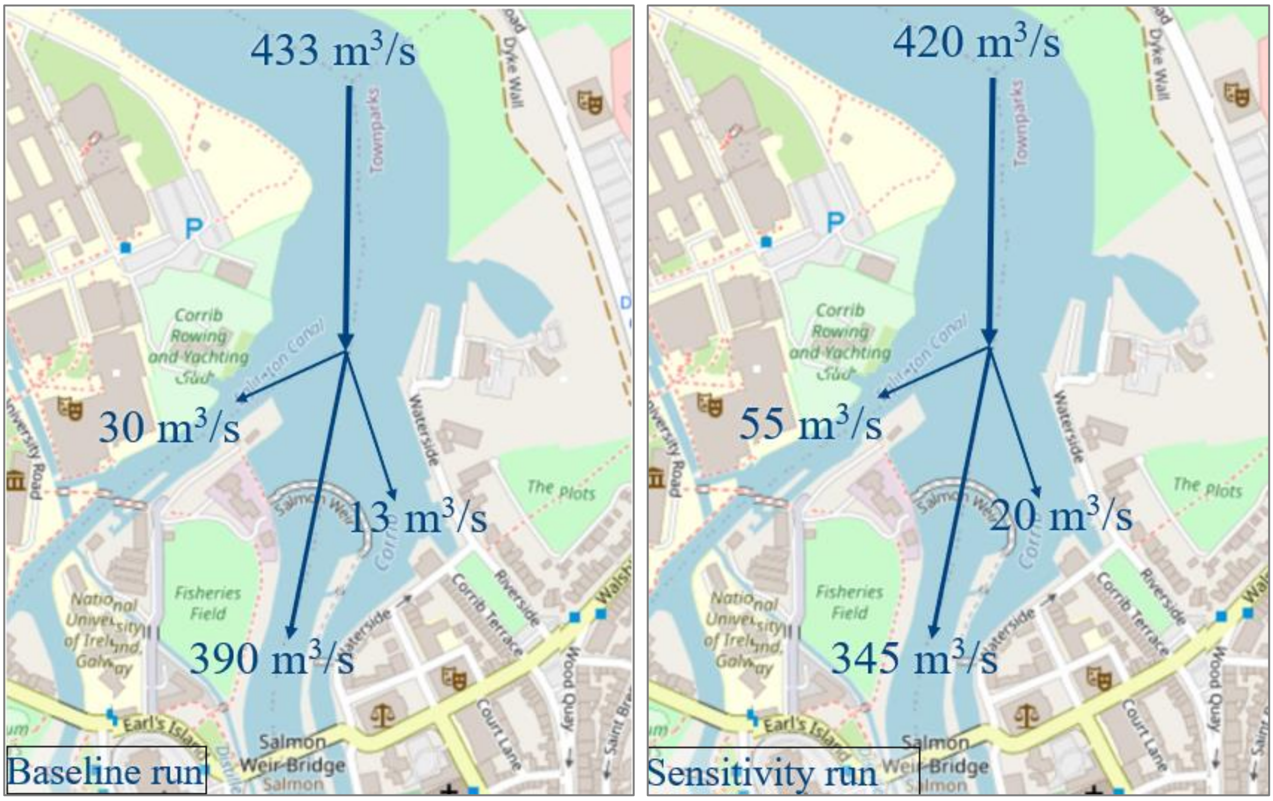

Figure 10.2.1 Salmon weir gate closure sensitivity – impact in flows downstream of weir. In the baseline run, all the gates are open, while in the sensitivity run 8 westerly gates are open

The impact of having eight gates closed also impacts on water levels. Figure 10.2.2 presents the maximum longitudinal water level through the reach for both the baseline and sensitivity run. It can be seen from the plot that the increase in water level is greatest immediately upstream of the weir but reduces further upstream. The key differences in water level between the runs is noted as:

- 430mm increase in water level directly upstream of the Salmon Weir;
- 360mm increase adjacent to the Dyke Road embankment;
- 190mm increase at Dangan gauge;
- 160mm at Lough Corrib.

As referred to above, the increase in flood levels along the Dyke Road causes overtopping of the embankment and extensive flooding of the Terryland/ Castlegar area in a similar manner as the inundation caused by the Q1000 year event and lead to a risk of flooding for 7 properties within the Terryland/ Castlegar area.

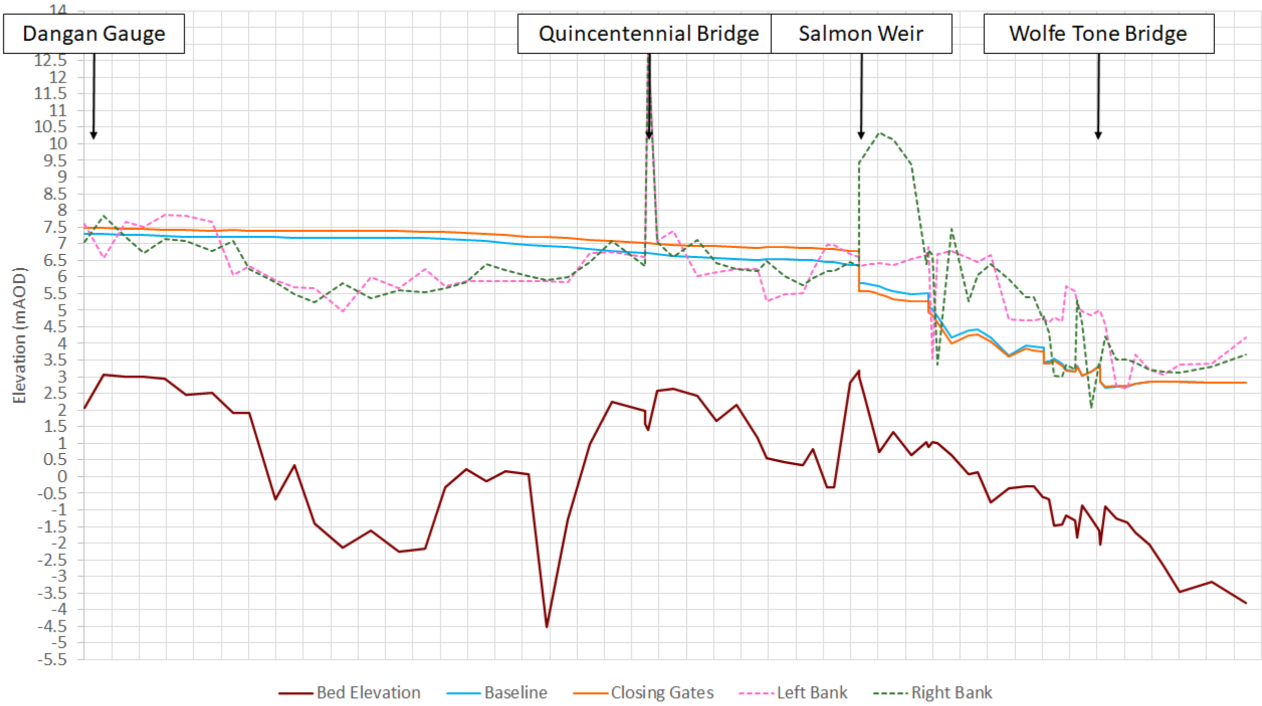

Figure 10.2.2 Longitudinal plot of the Maximum WLs along the River Corrib - baseline Q100 model with 8 gates at Salmon weir closed

Due to the increase in flow down the Eglington Canal, there is a greater risk of fluvial flooding along the East Canal system for the sensitivity run. Figure 10.2.3 below presents the increase in the flood extent associated with this event. It can be seen from the plot that a significant area along Presentation road/Mill Street and Nuns island street is inundated by water getting out of bank at St Clare and Gaol rivers. At least 72 new properties are at risk of flooding in these areas compared to the baseline.

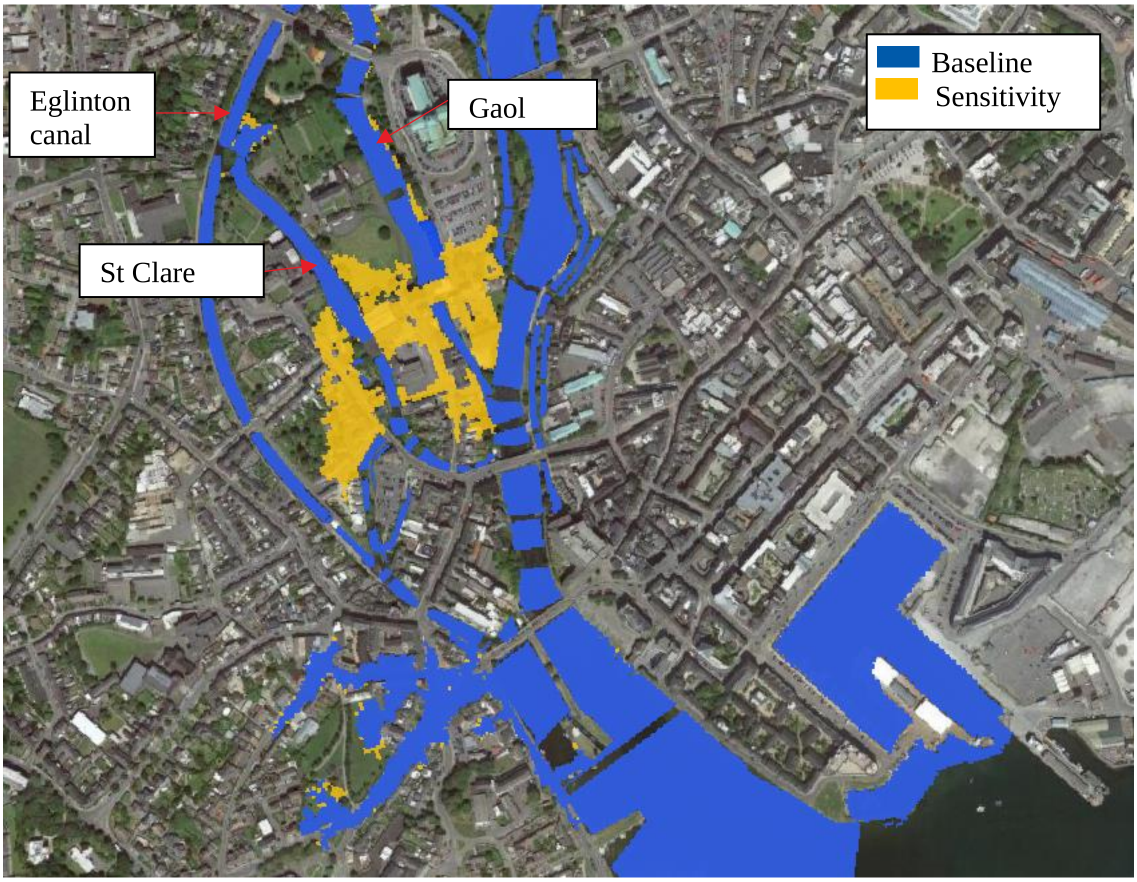

Figure 10.2.3 Salmon weir gate closure sensitivity – impact in Galway City for the Q100 event

The impact of keeping gates closed during the Q100 is significant and increases the flood risk to a number of properties. It is therefore recommended that all gates are opened as per current operation during high flow events from the River Corrib.

10.2.2 Changes to the Manning's number (1D/2D model)

Both a 20% increase and a 20% decrease were applied to the Manning's number for both the 1D and 2D model domains to test the sensitivity of the model to changes in roughness values.

Figure 10.2.4 presents a longitudinal plot of the maximum water levels reached along the River Corrib for the +20% Manning's n scenario.

It can be seen that the increased roughness increases the maximum water levels along the reach by circa 200 – 250mm. These differences diminish further downstream as the water level is dictated as the water levels are less sensitive to the specification of the manning's value in the tidal dominated reach.

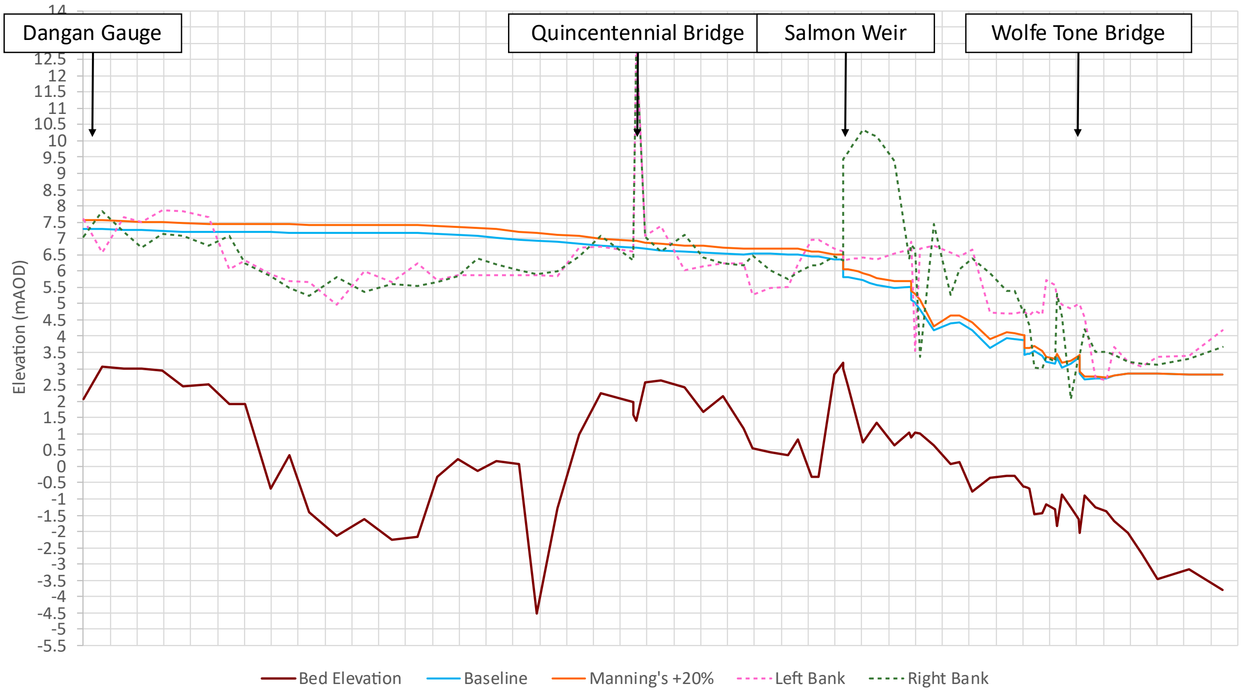

Figure 10.2.4 Longitudinal plot of the Maximum WLs along the River Corrib - baseline Q100 model with 20% increase in Manning's n

The increase in Manning's n value causes increase of water levels along the Dyke Road embankment, located between Quincentennial bridge and Salmon weir. This increase in levels causes partial overtopping of the embankment, increasing the flood extents in the Terryland area. No properties are however at risk of inundation.

The most significant difference arising from the manning's sensitivity is experienced in Galway City centre as indicated in Figure 10.2.5. It can be seen from the figure that areas around the University of Galway Old engineering building adjacent to Gaol river are inundated in the manning's sensitivity scenario. Similarly, Atlanta House along the left bank of the Eglinton Canal is also inundated compared to the baseline run. The maximum flood extents at Fr. Burke Park are also increased due to the increase in the Manning's number and 2 additional properties one on Father Burke road and another on Raven terrace are at risk of inundation compared to baseline.

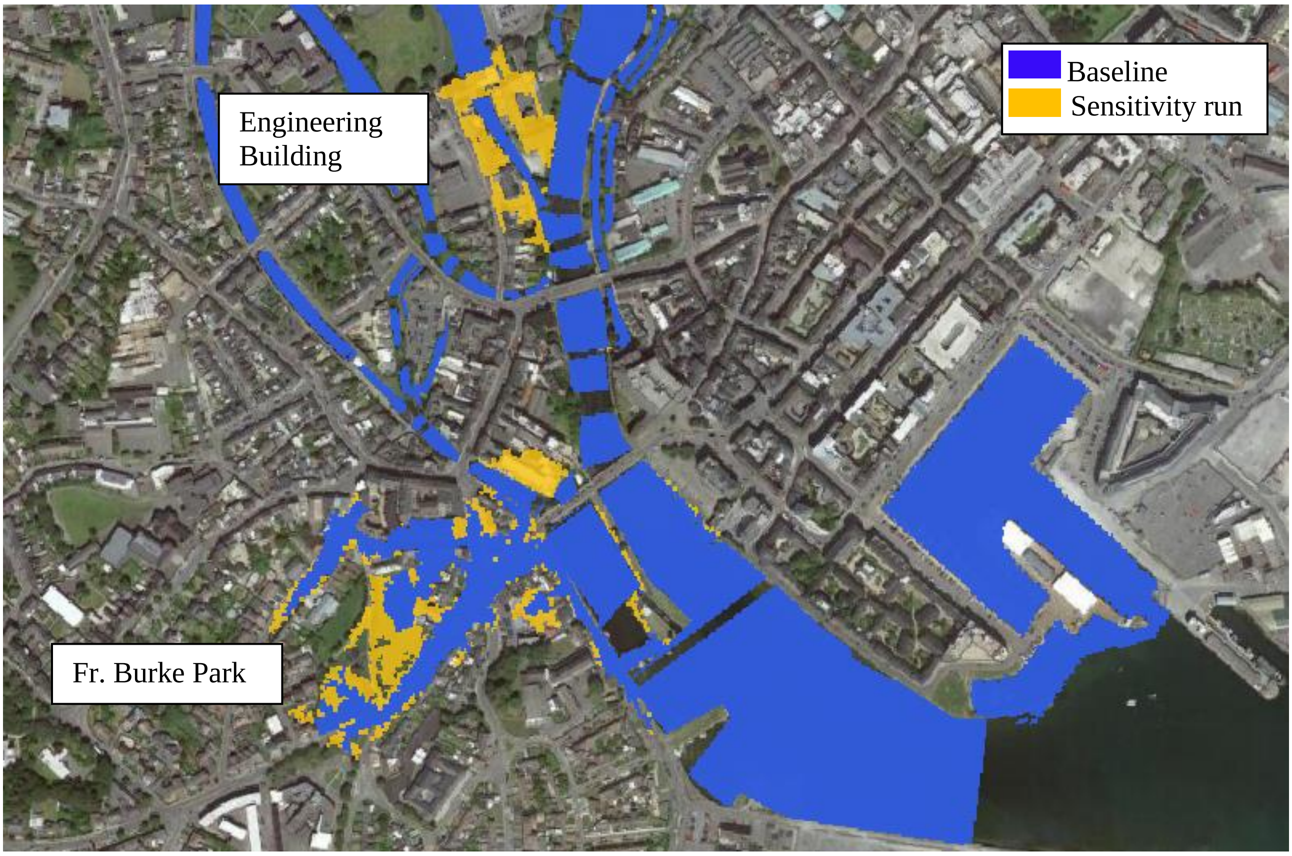

Figure 10.2.5 Manning's number sensitivity – impact in Galway City for the Q100 event

Figure 10.2.6 presents a longitudinal plot of the maximum water levels reached along the River Corrib for the -20% Manning's n scenario. It can be seen that the reduced roughness reduces the maximum water levels along the reach by circa 200-250mm. There is therefore no increase in the flood risk when this scenario is considered as the river channel is in effect made more efficient by the reduced roughness.

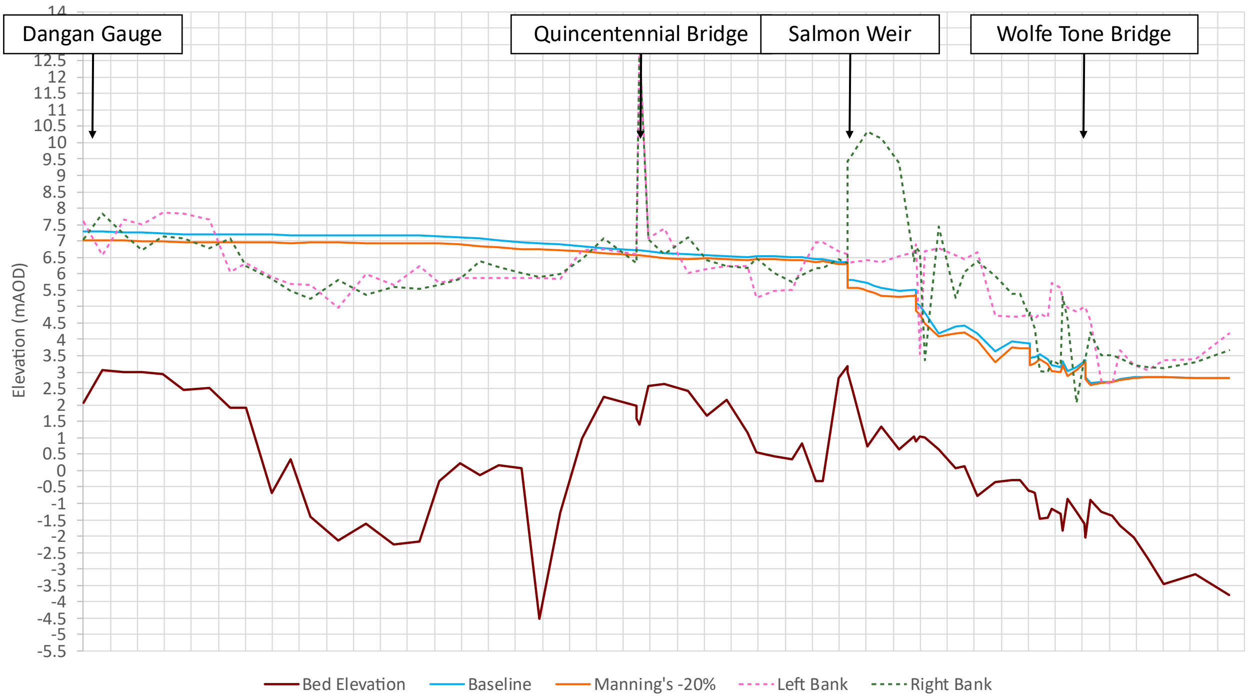

Figure 10.2.6 Longitudinal plot of the Maximum WLs along the River Corrib - baseline Q100 model with 20% decrease in Manning's n

10.2.3 Bridge Unit Type

The two key bridges of the model were changed from ARCH to USBPR bridge type unit in other to test the unit type sensitivity of the FMP component of the model. These were Salmon Weir bridge (30CORR00134D) and Wolfe Tone bridge (30CORR00072D) as indicated in the figure below. All other parameters were kept the same for the sensitivity run.

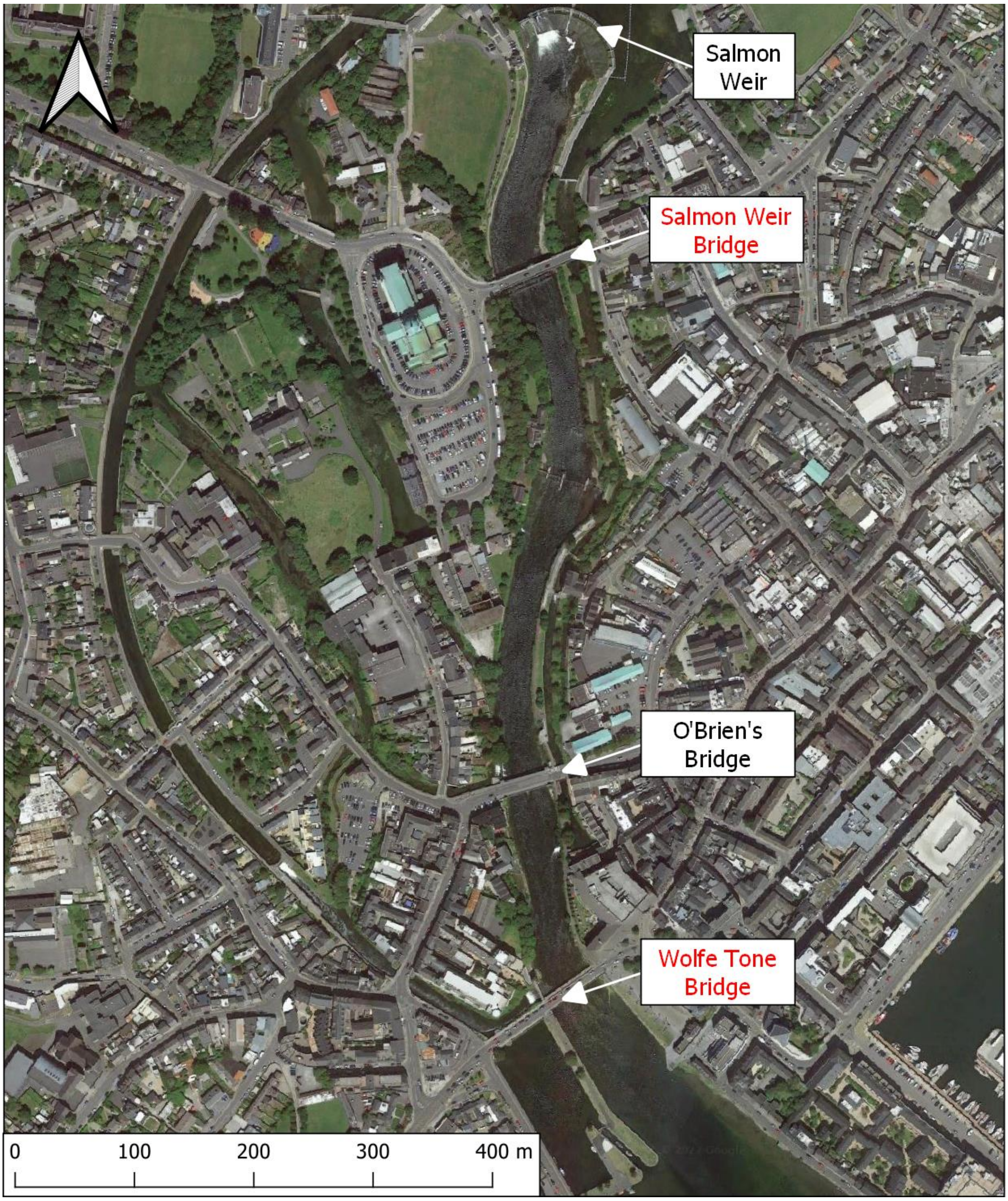

Figure 10.2.7 Location of bridges downstream Salmon Weir - River Corrib

Salmon Weir bridge (30CORR00134D)

The water levels are sensitive to the representation of this bridge as a USBPR unit. Directly upstream of the bridge, the levels are increased by 230-300mm which is deemed to be significant. At the Salmon Weir barrage (220m upstream), the increase in the water level is 140mm. At the Dangan gauge (3km upstream) the increase is circa 60mm and at Lough Corrib (8km upstream) it is circa 48mm.

The increase in levels upstream of the Salmon Weir has a direct impact on the water levels in the Eglinton Canal and the west canal and mill race system given that the higher levels will drive a great flow down these reaches. Maximum water levels on The Gaol river (NUNS) are increase by 124mm and result in an increase in flood levels upstream of the University of Galway Old Engineering building. The Nuns island road and surrounding buildings are also inundated which we note are not inundated in the baseline scenario. Flood levels along the St Clare River (GMRA) are increased by circa 75mm and lead to flooding along parts of the Presentation Road.

The increase in flood levels upstream of the Salmon Weir causes overtopping of the Dyke Road embankment along a 30m section of the embankment. The impact of this in the Terryland area is however minimal due to the relatively small volume of overtopping water.

Immediately downstream of the bridge, the water levels reduced by 30mm and by 5mm circa 500m downstream of the Salmon Weir bridge.

The findings of the model are very sensitive to the selection of the unit type and therefore needs to be considered in more detail as part of the optioneering.

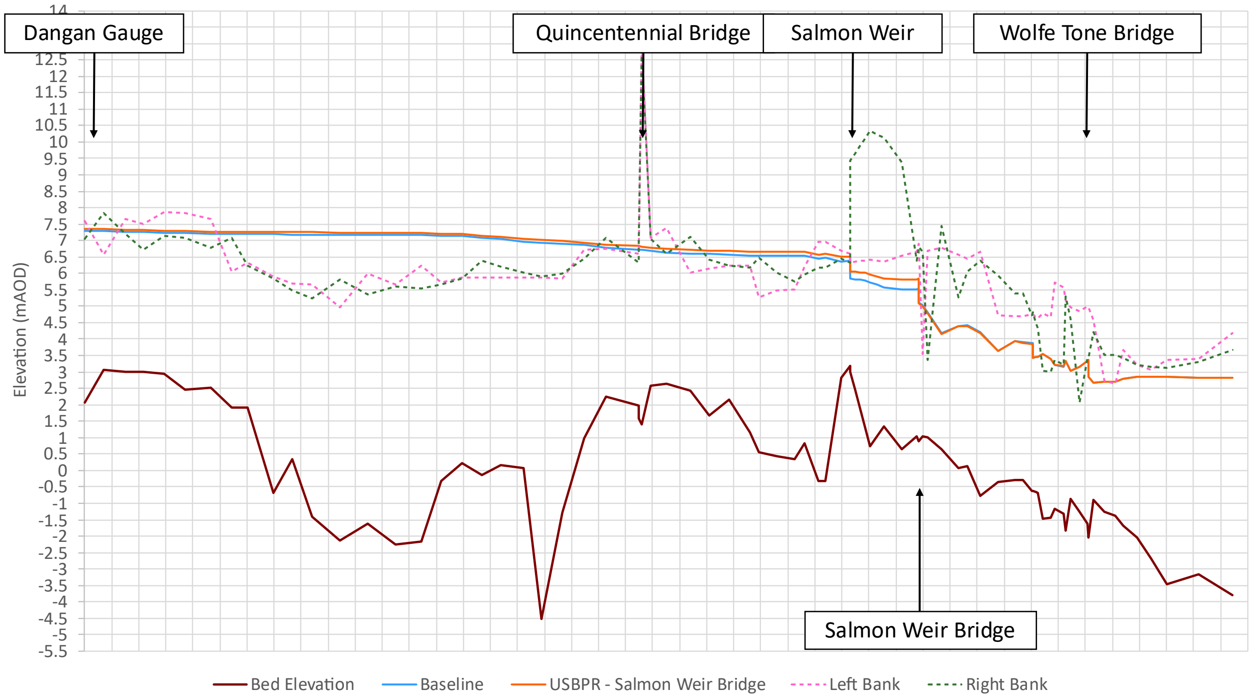

Figure 10.2.8 Longitudinal plot of the Max WLs along the River Corrib - baseline Q100 model with Salmon Weir Bridge defined as a USBPR

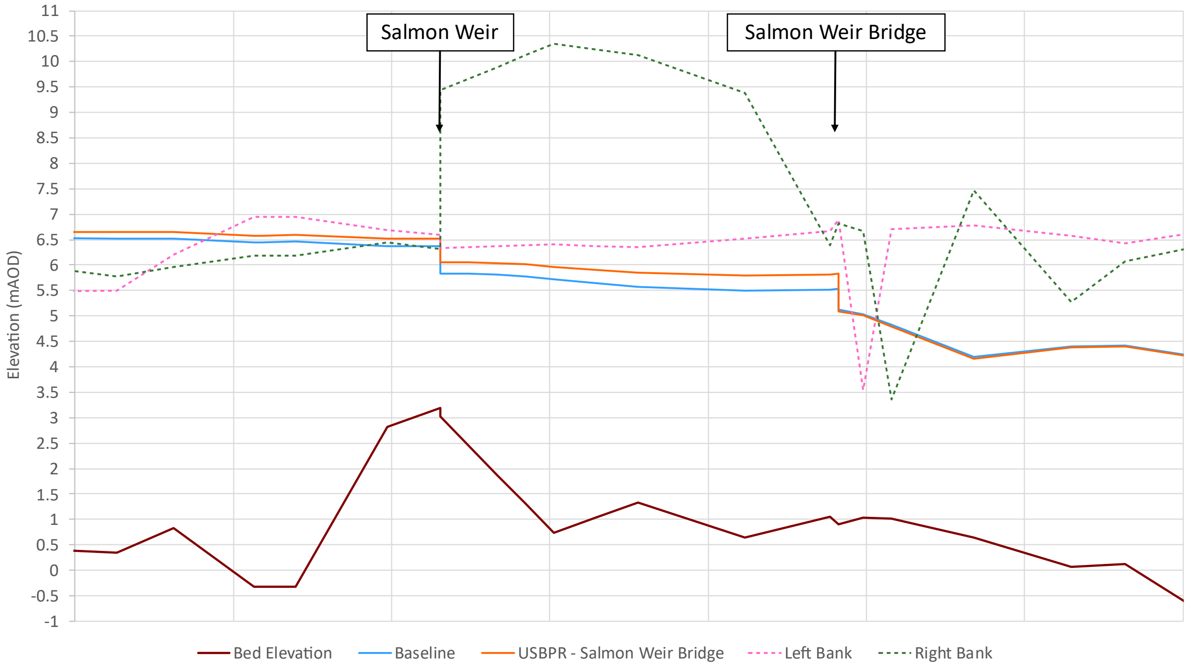

Figure 10.2.9 Zoomed in longitudinal plot of the Max WLs along the River Corrib - baseline Q100 model with Salmon Weir Bridge defined as a USBPR

Wolfe Tone bridge (30CORR00072D)

The model is also sensitive to the change of the representation of the Wolfe Tone Bridge unit from ARCH to USBPR. The maximum increase in levels within the Corrib upstream of the Wolfe Tone bridge is 123mm. The increase in water level extends up as far as the Salmon Weir where the increase is approximately 6mm.

The increase in levels impacts the Eglinton canal and Claddagh basin levels, with an increase of approx. 90mm causing further overtopping and an increase in inundated areas on both sides of the Eglinton and at Father Burke park. The maximum increase in levels within the floodplain occurs along Munster avenue and is circa 156mm.

This sensitivity will be considered as part of the optioneering when setting defence levels in the vicinity of Claddagh quay and the Eglinton Canal along Raven Terrace.

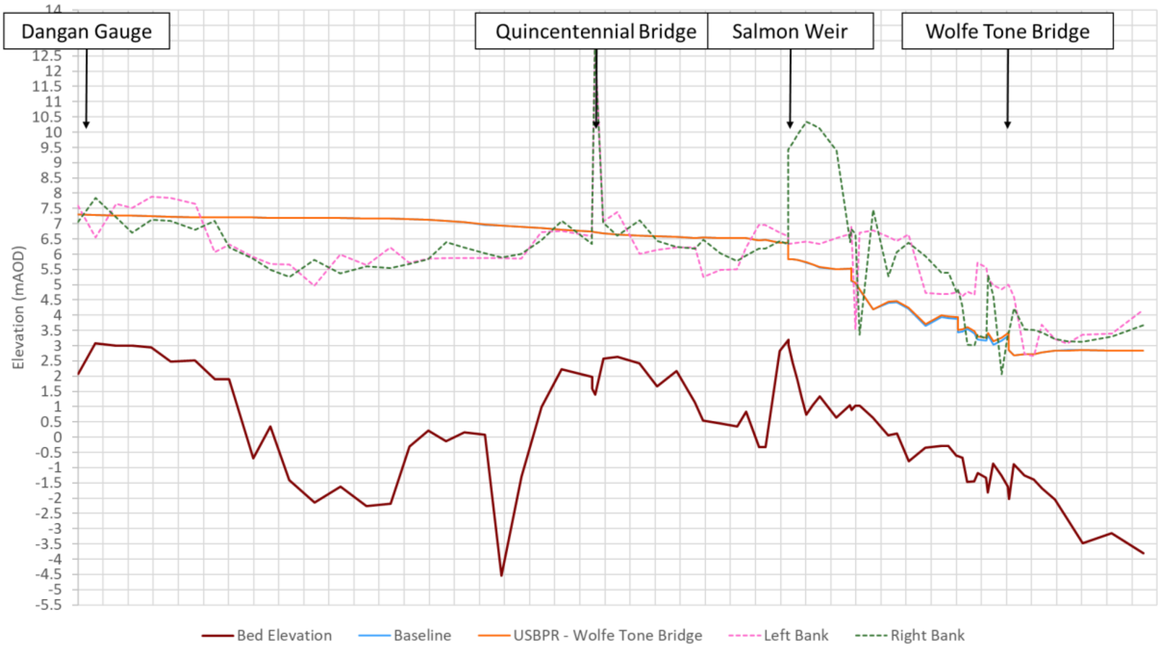

Figure 10.2.10 Longitudinal plot of the Max WLs along the River Corrib - baseline Q100 model with Wolfe Tone Bridge defined as a USBPR

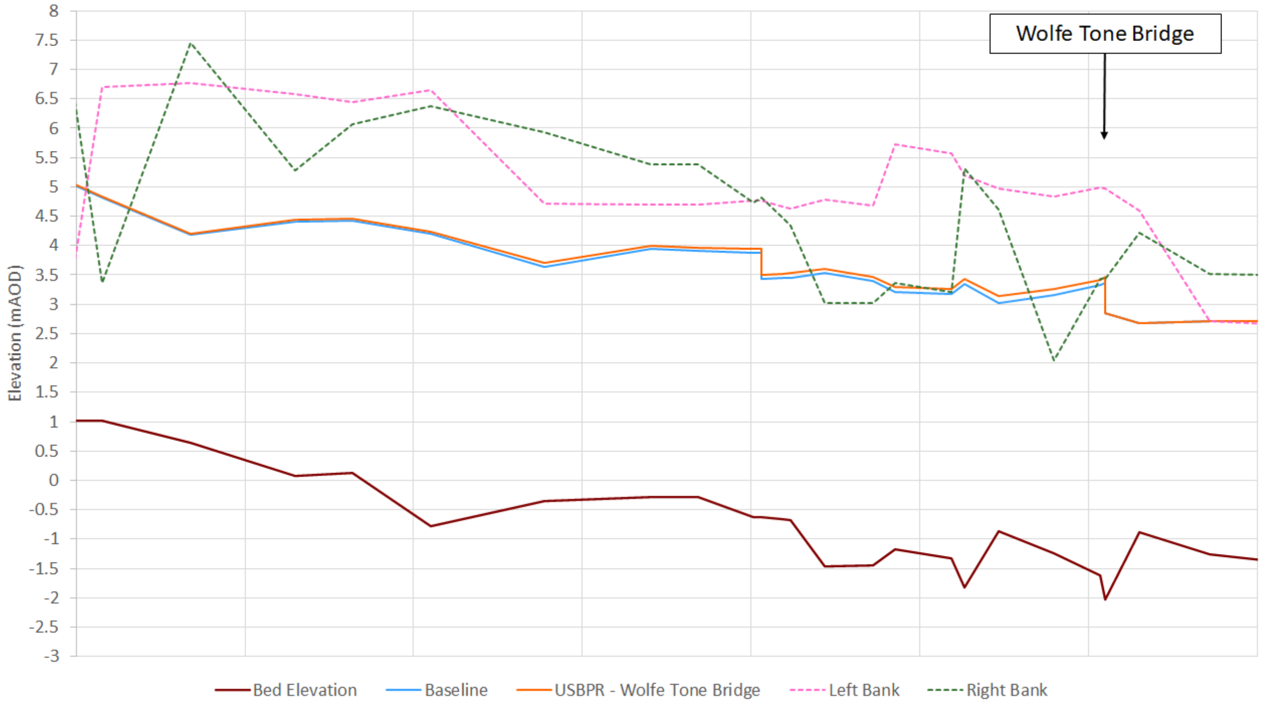

Figure 10.2.11 Zoomed in longitudinal plot of the Max WLs along the River Corrib - baseline Q100 model with Wolfe Tone Bridge defined as a USBPR

10.2.4 Ineffective flow areas

Three ineffective flow areas within the Corrib have been identified from our site visits: at the salmon weir bridge (which was considered as part of the design runs), upstream of Salmon Weir Barrage at the commercial boat club and at the King's gap weir. The baseline model has been reconfigured to omit conveyance from the second and third ineffective areas in order to test the sensitivity of the model to excluding them.

Ineffective area directly upstream Salmon Weir Barrage

The impact of removing these ineffective areas is minimal local. The maximum increase in flood levels is circa 22mm at the location of the ineffective area as a result of the reduction in cross sectional area. The impact downstream is minimal and is less than 5mm.

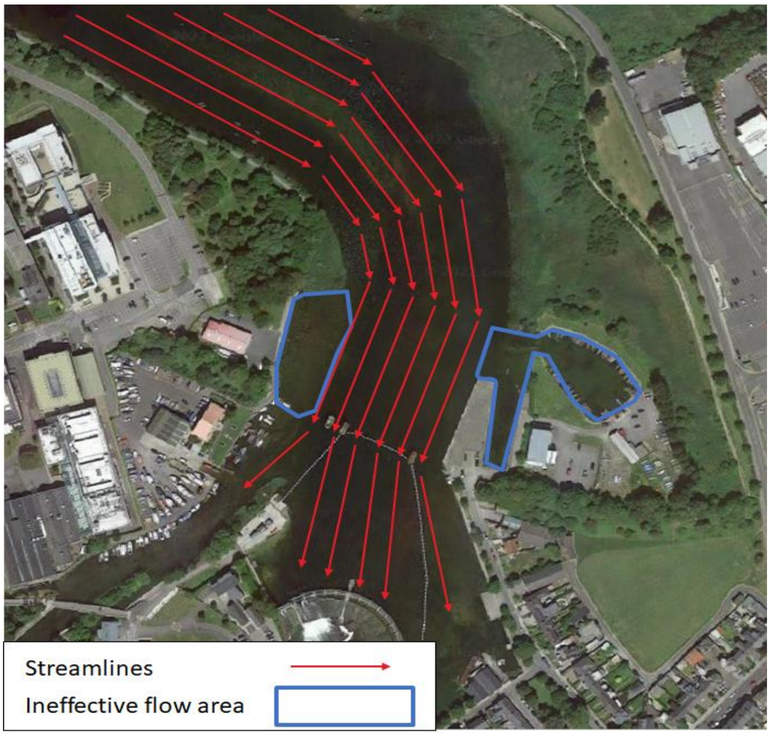

Figure 10.2.12 Ineffective flow areas upstream Salmon Weir barrage

King's gap weir

At King's gap weir, ineffective flow areas were identified on both the left and right bank were removed from the 1D model.

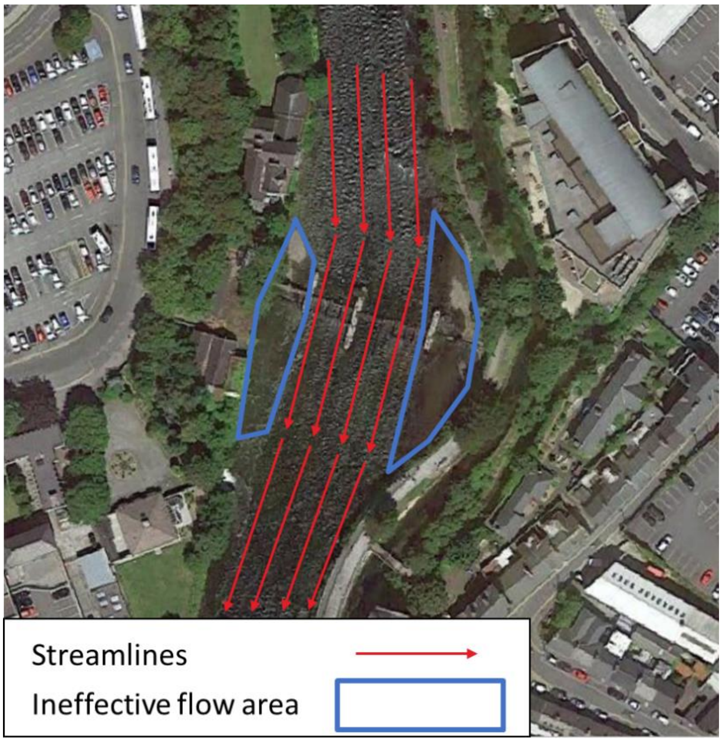

Figure 10.2.13 Ineffective flow areas at King's gap weir

The results of the sensitivity are presented in the figure below.

It can be seen from the plot that the removal of the ineffective flow areas here causes a local decrease in water levels of up to 265mm. The flow here is subcritical and, as a contraction is introduced compared to the existing model, the discharge per unit width increases and the depth and water level decrease.

Downstream of the King's Gap the difference in water levels between the baseline and the sensitivity is less than 5mm.

Upstream of the weir, the water levels are increased at the Salmon Weir by circa 78mm at the Salmon weir bridge and by 40mm at the Salmon Weir Barrage. The increase in levels reduces to less than 5mm upstream of Jordan's island. The model is therefore sensitive to the impact of excluding the ineffective flow areas at the Kings gap weir. This will be considered as part of optioneering and scheme design.

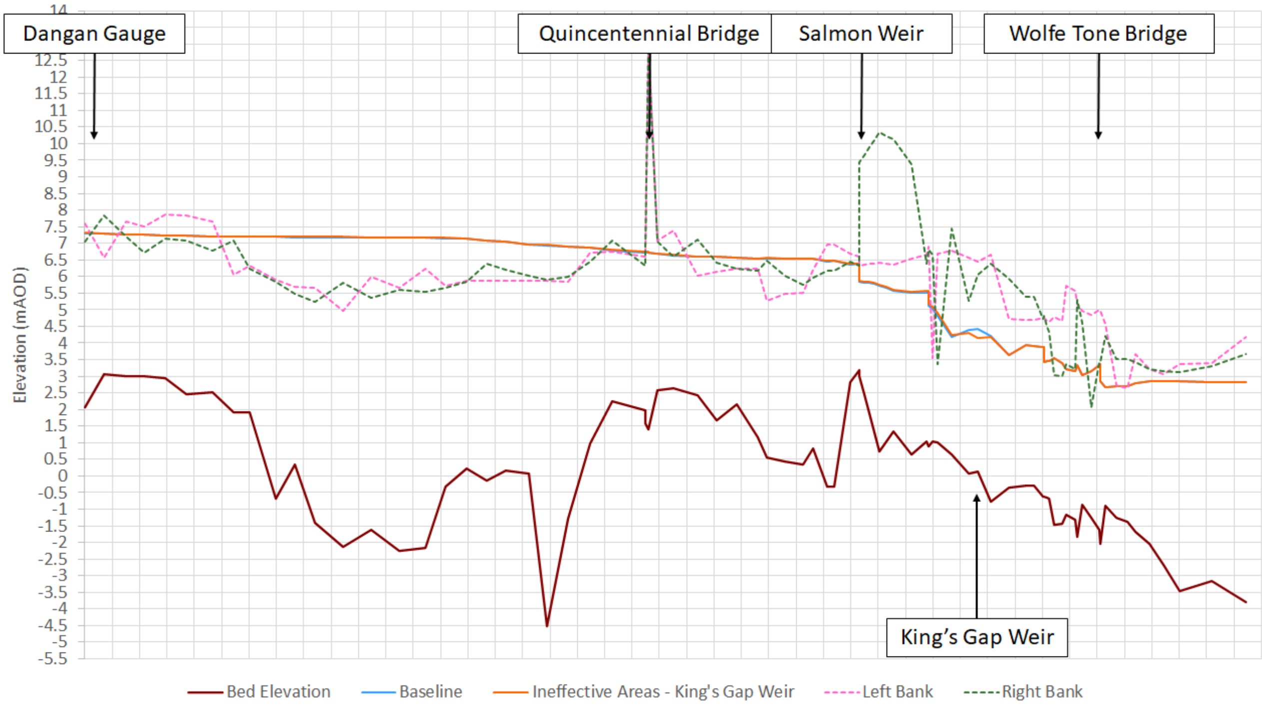

Figure 10.2.14 Longitudinal plot of the Max WLs along the River Corrib - baseline Q100 model with Ineffective Areas defined in King's Gap Weir

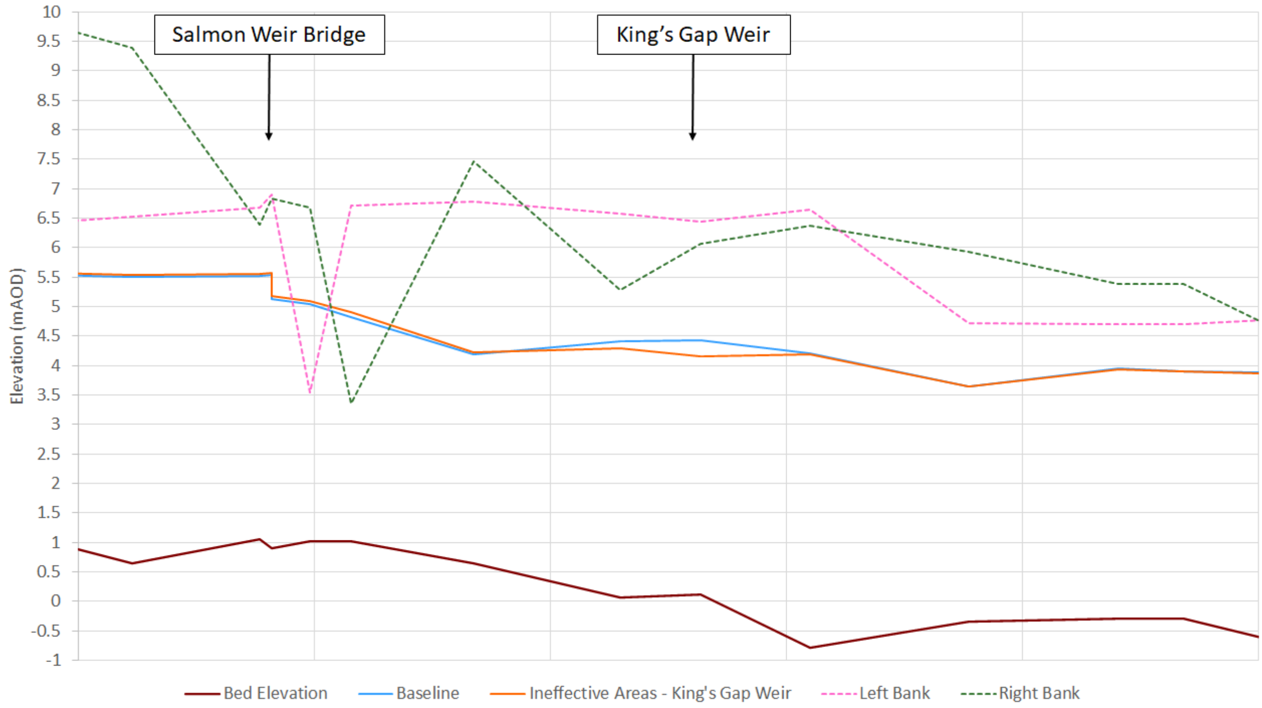

Figure 10.2.15 Zoomed in longitudinal plot of the Max WLs along the River Corrib - baseline Q100 model with Ineffective Areas defined in King's Gap Weir

10.2.5 Cell size variation

A sensitivity check was undertaken on the Tuflow grid cell size. The cell resolution was reduced from 8m to 4m in the RURAL and from 4m to 2m in the URBAN space.

The change in cell size has minimal impact on the flood extents and levels, with minor reductions in the flooded area west of Claddagh (Father Griffin Road, Father Burke Park, Fernhill road and Munster Avenue). In majority of these areas the levels reduce by 5mm, with small parts along Munster Avenue and Father Burke park reducing by up to 23mm and 14mm, respectively.

Overall, the model is not sensitive to the change in cell size.

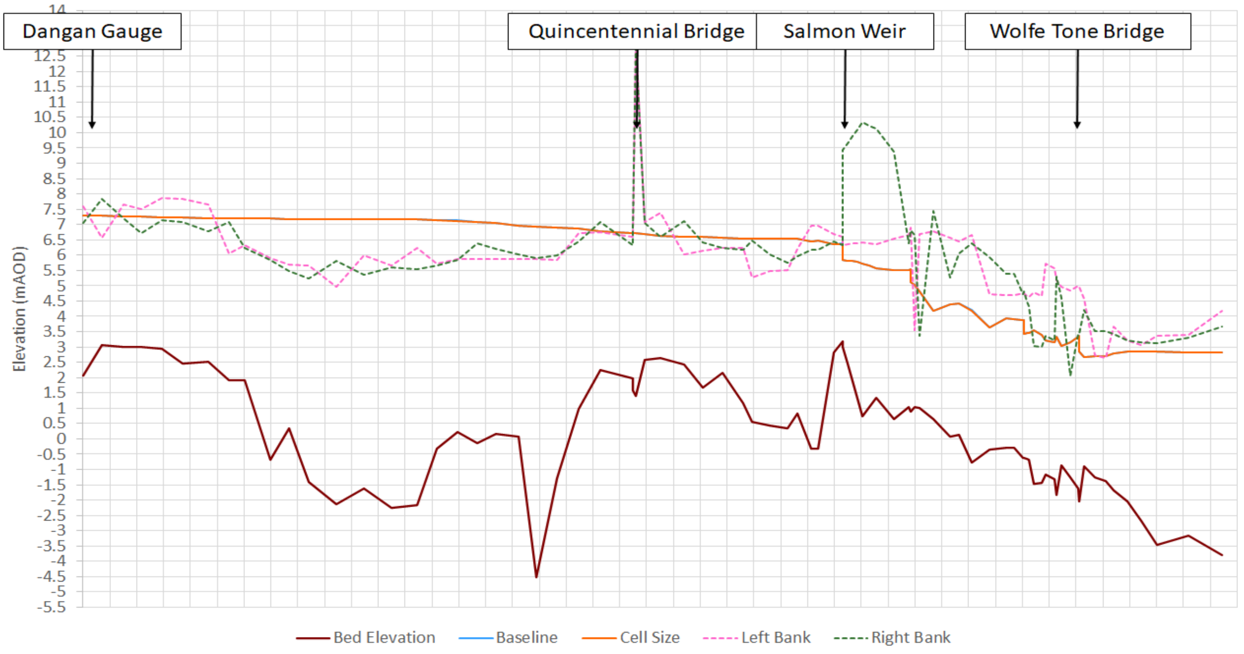

Figure 10.2.16 Longitudinal plot of the Max WLs along the River Corrib - baseline Q100 model versus the Reduced Cell Size model

10.2.6 Clifden Rail Embankment Culvert

Accounting for the Clifden Rail Embankment has been investigated by undertaking a sensitivity run in which the culvert has been included in the model. The dimensions of the culvert have been taken from a recent survey undertaken by the OPW. The results of the sensitivity for the Q100 event are presented in Figure 10.2.17.

It can be seen from the figure that with the culvert in place the area downstream of the embankment is inundated. The increase in the flood extent is however minimal and is limited to the green area of the pitch. No properties are inundated in the increased extent in the vicinity of the culvert.

The model is therefore not sensitive to the inclusion of the culvert.

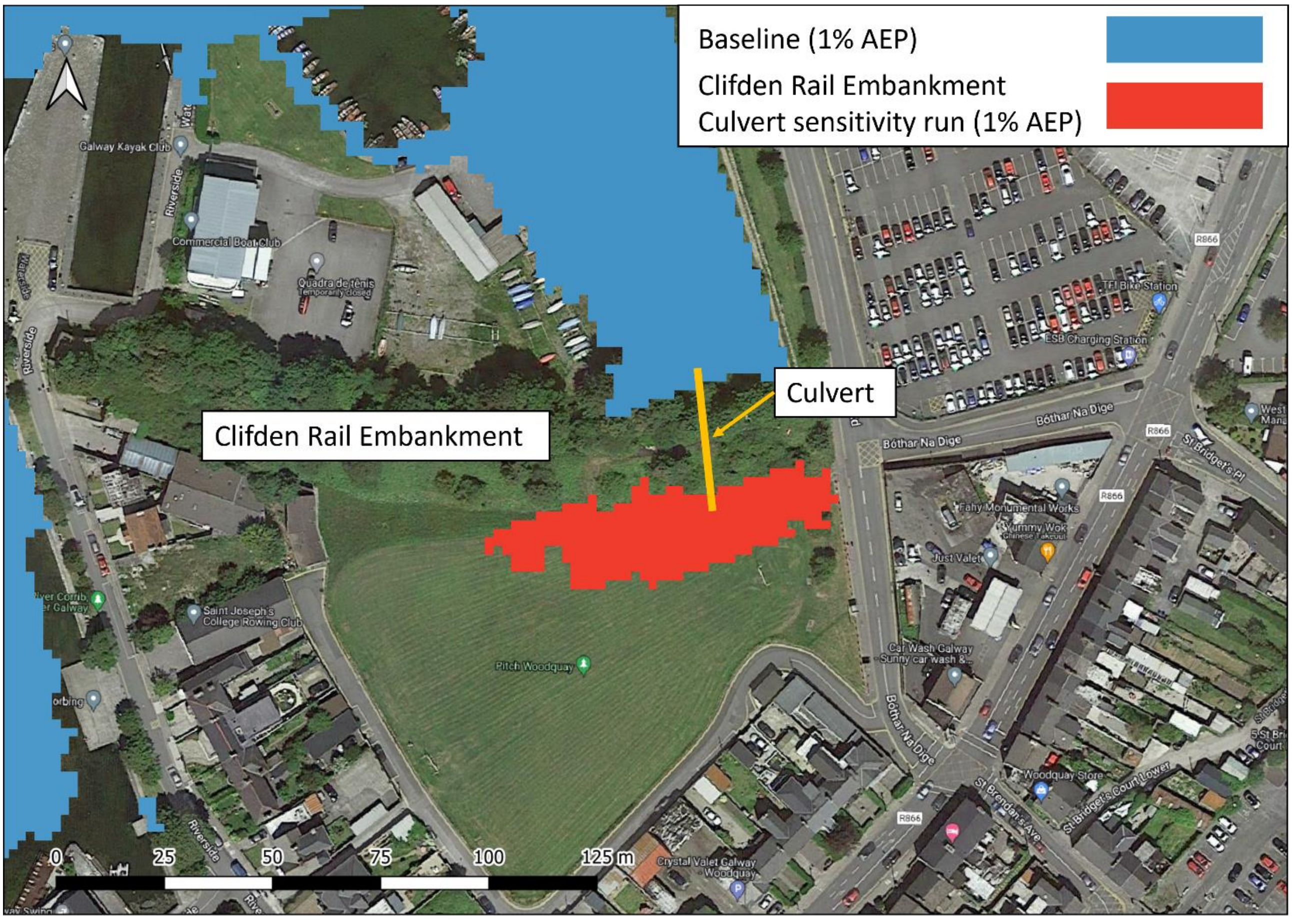

Figure 10.2.17 Sensitivity run for the Clifden Rail Embankment Culvert in the 1% AEP event

10.2.7 Coastal model - Changes to the Manning's number

A 20% decrease in the manning's number was applied to the 2D model domain in order to test the sensitivity of the model to changes in the roughness. The findings of the sensitivity are presented in Figure 10.2.18 which indicates the maximum flood extent for both the baseline and sensitivity run.

It can be seen from the figure that the model is not sensitive the changes in the manning's value given that the flood extents for both model runs is largely identical. This finding is not unexpected as the design tidal water level is the key driver of tidal flood risk and this has not been modified for the sensitivity run. Modest changes to the manning's value will therefore not have any significant impact on the inundated areas for the tidally dominated run.

No other sensitivity runs of the coastal model were undertaken given the absence of any structures from the model and the demonstrated lack of sensitivity of the model to reduced manning's sensitivity.

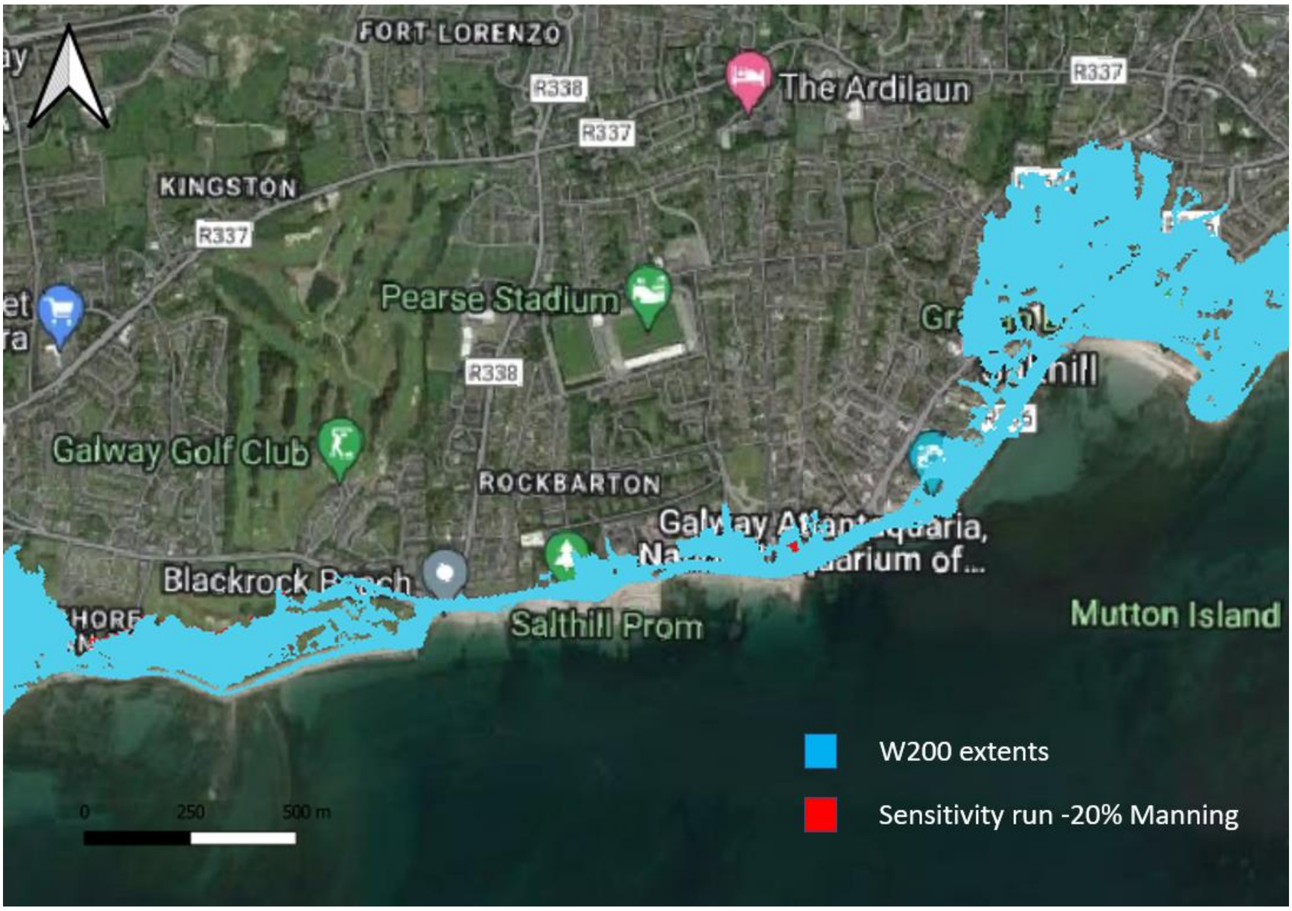

Figure 10.2.18 Comparison between W200 results and sensitivity run results with Manning's coefficient reduced by 20%.

10.2.8 Coastal model – WOT at the South West Corner of the Enterprise Park

A sensitivity analysis on the W200 scenario was conducted for the southwest corner of the Enterprise Park in order to assess if WOT at the crest of the boat ramp presents a significant increase in coastal flood risk in this area.

Wave conditions from the M7 point were used to inform the WOT calculations and account for the fact that the breaking point is set back from the land/sea interface. Two new WOT boundaries were created for the model: SW1 which accounts for WOT across the top of the boat ramp and SW2 which accounts for WOT for the land adjacent to the ramp. The location and alignment of the boundaries positions are shown in the figure below. The resulting peak WOT rates are shown in Table 24. It can be seen that the results are identical for both sections given that the input wave and water level conditions, as well as crest level of the sections are identical.[25]

[25] The only difference in the geometry between the two sections relates to the embankment slope and the WOT flows are not sensitive to this for the W200 scenario

Figure 10.2.19 Location of the sensitivity WOT boundaries: SW1 and SW2

Table 24 Q rates for W200 current climatic scenario for JP6

Point	Q_{design}	$Q_{overflow}$	Q_{total}
SW.1	0.138404	0.001691	0.140096
SW.2	0.138404	0.001691	0.140096

The modelled flood extents for both the baseline and sensitivity run are presented in the following set of figures and are part of the deliverables (w521_ttt_w_c_s_0200_d_s1_c_01). It can be seen that the modelled extents are almost identical and that inclusion of the additional WOT at the top of the boat ramp does not lead to any increased in the coastal flood risk to the existing buildings in the business park. There are however very minor and largely insignificant differences noted in the peak water levels in the immediate vicinity of the boundary as presented in Table 25.

Figure 10.2.20 Baseline and Sensitivity W200 run flood extents

Table 25 Comparison of the water levels for the baseline and sensitivity W200 runs

Location	W200 Current WL [mOD]	W200 Sensitivity WL [mOD]
Point 1	4.01	4.01
Point 2	4.08	4.10
Point 3	4.16	4.16

10.3 Climate Change Design runs – Fluvial/Tidal Model

The hydraulic model was simulated with uplifts in the design flow to account for the potential impact of climate change. A 20% uplift for the Mid-Range Future Scenario and a 30% uplift for the High-End Future Scenario have been applied to the design flows with increases of 0.5m and 1m respectively applied to the tidal levels to represent sea levels rise, as specified in the project brief.

Figure 10.3.1 presents the findings of the sensitivity run for the Q100. The increase in WL is 370-400mm upstream of the Salmon weir barrage, increasing to 500mm downstream of the weir due to the tidal influence for the MFRS, when compared to the baseline case. During the HEFS, the increase is on average 550mm upstream of the Salmon weir barrage, increasing gradually to 1600mm upstream O’Brien’s bridge, and reducing again to approximately 1000mm towards Galway Bay to match the increase in sea level rise.

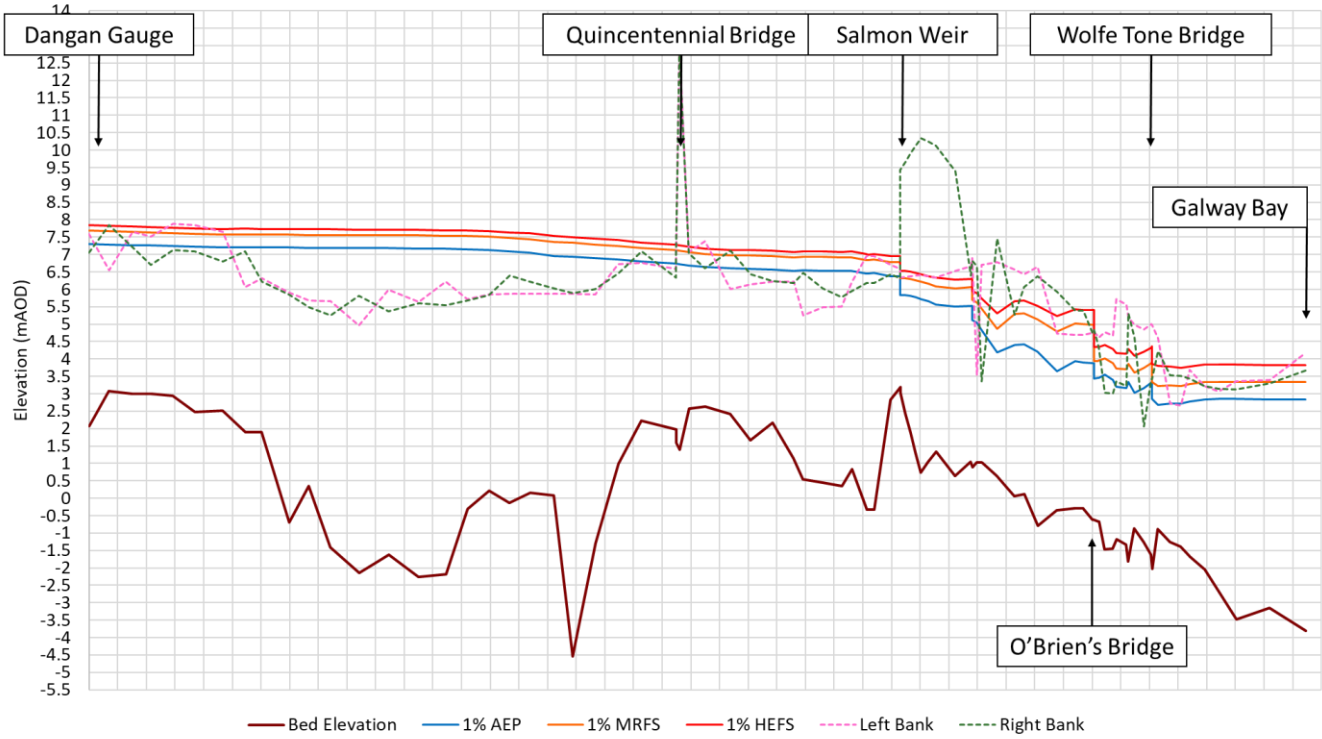

Figure 10.3.1 Longitudinal plot for the Q100 Climate Change runs

Figure 10.3.2 presents the findings of the sensitivity for the T200 sensitivity run. The increase in the tidal water level associated with the MRFS scenario results in a significant increase in flood extents in the flooded area in the tidal zone. The maximum increase of 680mm occurs upstream of O'Brien's bridge. The increase is circa 560m downstream the Salmon weir barrage.

Upstream of the barrage the increase in WL gradually increases from 160mm directly upstream of the weir to 250mm at Lough Corrib. While the current T200 was maintained in bank upstream of the weir, during the MRFS there is extensive out of bank flooding occurring around the Coolough lakes. Furthermore, the higher tidal levels cause increased backwater effect to Lough Corrib than for the current scenario.

The HEFS results in significant increases in flood extents around the Dock area, Spanish Arch, Claddagh Quay, and Eglinton Canal. The maximum increase is upstream O'Brien's bridge (1670mm), reducing to 910mm downstream the barrage. Upstream of the barrage the increase in WL between the current and HEFS scenarios is approx. 370mm upstream of the weir increasing to 384mm at Lough Corrib at the furthest upstream point of the model. Similar to the MRFS scenario, large areas around Coolough lakes are flooding during the HEFS.

The increase in flood risk associated with climate change is therefore significant and will result in a greater number of properties being inundated when compared with the current scenario.

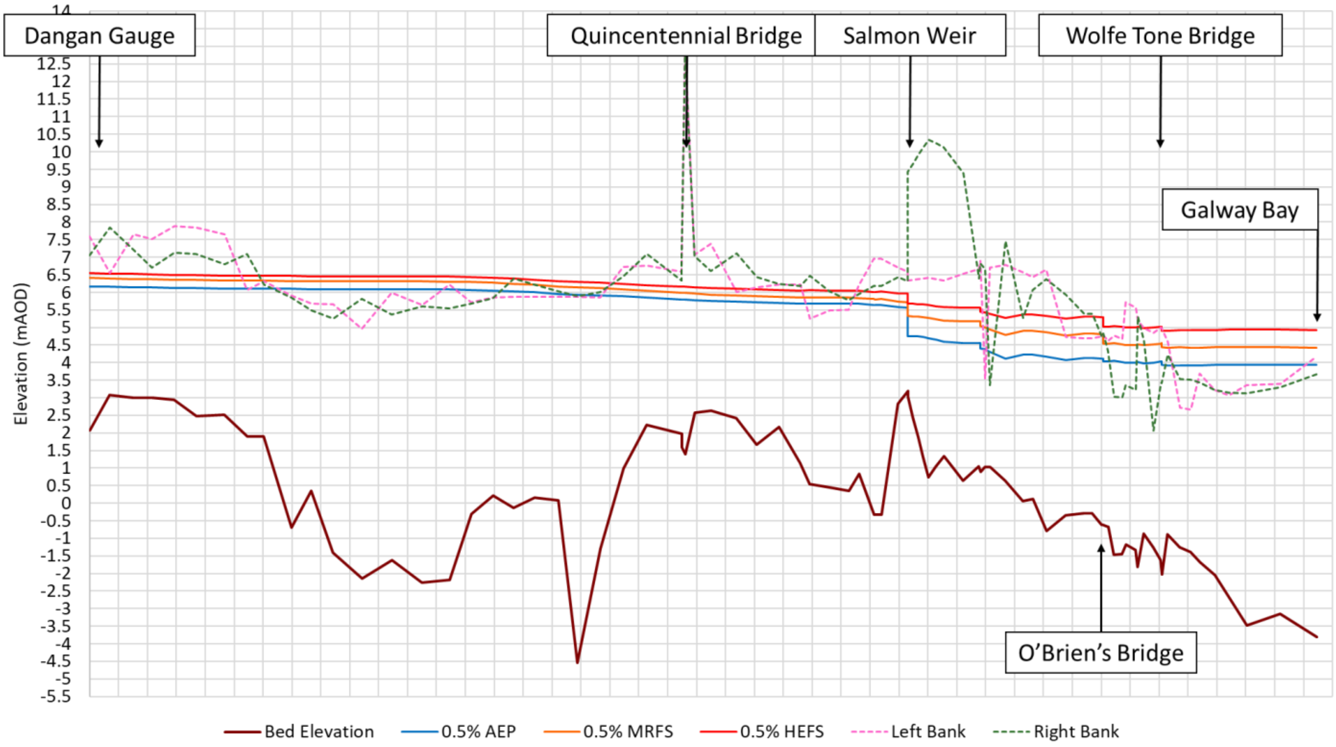

Figure 10.3.2 Longitudinal plot for the T200 Climate Change runs

10.4 Climate Change Design runs – Coastal model

The 2D coastal model was simulated to account for the potential impact of climate change. A 0.5m and 1m uplift for the Mid-Range Future Scenario and High-End Future Scenario respectively have been applied to the tidal levels to represent sea levels rise while the WOT calculations have been updated to take account of increases in the wave heights and water levels associated with the future scenarios. Both boundaries (tidal and WOT) have been included in the future scenario runs as per the set up of the Current scenario models.

It is evident from the climate change runs that a significant area of Galway is at risk from flooding in the climate change scenario. The maximum flood extent is not however significantly greater than the current scenario extent as the higher design water levels associated with climate change are largely contained by higher ground levels that encompass the floodplain. The only two areas where a noticeable increase in the maximum flooded extent is observed are to the West of Salthill Road Upper and along Lenaboy Avenue.

11. Data limitations

A number of data limitations have been identified while undertaking the study and have been discussed at various points throughout the report. The key limitations are listed below.

- A number of culverts were not able to be surveyed internally due to health and safety concerns (high flows, uneven ground, confined spaces) or accessibility (vegetation growth, trash screen). A number of assumptions on the internal dimensions of the culverts were therefore made based on the surveyed dimensions of the inlet and outlet faces of the culverts, with the smallest opening used as a conservative approach. There is a risk that some of the longer culverts might have a further constriction within the culverts. Blockages to culverts will be assessed as part of the optioneering given that the impact of blockages is more directly relevant to the design of the proposed flood scheme given the assumption in the existing scenario that all culverts are generally simulated as being blockage free.

- The minor culvert which runs under the Clifden Rail Embankment was not included as part of the model due to the absence of any data on the culvert. It will however be assessed as part of the optioneering.
- The University of Galway Old engineering building located on Gaol river (NUNS) has been assumed to allow flows of up to 5m^3/s to flow under the culverts. It is noted that it was not possible to undertake CCTV surveys at this location due to high flows and uneven ground. The impact of blockages or smaller geometry that allows less flows to pass will be undertaken as part of a blockage assessment.
- A number of surveys of the Sruffnacashlaun Siphon on the Distillery channel (which runs under the Eglinton canal) have been undertaken. Some of the surveys provide conflicting information on the geometry of the structure. The geometry of the Siphon used as defined in the model is based on information taken from two surveys: the recent 2021 Infill Surveys and a long section taken by the OPW in 2014. A partial blockage scenario will be undertaken as part of blockage assessment to determine the increase in risk associated with an internal constriction in the structure,
- There is limited information on the operation of the penstocks within the Galway Canals system. Assumptions were made for each penstock depending on best available information and surveyed data. For example, the penstocks along the Kingfisher channel have been assumed closed, blocking flows from the Corrib to the Distillery channel.
- Finished floor threshold levels were not recorded at all buildings. As such, the average ground data across the building footprints from the Lidar DTM were used to set the threshold levels where survey data was unavailable. No allowance for a step up into the property has been made for these buildings. This assumption/limitation will need to be considered further when assessing damages on a property-by-property basis.
- Terryland waterworks abstraction - The abstraction from the Terryland stream is 35,000m^3/day, which equates to 0.405m^3/s and is considered negligible compared to the flows in the river. This was not included in the model.
- Terryland old waterworks – Arup undertook a site visit to the plant in March 2022 and observed the blocked turbines and stagnating water. Based on this inspection it was assumed that the opening under the Terryland old waterworks is very small and only allows a minimal flow through from the River Corrib and Jordan’s cut. The bore area of the two openings in the model was therefore reduced to 0.1m^2 in order to represent this blockage.
- Salmon Weir Barrage: All gates are assumed open for all fluvial events, based on information from OPW on the operation of the gates, review of the gate log and comparison with recorded levels equating to the Q2 flood flows. A sensitivity check has been done to assess the impact of closure of gates during the design event.
- Salmon Weir Barrage: All gates are assumed open for all tidal events. It is assumed that if a flood warning for a large tidal event is issued, the gate operator will open the gates. There is minimal impact from the tides upstream of the Salmon Weir.
- The Eurotop empirical equations have an element of uncertainty associated with them and as noted in the report are stated as having an order of magnitude level of accuracy. This must be considered when assessing the risk from the WOT.

12. Conclusions

Arup has been commissioned by Galway City Council to develop a Flood Relief Scheme (FRS) for Galway City, referred to as the Coirib go Cósta project. The overall scheme will consist of flood alleviation measures within the scheme area of the project which includes along the River Corrib and its tributaries/canals, Salthill, and the docks area. This report has considered the hydraulic modelling undertaken for the existing baseline scenario.

Two separate hydraulic models have been developed as part of the study: (1) A dynamic 1D/2D fluvial/tidal hydraulic model of all the relevant watercourses in Galway City and associated floodplain areas, and (2) a standalone 2D hydraulic model with a spatially varying grid resolution of the coastal floodplain which simulates WOT and direct tidal inundation.

The findings of the hydrological assessment undertaken as part of the study were used to define the inflows for the fluvial/tidal model as well as the downstream tidal water level boundary conditions. The 1D/2D fluvial/tidal model was calibrated against a number of different historic events: two fluvial in-bank events which occurred in February 2020 (5% AEP) and February 2022 (50% AEP) and also against the tidal out-of-bank event from February 2014 (5% AEP). Overall, a very good match was achieved between the modelled and measured results across Galway City as the modelled water levels at the respective gauges are all generally within the tolerances specified by the project brief (vertical accuracies of +0.1m, but not greater +0.2m) and also as specified by SEPA guidance (+/- 150mm for "high confidence").

It is therefore evident that the model is able to reproduce maximum flood extents and maximum water levels within the specified tolerances across the study area for flood events with an AEP equivalent to the 5%. As this is a relatively low AEP event it can be concluded that the model is also equally able to accurately reproduce flood events with AEP's up the SoP of the scheme i.e., the 1% AEP fluvial and 0.5% AEP tidal events. The 1D/2D fluvial/tidal model is therefore deemed suitable to simulate design model runs as part of the study. The model is also deemed suitable to assess various engineering options to mitigate flood risk in the city.

The standalone 2D coastal model (developed in Tuflow Quadtree) has not been calibrated to any historic event due to a lack of suitable data with which to derive boundary conditions for any calibration simulation. This however does not impact on the accuracy of the coastal model as high-quality data has been used to define the geometry of the model and best practice in modelling has been followed in setting up the model. Where possible the model was ground-truthed against anecdotal WOT data in the key areas at risk.

The model utilises a spatially varying grid resolution in order to resolve the area in the vicinity of the Long Walk with a finer resolution that the rest of the coastal floodplain.

The WOT risk was considered in parallel with the tidal risk given that WOT generally requires an elevated tidal water level to occur. The Eurotop manual was used to generate the WOT boundary conditions of the coastal model using wave heights and tidal water levels derived from the CWWS study which was supplied to us by the OPW. Any WOT study achieves an order of magnitude level of accuracy and while this study has adopted a very rigorous approach to the WOT calculations and utilised the best available datasets as input, uncertainty over the results remain. The WOT/tidal inundation flood maps produced as part of the study need to be considered in this regard.

Fluvial and tidal flood extent maps were produced from the result files of the model and highlight all the flood risk areas in the city. It was seen from the results that a large area of Galway City around the Docks, Spanish Arch area, Claddagh Quay and Eglinton Canal are at risk of flooding. The key mechanism of flooding is from tidal inundation as the existing ground levels are lower than the peak tidal water level for a number of the tidal AEP events. The threshold of tidal flooding is the T2 event which is deemed to be low. Further upstream in the study area there is a risk of overtopping of the Dyke Road embankment during the Q200 and Q1000 year events.

Following a detailed review of the Sruffnacashlaun stream/culvert, it was decided to exclude it from the scheme, as flood risk within this small and heavily urbanised catchment is a function of the drainage system which is being assessed separately by GCC.

Significant areas of the coastal area at risk from inundation during a coastal flood event i.e., from both WOT and tidal inundation. The findings of the coastal model confirm what was observed from our review of the historic record of flooding: Salthill and the areas adjacent to it are mainly at risk from WOT while the city centre is mainly at risk from tidal inundation.

The findings of the study will be brought forward to optioneering stage of the project where additional hydraulic analysis of the options will be undertaken. This work will be reported on in the Options report.

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